Avelino Núñez-Delgado *Editor*

Planet Earth: Scientific Proposals to Solve Urgent Issues

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Preface

When the scientific editor conceived and proposed the book to Springer Nature, the intention was to finally include chapters elaborated by top researchers working on different fields, from “experimental” to “social sciences and humanities”. At that time, the aim was to explore some of the main issues affecting our planet, as well as to propose solutions for specific aspects in relation to climate change, air, water, and soil pollution, problems related to demography, access to food, water, etc. Now, with the book completed, we can confirm that it counts with the participation of authors that have huge experience, which have provided high-quality chapters dealing with both broad and specific issues of main relevance. At the time of starting the book, as well as now, inspiring and motivating readers to promote sustainability, biodiversity, and survival in the whole Earth were and are key objectives. As the final shape was reached, we think that the interested audience could be not just scientists working in any of the fields covered, but also students and any member of the society worried about the crucial problems treated in this work. We really believe that we have achieved the first objective, namely that those asking for views from top scientists analyzing these issues and proposing possible solutions could find here an interesting and detailed reading Fig. 1.

Fig. 1 Forest in Galicia (NW Spain). Forest and soils where trees grow are key for helping to solve many of the current environmental issues affecting the Earth

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About the Editor

Avelino Núñez-Delgado, Ph.D. born in O Barco de Valdeorras (Ourense province, Galicia, Spain). He obtained Ph.D. at the Department of Soil Science and Agricultural Chemistry, USC, in 1993. He was Postdoc Researcher in France (University of Montpellier) and Spain (USC), between 1993 and 1996; Professor at the Department of Soil Science and Agricultural Chemistry, Engineering Polytechnic School, Campus Lugo, University of Santiago de Compostela (USC), Spain, since 1996; he has nine patents and earned several research awards. He has published more than 400 publications at the date (December 2023), with around 200 in D1 and Q1 JCR journals. He was Principal Investigator and/or collaborates with more than 40 research projects. He was listed among the 2% of the top world researchers by the Stanford ranking and among world top researchers by Researchgate, Expertscape, Web of Sciences, Scopus, and other world research classifications. Currently, he is collaborating with a variety of research teams from various countries around the world. He is Book Editor for Springer Nature, Elsevier, and other top scientific publishers. He is Book Series Editor for Springer Nature, Editor for various top research journals (with roles of Chief Editor, Associate Editor, Special Issues Editor, Managing Guest Editor, and Guest Editor), and Reviewer for national and international research projects.

The Impact of Food Overproduction on Soil: Perspectives and Future Trends

Florentios Economou, Iliana Papamichael, Teresa Rodríguez-Espinosa, Irene Voukkali, Ana Pérez-Gimeno, Antonis A. Zorpas, and Jose Navarro-Pedreño

Abstract This comprehensive document explores the multifaceted implications of food overproduction on soil sustainability, encompassing environmental, societal, and economic aspects. It delves into the global landscape of food production, highlighting key statistics and the leading countries in this domain. The European Union's directives, strategies, and action plans related to food production are discussed, emphasizing the Farm to Fork Strategy, Common Agricultural Policy (CAP), and Biodiversity Strategy for 2030. Furthermore, the document scrutinizes the environmental consequences of food overproduction, including deforestation, soil degradation, and greenhouse gas emissions from food waste. It also examines the societal impacts, such as food insecurity, malnutrition, and economic disparities resulting from market dynamics. The economic ramifications of food overproduction, including direct economic losses, waste management costs, and the adverse effects on farmers' livelihoods, are thoroughly analyzed. In particular, the document emphasizes the critical importance of soil health in sustainable food production. It discusses how soil degradation, erosion, pollution, and acidification are interconnected with food production practices and explores the global implications of these

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soil-related issues. Ultimately, this document underscores the urgent need for transitioning towards sustainable and regenerative agriculture practices to address the challenges posed by food overproduction.

Keyword Agriculture · European green deal · Farming · Food losses · Food system life cycle · Soil degradation · SDGs

1 Food Production Statistics Around the World

Food production worldwide has been steadily increasing to meet the demands of a growing global population. According to the United Nations (2022b) "World Population Prospects 2022" report, the global population was estimated to be 7.9 billion people in 2021, with a gradually declining population growth rate of about 1.1%. Global population is projected to continue growing, reaching an estimated 9.7 billion by 2050 and could stabilize by the end of the 21st century at around 10.9 billion people (United Nations, 2022b, 2022c). Over the course of five distinct scenarios that encompass a range of plausible socio-economic trajectories, it is projected that global food demand will undergo an increase ranging from 35% to 56% from 2010 to 2050 (van Dijk et al., 2021).

Major staple crops like rice, wheat, and maize are produced in large quantities, accounting for about 90% of the total cereal production, providing a significant portion of the world's calories. Agricultural production, as shown in Fig. 1, increased

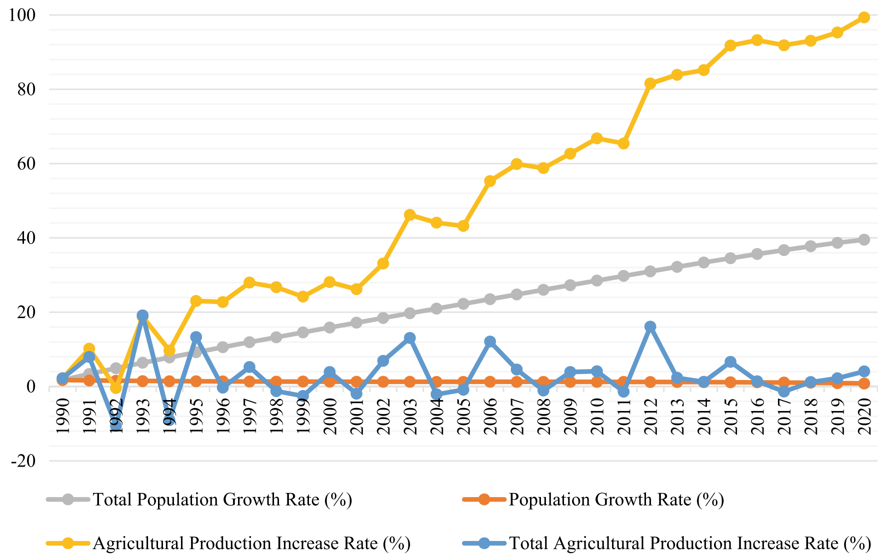

Fig. 1 Population and Agricultural Production Growth rate from 1990 until 2020 (figure created by the authors)

by 98% since 1990, overpassing the population growth rate (39.5%). This is mostly due to intensification of agriculture, improved farming practices, cropland expansion and efficient use of water and fertilizers. Agricultural production in 2021 reached 9.5 billion tons worldwide, that were used as food, feed or input for other products (FAO, 2022a).

The top leading countries in terms of food production include China, United States, India, Brazil and Russia. The majority of food production in China and India is used internally to feed their large population, prioritizing food security. China's production provide food to around 22% of the world's population and holds the distinction of being the largest producer of rice worldwide (149 million metric tons), contributing to 23% of the total rice production (Shahbandeh, 2023a, 2023b). The United States is the largest producer of corn with 348 million tons of corn produced in 2022 (Shahbandeh, 2023a). Additionally, the United States leads in global exports, with corn being its most exported commodity, making around 30% of worldwide exports and valued at 18.57 billion dollars in 2022 (USDA 2023). Brazil is the world leader in sugarcane production (715 million tons), second in soyabean production (135 million tons) and produces 33% of the world's oranges (16.2 million tons) as FAOSTAT showed in 2021. France is the largest agriculture producer in the EU, with the main commodities being oilseeds, cereals, sugar beets, milk, wine, and beef. The EU produced 297.5 million tons of cereals, 2.15 tons of olive oil, 11.5 million tons citrus and 504 million tons of roots and tubers in 2021. The favorable climate, farmers expertise and the constant development and improvement of the agricultural industry makes the production in EU very efficient (Table 1).

Table 1 Population and cereal production yields by country (FAOSTAT, 2021; USDA, 2023)

	Population (in million inhabitants)	Total production area (km^2)	Cereal production area (ha.)	Cereal production (t)	Cereal yield (t/ha.)
China	1412.0	5,285,081	100,278,968	633,846,950	6.321
United States	331.9	4,058,104	54,744,521	452,628,438	8.268
India	1408.0	1,785,279	102,434,744	356,345,000	3.479
Brazil	212.6	2,368,788	25,056,632	112,220,282	4.478
Russia	145.6	2,154,940	43,457,121	117,574,453	2.71
France	65.8	285,538	9,326,650	66,880,910	7.171
Germany	83.3	165,910	6,053,000	42,359,400	6.998
Poland	38.0	144,610	7,451,270	33,996,290	4.562
Italy	58.9	124,030	2,978,390	16,568,150	5.562
Spain	47.4	261,426	6,034,580	25,510,560	4.227
United Kingdom	67.3	172,151	3,210,819	22,369,109	6.967
Netherlands	17.7	18,120	169,720	1,336,080	7.872

2 EU Directives, Strategies, Action Plans Targeting Food Production

The European Union (EU) has implemented various directives, actions and plans to regulate and make food production more efficient, environmentally friendly and safer (European Comission, 2020a). There are three main tools that aim to balance the needs of agriculture with environmental protection, animal welfare, and consumer interests; Farm to Fork Strategy, Common Agriculture Policy (CAP) and Biodiversity Strategy for 2030.

The Farm to Fork Strategy was launched on May 20th, 2020 and is a key component of the European Green Deal. Its overarching objective is to enhance the sustainability of food systems by reducing GHG emissions to achieve carbon neutrality by 2050 and ensure food production in the basis of social, environmental and economic stability. Farm to Fork Strategy requires a transition of the entire food system towards a fair, healthy and environmentally friendly food system (Schebesta & Candel, 2020). It includes targets to reduce pesticide use, increase organic farming, and reduce food waste (Wesseler, 2022).

A new initiative that is part of Farm to Fork strategy has been proposed and is expected to be adopted by the European Commission by the end of 2023. The 'Framework for Sustainable Food Systems' (FSFS) aims to promote sustainability within the EU food system and integrate sustainability into all policies related to food at EU level and national level (European Commission, 2023b). FSFS will set the objective, principles and rules regarding sustainability labels for food products, criteria for sustainable public food procurement, as well as governance and oversight (European Commission, 2023c).

The Common Agricultural Policy (CAP) is one of the most significant EU policies related to food production. CAP policy framework provides financial support to farmers and promote rural development. It aims to support sustainable agriculture, ensure a fair standard of living for farmers, stabilize markets, and provide consumers with quality food at reasonable prices (European Commission, 2022). The CAP includes subsidies for young people to set up their agricultural operation and for investments in the processing of agricultural products. The overall budget for the CAP Strategic Plan 2023-2027 totals €454.9 million (European Funds Portal, 2023). The new CAP 2023-2027 measures have been adapted to place a stronger emphasize on climate change mitigation practices and the sustainable utilization of natural resources (European Commission n.d.).

Farm to fork strategy address the sustainability issues in the food sector separately from the CAP, but they are both interlinked in several ways. They both work towards food safety, as the CAP provide incentives for good agricultural practices and safety regulations compliance, whilst Farm to Fork strategy enhances food traceability and improves safety standards. CAP promotes sustainable practices to meet the environmental standards, whilst Farm to fork strategy has the possibility to transform the food supply system and reduce the environmental impact of agriculture and food sector (Corporate Europe Observatory, 2020).

The EU Biodiversity Strategy for 2030 is also part of the European Green Deal (which aims for carbon neutrality until 2050), that aims to protect and restore biodiversity in Europe, including agricultural landscapes. Biodiversity conversation is crucial for safeguarding food security and has potential direct economic benefits in all sectors (Rehman et al., 2022). Its objective is to halt biodiversity loss and set EU on a trajectory of ecosystem restoration by 2030, for the benefit of the people, the planet, economy and contributing positively to climate efforts (European Commission, 2020b). The strategy promotes more sustainable farming practices such as precision agriculture, organic farming, agro-forestry, reduced pesticide and fertilizers use. These practices can prevent ecosystem degradation, improve soil health and increase the sectors resilience to climate change. A key outcome of this Strategy is the EU's soil strategy for 2030, that establishes both a framework and specific measures designed to safeguard and rehabilitate soils while promoting their sustainable use. It targets to achieve soil health by 2050, accompanied by tangible initiatives to be implemented by 2030 (European Commission, 2021).

The definition 'Food waste' is included for the first time in the updated Waste Framework Directive (2018/851/EC). The directive mandates member states to develop waste prevention programs, including prevention and reduction measures for food waste that are in line with the SDGs (Calisto Friant et al., 2021; Loizia et al. 2021). Member states are encouraged to work towards a suggested EU-wide goal of reducing food waste by 30% by 2025 and 50% by 2030 (European Parliament and Council, 2018). Out of the proposed measures is the provision of incentives for collecting waste and the enhance consumer understanding of the distinctions between 'use-by' and 'best-before' in the food labeling. The necessity for developing a common methodology for measuring food waste is also emphasized (European Parliament and Council, 2018). The proposal of the new Waste Framework Directive has required Member States to develop dedicated food waste prevention programs in accordance with the waste hierarchy (Fig. 2), to reduce food waste along the food supply chain (European Parliament & Council, 2023). Europe's 'Circular Economy Action Plan' adopted in March 2020, focus on the circularity of the products along the entire life cycle of products (European Commission, 2023a). Measures include prevention of food waste by minimizing the amount send to landfill, redistributing food, treating bio-waste or repurposing as animal feed or fertilizer measures on treating bio-waste, including by limiting the amount sent to landfill (Bigdeloo et al., 2021; Stylianou et al., 2023).

3 Link of Food Production to European Green Deal, SDGs and Paris Agreement

Food production sector has a significant impact on environmental degradation, resource depletion, social equity and economic viability of farmers. Therefore, any improvements in the sector play a crucial role in achieving the targets of the European

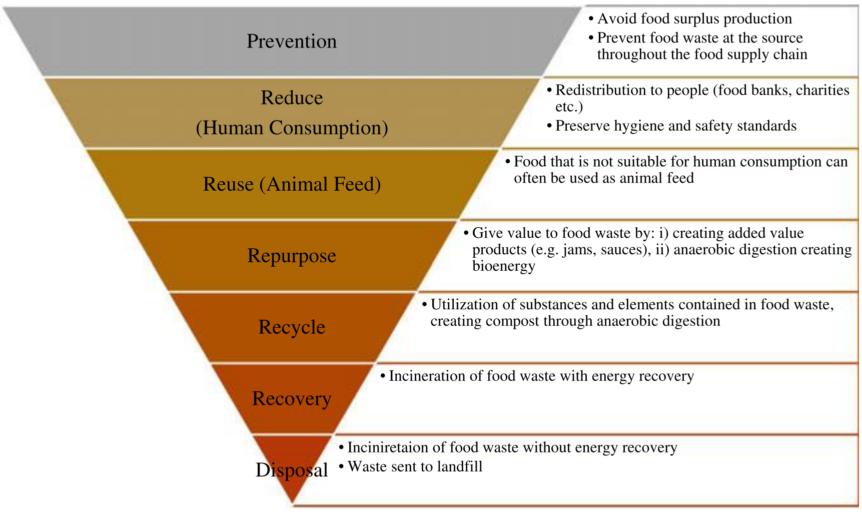

Fig. 2 Waste hierarchy in the case of food waste—European Union, 2020 (figure created by the authors)

Green Deal, the Paris Agreement and the Sustainable Development Goals (SDGs), as they are all interconnected components of global efforts to address environmental, social, and climate challenges.

The European agricultural and food production sector is already leading the way providing EU citizens with safe, secure, quality and nutritional food commodities. The European Green Deal takes a step further transitioning the entire food supply chain into a sustainable food system, offering environmental benefits, social coherence and economic gains. The 'Farm to Fork' strategy and 'Biodiversity Strategy for 2030' are embedded in the European Green Deal and they are closely linked towards this goal. The strategy also aims to develop sustainable food production in rural areas and raise consumer awareness about their food choices by educating consumers about the health and environmental impact of these choices. The ambitions and targets of the European Green Deal concerning agricultural practices are shown in Table 2.

At the same time, the Paris Climate Agreement seeks to constrain the increase in global temperatures to a level significantly below 2° above pre-industrial levels and actively pursues efforts to limit the increase to 1.5° (Doelman et al., 2019). Commitment to limit the aggregate long-term emissions and develop long-term greenhouse gas reduction strategies has been signed from most countries globally. The agreement recognizes the importance of constraining climate change to safeguard food security and the need for the assessment of risks and vulnerabilities in the food production sector (United Nations, 2022a). At the same time, many countries identify the agricultural sector as the highest priority in developing mitigation and adaptation strategies, while providing economic and social co-benefits. The agricultural sector offers mitigation opportunities, such as farming methods that enhance carbon sequestration and technologies that increase productivity. A key element is to implement climate

Table 2 Targets of the European Grean Deal by 2030 (European Commission, 2020b)

Climate	35% reduction of GHG emissions between 2015 and 2030 Achieve net-zero emissions by 2050
Fertilizers	50% reduction in nutrient losses No deterioration of soil fertility 20% reduction in the use of fertilizers by 2030
Pesticides	50% reduction in use and risk of (hazardous) pesticides by 2030
Antimicrobials	50% reduction in sales by 2030 for farmed animals and aquaculture
Organic	25% of land under organic farm management in 2030
Biodiversity	10% of agricultural area to be set aside for high diversity landscape features + additional habitat and species protection

resilient agricultural practices, for the farming system to prepare, adapt, absorb and recover from the possible impacts of climate change (Radschinski, 2017).

The agenda was jointly signed in the New York summit, by all the 193 nations that make up the United Nations (UN). It consists of 17 Sustainable Development Goals (SDGs) that are interlinked, meaning that action in one area will affect other areas. The 17 SDGs provide a shared set of targets that aim for peace, environmental preservation, justice, social equality and support local communities. Food and agriculture play a prominent role in numerous SDGs, as they are intricately linked to nearly every facet of the economy, environment, and society. These connections span from addressing hunger, malnutrition, and desertification to ensuring sustainable water usage -SDG 6-, preserving biodiversity, addressing issues such as overconsumption, obesity, and public health -SDG 3-, achieve gender equality -SDG 5- and bridge inequalities within and among countries -SDG 10- (Tomić, 2018).

Food production systems need to improve the efficiency of natural resources -SDG 12 and 6- use, while reducing waste and pollution at the same time. Increasing crop diversity and enhancing productivity, agricultural sector can provide a nutrient balanced diet, reduce the number of malnourished people -SDG 2- and combat soil degradation and deforestation -SDG 15-. The WorldBank (2023) has estimated that agriculture is about two to four times more effective in raising incomes amongst the poorest than growth from any sector, as it is the largest industry, employing over 1 billion people -SDG 1 and 8-.

The implementation of the European Green Deal strategy and the Paris Agreement in the food production sector, directly address the sustainability issues and contributes to the 2030 Agenda for Sustainable Development. The three frameworks provide complementary approaches to tackling the complex and interrelated challenges facing the world today. For that is important to properly understand the context of sustainable development and develop common pathways (Fig. 3).

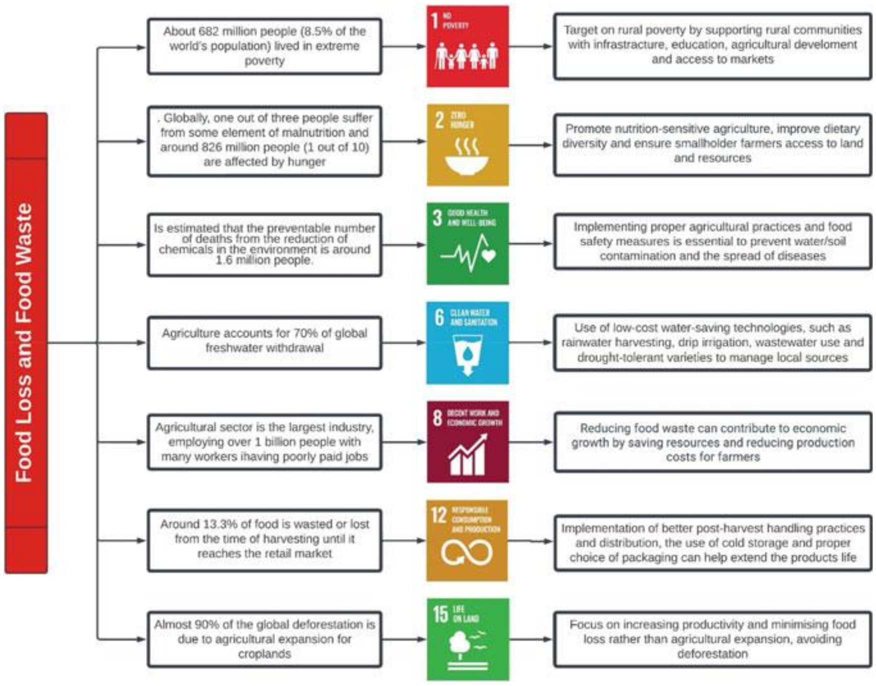

Fig. 3 Food loss/waste and the linkage with the SDGs and agriculture (figure created by the authors)

4 Impact of Overproduction of Food on Sustainability

Agriculture is inextricably linked to the prosperity and development of a country and the most important aspect in developing economies. Agriculture often employs a significant portion of the population, especially in developing countries and ensure access to nutritious, affordable and stable food supply for the population (Pawlak & Kołodziejczak, 2020). The principles that constitute the economy of the developed governments justify the overproduction phenomenon. Free market economies encourage production to promote economic growth and competition (Messner et al., 2021). Developed economies often aim to produce more goods to remain competitive and to offer a wide range of goods to the consumers (Messner et al., 2020). The excess food has consequential implications in the environment, society and the economy (Fig. 4).

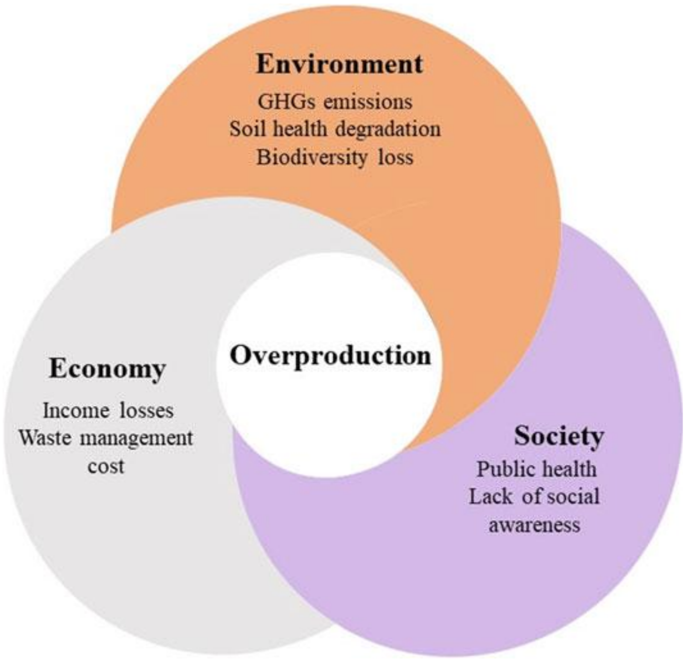

Fig. 4 Main implications of food overconsumption in the three sustainability pillars (figure created by the authors)

4.1 Environmental Implications

Current agricultural system operates in a non-viable way, putting immerse pressure on the available environmental resources and ending up producing more food than needed to feed the global population. Out of that, a third of the agricultural production ends up in landfills, further deteriorating the environment. Food that goes to landfills decomposes producing methane gas, which has 21 times higher Global Warming Potential (GWP) than $CO_{2,}$ and other greenhouse gasses affecting air quality (Seberini, 2020). Among the human-made origins of methane emissions, 35% originate from fossil fuels, 40% arise from agricultural activities, and 20% come from landfills and wastewater (Saunois et al., 2020). Gases emitted from landfills, such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2), H_2S and NO_x have detrimental effects on the environment (USEPA, 2012). Inhalation of these gases may lead to irritation of the throat and nose, potentially triggering the onset of asthma and increase the risk of some specific cancer type (Siddiqua et al., 2022). Njoku et. al. (2019) performed a study in South Africa and shown that 78% of people living around landfills are affected by air pollution.

For that, waste management alternatives, are promoted in the recent years to restrain the negative impact. Looking at the waste hierarchy pyramid from the bottom

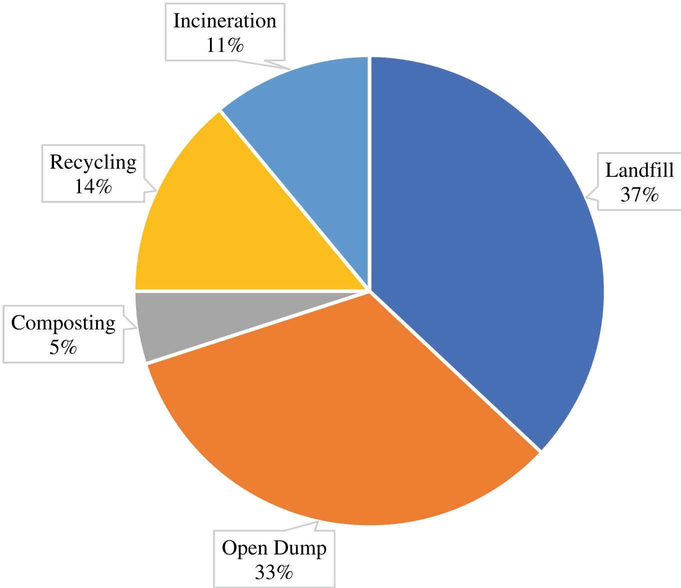

Fig. 5 Global waste management and disposal methods (data from Kaza et al., 2018) (figure created by the authors)

up, the waste alternatives are energy recovery, composting, animal feed and donations (Fig. 5).

Deforestation is perhaps the most important cause of overproduction, driven by the increased demand in crops, especially soya (Gollnow et al., 2018). Natural ecosystems and habitats are destroyed to clear land that will be used for agriculture. The issue is more evident in Brazil, where in 2020, almost 11,000 km^2 of the Brazilian Amazon Forest was transformed in agricultural land to produce soya and for cattle ranching. The removal of the forest land equates to 648 TgCO_2 emitted to the atmosphere (Silva Junior et al., 2020). Farmers colonizing the tropical, are using the slash and burn technique, increasing the risk of fire and affecting human health. Adding to that, the removal of forest cover makes land very prominent to soil erosion.

Food production systems also have a direct impact on soil health. Every growing cycle removes non-renewable macro- and micro—nutrients found in soil, making the land less productive over time. The use of heavy machinery and tillage, cause both soil compaction and soil erosion, leading to lower yields. Farming practices often include high inputs of fertilizers and pesticides in the effort to compensate that and maximize yield. Irrational use of inputs however, can have the opposite effect causing soil acidity and decline in the soil microbiota. Production of fertilizers and agricultural chemicals also require energy intensive procedures and fossil fuel resources. The production of fertilizers is estimated to be responsible for around 1.4% of annual CO_2 emissions (Tsangas et al., 2023; Viglione, 2022). Therefore, when food is thrown away is like throwing away the natural resources used. The average loss of nutrients due to food waste in China is approximately 0.29 kg phosphorus and 2.54 kg N per capita (Niu et al., 2022). A study caried out in Europe by Scherhaufer et al. (2018), estimated that the environmental impact for each kg of wasted food is 2.13 CO_2 eq.

In addition, during the cultivation, preservation, processing and transportation of foodstuffs, energy consumption is required, which also generates CO_2 emissions. The most widely used tool for the analysis and quantification of environmental impacts associated with food production systems is life cycle assessment -LCA- (Cucurachi et al., 2019; Roy et al., 2009). The consumption of raw materials, water and energy resources is required during all stages of agricultural food production. Waste, direct and indirect emissions and discharges are together with agricultural products, outputs of food production systems (Fig. 6). The magnitude of the impacts generated is directly related to the food system used. Thus, it is considered that food production systems based on organic criteria generate fewer impacts per unit of land occupied than traditional systems (van der Wert et al., 2020). However, the unit of reference chosen can tip the balance towards traditional production systems, when expressed in units of production (Cucurachi et al., 2019). In any case, knowing the impacts associated with production processes is the first step towards reducing the footprint of feeding the population.

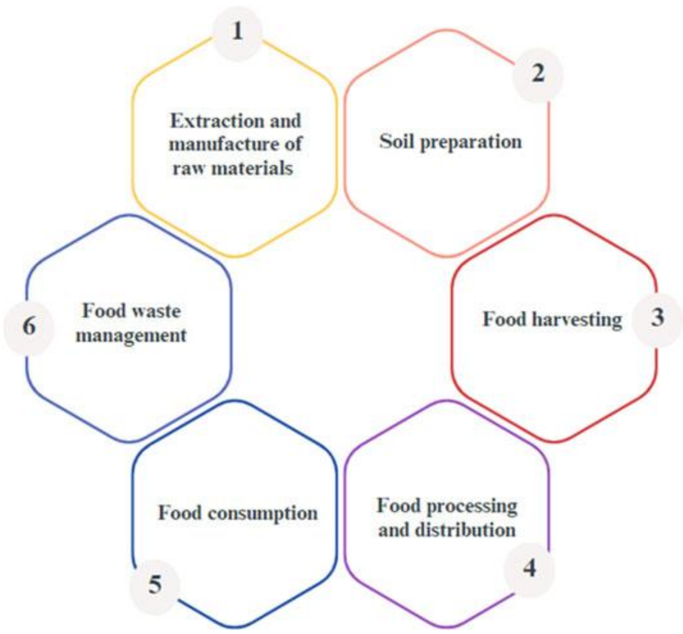

Fig. 6 Food system life cycle (figure created by the authors)

4.2 Societal Implications

Food is an irreplaceable commodity that is important for human consumption and preservation of a healthy and improved life. Food sector affects people from all the levels of society; from production stage, at retail stage and consumption. Maintaining a balance within the system and good communication is of high importance to encompass social sustainability. Food security promotes positive effects on human capital and reduces volatility and violence in a country (Breene, 2016; Bereuter & Glickman, 2017).

The latest Food Security and Nutrition report show that around 826 million people are affected by hunger. The global hunger number rise, is seen as the consequence of the Covid-19 pandemic (United Nations, 2022a, 2022b). Globally, one out of three people suffer from some element of malnutrition, a serious condition identified by the poor nutritional value in peoples diet causing obesity, stunting or wasting (Adebiyi, 2016). Obesity can be seen as the symptom of food overproduction driven by the modern economy. Food companies in the developed countries tend to overproduce food and drive human consumption beyond the feeling of sated, focusing on rising profits. Marketing strategies are developed to communicate their products to consumers and create non-existent needs (Zorpas et al., 2017a, 2017b).

A rather unseen occurrence is the ramification of overproduction on poverty. The market law of supply and demand implies that in the case of increased supply, prices fall when demand remains constant. This has immediate implication on farmers' selling price and consequentially on their household income. Profit margins of farmers are tight and as a response they increase volume of production to maintain an adequate income. This resembles a closed loop effect with few farmers expanding their farm size and smallholder farmers risking foreclosure as they lose competitiveness.

To sell excess production, producers may have to lower prices, which can lead to a decline in market prices for the goods. Overproduction can contribute to deadweight loss, which refers to loss occurring when the allocation of resources in a market is inefficient, resulting in a loss of overall economic welfare (Fig. 7).

4.3 Economic Implications

Production and consumption are part of the economic system that interlink in complex ways (Fig. 8). Production seeks to meet the demands and preferences of consumers, striving for efficiency and innovation to provide more goods and services. In turn, consumption drives economic activity, job creation, and income generation. As consumers' needs and desires evolve, production adapts to cater to these changing demands. The level and efficiency of production directly impact the availability and affordability of these goods and services.

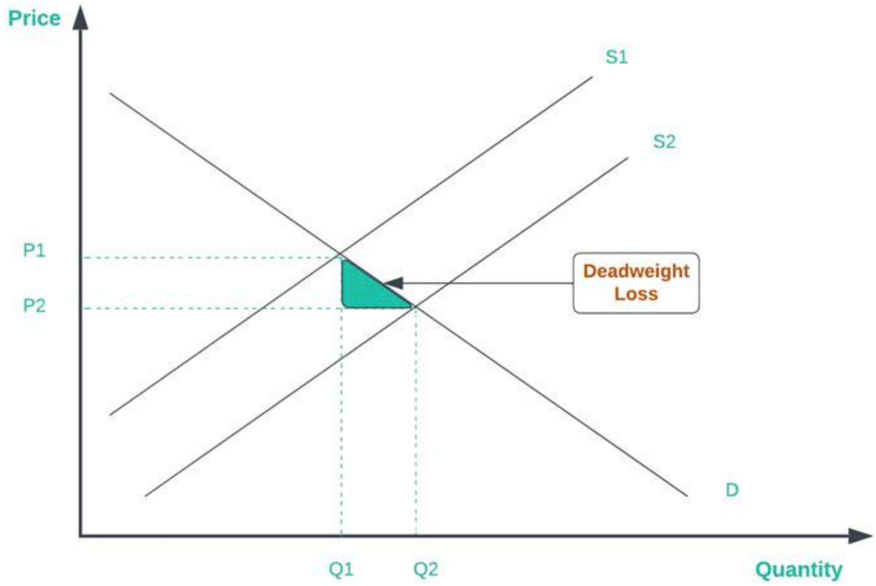

Fig. 7 Supply and demand curve (P: Production, S: Supply, D: Demand) (figure created by the authors)

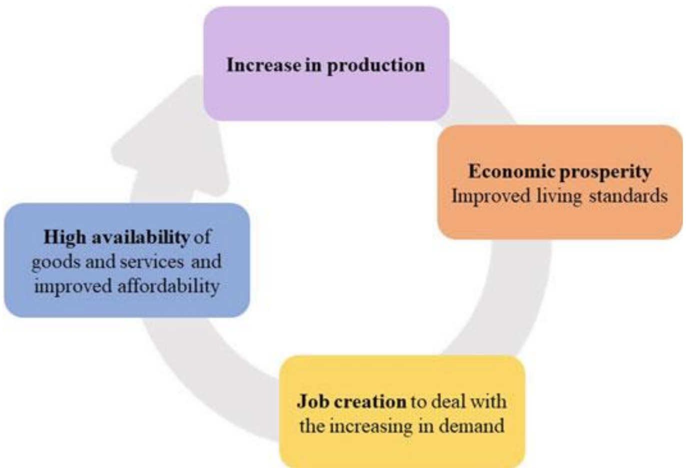

Fig. 8 Positive feedback loop between economic growth and living standards (figure created by the authors)

Consumer's preferences are the driving factor influencing the farmers management—planning and waste generation. However, this relation also works *vice versa* as limitations to production capacity and climate change affect production patterns.

Overproduction of food translates into immediate loss of income in micro and macro level and can have a noteworthy impact on a country's economy. The FAO report (2014) calculated that annually food waste accounts for about 1 trillion direct economic loss, 900 billion social cost and 700 in environmental cost around the world. An average family of four people in America, throws away about 1500$ of food every year.

The problem with wasted food is not limited just in the developed countries. Several studies indicate the huge impact in developing economies, where their GDP is more dependent on food sector (Ali et al., 2021; Malahayati & Masui, 2021; CM, 2022). The most obvious example is in Ethiopia, where postharvest losses account for 10% of country's annual budget (Teferra, 2022). The economic damage due to FLW to Ukraine was estimated at 2.5 thousand euros per 100 people, which accounts for 2% of the average annual salary. Out of that, production stage accounted for 520 euros per 100 people (Kotykova & Babych, 2019).

Cosmetic standards have been long established in developed countries, having a rather direct impact on farmers management. Farmers feel that they need to produce more to avoid losing contracts. Extreme weather event, growing cycle time, domestic or export conditions are some of the risk's farmers try to avoid in order to meet the agreed terms, often leading to over surplus. Additionally, farmers have a strong belief that maximizing yield is equivalent to maximizing profitability. However, this is baseless as overproduction often leads to economic loss from declined prices. In a micro-level, oversupply of produce has a clear impact on farmers profitability and subsequently their livelihoods.

The hidden cost of overproduction is waste management, extending beyond the sphere of agriculture. Food waste generation in hospitality sector has significant implication in operational cost, collection and disposal (Filimonau & De Coteau, 2019; Zorpas, 2020). A reduction of food waste in hospitality sector by 5% can save up to 3 billion UK pounds (WRAP, 2013). The generation of food waste in the hospitality sector is closely linked to the growth of tourism. To illustrate, consider the case of Mallorca, where a 1% increase in the number of tourists visiting the destination results in a corresponding 1.25% rise in waste generation, out of which food waste constitutes the largest portion of this generated waste (Arbulu et al., 2017).

Besides that, the indirect impact of overproduction on human health must not overlooked. Surplus production usually ends up in landfills which, during decomposition, emit gases harmful to human health, burdening the country's health budget. A study carried out in Los Angeles by Krautwurst et al. (2017) in a landfill that accept maximum 8000 tons of waste per day, estimated 11.6 and 17.8 kt CH_4/year of fugitive emissions. The global landfill CH_4 emissions for 2020 were estimated to be around 905 Mt/CO_2 eq (Zhao, 2019). Recently, a growing level of concern regarding the release of trace gas emissions from landfills for municipal solid waste (MSW) is noted due to the potential link to human illness. Trace gasses originating from food waste in landfills include organic sulfur and oxygenated compounds when newly waste is deposited, and hydrogen sulfide (H_2S), aromatics, and aliphatic hydrocarbons during the methanogenesis stage (Duan et al., 2021).

5 Impact of Food Overproduction on Soils

Soil conservation is critical to maintain a healthy food production system. Soil is the medium in which crops grow to provide economic viability and social coherence. Overproduction of food creates a domino effect that negatively affect the three sustainability pillars (Fig. 9). However, most studies focus on the impact of soil degradation to food production and not in reverse. The growing population, economic prosperity and changes in dietary patterns, poses significant challenges to provide sufficient food on the globe (FAO, 2018).

Until recently, researchers believed that the solution to feeding adequately the ever-increasing world population lies in increasing farm productivity, since the availability of new fertile land is limited. The study carried out by FAO in 2011, showed that excessive amount of food is waste from farm to fork. Enough to feed the 870 million hungry people four times. Since then, the research focus shifted to discovering the causes of this phenomenon and to propose solutions on how to utilize surplus food.

In soil-based agriculture, soil health is the most important foundation of a healthy farm ecosystem (Rodríguez-Espinosa et al., 2023a, 2023b). Yet most of the common farming techniques employed in industrial crop production, such as synthetic fertilizer application and monocropping, can degrade soil over time, causing a cascade of problems necessitating the use of even more man-made inputs, which in turn contribute to climate change (Saljnikov et al., 2021).

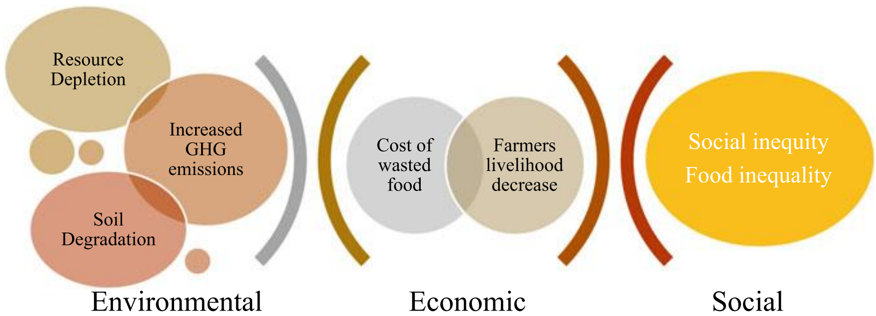

Fig. 9 Interaction among sustainability pillars resulting from food overproduction (figure created by the authors)

Land use change is one of the most threatening activities, causing remarkable changes in soil characteristics. For food production it refers to the repurposing of land by human activities, transforming the natural status of the land to be used for agriculture. Since 1960, one third of the earths land surface (43 million km^2) has changed to a degraded state. On average 720,000 km^2 of land has change every year since 1960, with the most alternations in Europe, Australia and India (Winkler et al., 2021). Expansion of agricultural land is responsible for 25% of forest loss in Argentina and 85% in Liberia (Radwan et al., 2021). Forest conversion to pasture or farmland decreases the Soil Organic Carbon (SOC), a natural way of storing CO_2, and emits carbon dioxide in the atmosphere due to biomass loss and burning (Schulp et al., 2008). SOC in croplands is projected to further decline by 10–14%, even assuming constant C input because of the climate change, persistent farming and low-input agriculture (de Blécourt et al., 2019). Amazon rainforest has reach to the point to emit more carbon dioxide than it can absorb, due to deforestation and fires that reduces the carbon sink.

An equally important implication induced by land cover change is soil erosion. Removing the vegetation cover of the land, either if it is forest or pastureland, soil becomes suspectable to wind and water erosion. Climate is projected to increase the average length of drought period and the extreme rainfall events, inducing soil and water erosion respectively (United Nations, n.d.). Higher rates of soil erosion are observed in the absence of vegetative cover and slope length factor (Gobin et al., 2006). Agricultural intensification largely in regions around the world with low crop production, leads to the use of land with steep slope or marginal land, aggravating erosion rates. Erosion is a slow continuous process, that goes unnoticed by the farmers. Yet, 1 mm of soil lost in an event of intense precipitation, amounts to about 15t/ ha soil (Soil erosion threatens food production). Eroded topsoil carries away the most nutrient reach sediments, estimated to be 23–42 Mt (megaton) N and 14.6–26.4 Mt P per year (Imdad & Rafique, 2019; Rodríguez-Espinosa et al., 2023a, 2023b). This loss of nutrient to the effect of soil erosion, require the enrichment with inputs of fertilizer to make up for the lost nutrients and maintain soil productivity. Erosion also reduces the organic matter content, an important soil characteristic for the preservation of soil biodiversity that support crop resilience and productivity (Pimentel & Kounang, 1998). Soil erosion in the United States is estimated to cost 44 billion a year (Telles et al., 2011).

Few studies (Davies & McMahon, 2021; Wuepper et al., 2019) have tried to calculate the global erosion rates, but the high variabilities and methodologies used gives a different variation in each study. Countries' agriculture characteristics applied and implemented policies, influence the soil erosion rate (Bouguerra et al., 2023; Wuepper et al., 2019). A multinational study calculated the predicted global annual soil erosion at 80.4 billion Mg/year, with an average area-specific soil erosion rate of 16.6 t/ha/year. The most likely global soil erosion by water is 20-30 Gt/year, while erosion form tillage amounts to ca. 5 Gt/year. Higher uncertainties are prominent in the estimation of total erosion caused by wind. On arable land the approximate dust amount relocated yearly by wind erosion is ca 2 Gt/year.

Only a small fraction (10.7%) of the world's land surface is suitable for arable farming. Arable land in China accounts for the 12.7% of land area, whereas in Europe arable land is steadily declining but remains high compared to other continents accounting for 25% of the total land (WorldBank n.d.). The increasing demand for food production and climate change makes quality fresh water a very scarce resource. Many European countries have adopted the use of treated urban wastewater as an alternative source and avoid surface water pollution. Despite that, excessive use of treated water accumulates heavy metals on soil, such as COD, BOD5, Cd, and Ni causing pollution in local rivers and agricultural land (Belhaj et al., 2015). Accumulation of pollutants beyond the recommended values, negatively affect the photosynthesis and plant growth of agricultural crops. Wastewater irrigation is also more likely to have a toxic effect on soil fauna, with implication in agronomical important groups, such as pollinators and predators (Singh et al., 2012).

The use of heavy machinery for the cultivation practices induces soil compaction, reducing soil porosity and the ability of air and water to move around the soil, leading to stunted root growth and lower yields. Apart from that, soil compaction has adverse effect on microbial biomass, C- mineralization and increases the potential of soil erosion (Beylich et al., 2010). Pesticide and fungicide use in conventional farming is the primary reason for toxicity effect and decreased soil ecology. Microbial diversity and particularly bacteria have proven to be significant when compared to organic farming. Elimination of fungicides in agriculture is estimated to avoid the loss of up to 90 species per year (Tsalidis, 2022). Despite that, the global use of pesticide in agriculture remains relatively high at 2.7 Mt per year, corresponding to 0.37kg per person. Remarkably in America, the pesticide use per cropland is two-fold compared to other continents (FAO, 2022b).

Nutrient management is an important component in agricultural system that is often overlooked resulting in acidification of the soil ($pH < 5.0$). Soil acidification greatly reduces plant-soil interactions and influence the capacity of soil biota and soil health remarkably (Xiao et al., 2020; Zhang et al., 2022). The degree of acidification has the potential to alter soil biogeochemistry, by affecting the weathering process of primary metals. Additionally, the soil function of absorbing nutrient cations such as Ca^{+2}, Mg^{+2}, K^{+}, available N and P is greatly reduced, affecting soil fertility (Zhuge et al., 2023) and the potential agricultural production. The overuse of ammonium-based fertilizers as part of the conventional farming, is the dominant factor that results in soil acidification. Export of produce (removal of base cations), excessive application of organic matter and nitrate leaching are also contributing factors. The global consumption of fertilizers in 2019 reached 213 million tons, 123 million tons of nitrogen and 45 million tons phosphors and an equal amount of potassium (Ritchie et al., 2022). A balanced fertilization program is important to maintain the soil pH level in optimal levels (5.5–6.5), restore the loss of nutrients and thus, maximize agricultural production.

SDG 12 'Responsible Consumption and Production', highlights the importance of sustainable resource management and efficient supply chain and production. Promoting sustainable agriculture is a way of achieving food security in a rapidly growing population and achieving SDG 2: 'Zero Hunger'. Specifically, targets 2.1

Table 3 Soil health sustainable management practices

	Soil erosion	Soil chemistry	Soil structure	Soil ecology	Carbon balance	Nutrient balance	Water capacity
Integrated pest management		+		+		+	
Organic farming	+	+		+	+		
conservation or no-tillage	+		+	+	+	+	+
Crop rotation		+	+	+	+	+	
Cover crop	+	+	+	+	+	+	+
Intercropping		+		+		+	
Agroforestry	+	+	+	+	+	+	+
Precision farming		+		+	+	+	
Buffer strips	+			+		+	+
Adding organic matter		+	+	+	+	+	+

and 2.2 aim on ending hunger and any form of malnutrition by securing sufficient nutritious food by the year 2030. This global incentive is the last defense of humanity to maintain sustainable levels of arable lands and provide better and healthier living.

The negative impacts on soils derived from the agricultural production systems, effect distant in space and time. Maintaining soil health by using sustainable agricultural practices is of high importance to meet the increased projected demand in food (Table 3). The total ecosystem services value derived from soil, with respect to natural capital is estimated to be 11.4 trillion USD (McBratney et al., 2017). Sustainable and regenerative agriculture seeks to ameliorate soil health, sequestering carbon, storing water and building healthier farm ecosystems along the way (Table 4).

6 Case Studies of Sustainable Food Production

There are several examples of studies around the world that highlight sustainable food production initiatives from different parts of the world. Solutions examine various point of views and extend from the agricultural production stage up to consumer level changing.

There is growing tendency in the direction of conservation agricultural practices around the world. Conservation agriculture is an adapted set of management principles where farmers are using minimal tillage, crop rotation, cover cropping to improve soil health and reduce erosion and practice integrated pest and fertilization strategies management. These practices enhance crop yields, reduce the need for

Table 4 Sustainable agriculture practices to prevent soil degradation

Agricultural practice	Explanation	Benefits	References
Integrated pest management (IPM)	IPM incorporates mechanical and biological control measures to maintain pest and diseases populations at a minimal level	• Minimizes the use of synthetic pesticides • Protect beneficial organisms • Cost-effective • Improve crop quality and yield • Reduce the risk of developing a pesticide-resistant population	(Deguine et al., 2021; Desneux et al., 2022)
Conservation or no-tillage	Minimize or eliminate soil disturbance by planting crops without plowing or tilling, maintaining the natural soil structure. Crop residue can be left on the field to protect against erosion	• Save time and fuel • Soil compaction from heavy machineries is avoided • Moisture and reduced temperature on the top-soil favors the biodiversity of insects and bacteria • Reduced erosion and possibility to sequester carbon	(Jacobs et al., 2022; Li et al., 2021)
Crop rotation	The practice of planting different crops, originating from distinguished botanical family groups, sequentially in the same plot. Ranges between 3 and 7 years	• Break the cycle of herbivores, weeds, pest and diseases • Maintain soil health • Improve the stability of the planting system, and make it climate-resiliant • Enhance soils' chemical and physical properties	(Shah et al., 2021; Yu et al., 2022)
Cover crop	Cover cropping involves planting non-cash crops (cover crops) alongside main crops	• Protect the soil from erosion • Improve soil structure • Add organic matter when incorporated	(Blanco-Canqui and Ruis, 2020)

(continued)

Table 4 (continued)

Agricultural practice	Explanation	Benefits	References
Intercropping	The practice of growing simultaneously two or more crops in the same plot of land for a significant part of their growing cycle	• Effective against suppressing the most persistence weeds • Some crop combination may have synergistic or allelopathic properties, boosting crop efficiency • Certain crop combinations can naturally deter pests and diseases	(Huss et al., 2022; Maitra et al., 2021)
Agroforestry	Integration of perennial trees, livestock and crops the same piece of land. Trees may provide valuable wood, softwood for fiber production and/or sellable fruits and nuts	• Preservation of biodiversity • Carbon sequestration ability • Diversified income • Provides shade for crops and livestock • Reduce soil erosion and minimize soil degradation	(Pantera et al. 2021; Fahad et al., 2022)
Organic farming	Organic farming avoids synthetic pesticides, fertilizers, and genetically modified organisms (GMOs). It relies on natural methods like composting and crop rotation	• Produce food without harming the environment • Reduce chemical exposure • Preserve soil and water quality	(Kirchmann, 2019; Nedumaran & Manida, 2020)
Precision farming	Precision agriculture uses technology like GPS, sensors, and data analysis to optimize crop management. It enables precise application of inputs such as fertilizers and water	• Optimize resource use • Reduce cost and environmental burden • Increase crop yield and animal performance • Helps farmers make informed decisions about crop management and make a better planning in the future	(Blasch et al., 2020; Raj et al., 2021)

synthetic inputs, and promote long-term sustainability. In Portugal, straws left on the soil surface improved soil organic matter, water infiltration and drainage, that can prove to be beneficial for the economic and environmental sustainability of rainfed agriculture in Mediterranean (Carvalho & Lourenço, 2014). Conservation agriculture can be proven beneficial especially for developing countries that access to resources, labor and equipment is restricted. For example, farmers in Zambia successfully practice early planting enabling the crop to use of the first effective rain and better manage weed emergence (Baudron et al., 2007). Verhulst et al. (2013) claim that physical, biological and chemical soil quality improvements derived from conservation techniques have the ability to increase the crops' climate resilience and achieve a net global warming potential. Crop residues retention, timely planting and optimized fertilization application and investment in innovative technologies are crucial for a successful development of conservation practices.

Traditional agriculture practices are considered to be a climate-smart approach for food production, as they are tailored to local production and are based on many years of observation, experience and modifications of the agricultural system. Practices include agroforestry, intercropping, integrated crop-animal farming, cover cropping etc. They are low cost, energy efficient, based on locally available resources and have the potential to increase agrobiodiversity (Singh & Singh, 2017). However, this practice is mainly restricted to small-scale farmers and rapidly declines due to pressure from globalization (Lieskovský et al., 2014).

Small-scale food production in urban areas plays a multifaceted role in contributing to sustainability, food security, community well-being, and environmental resilience in cities. The results of a pilot study conducted among small-scale home growers in the UK corroborate this (Nicholls et al., 2020). Urban growing uses fewer agrochemicals, provide habitat for wildlife in the cities, reduce air pollution, provide a recreational space for citizens and access to more diverse diet, while having a comparable or higher yield than large scale-conventional farms.

Japan has seen the rise of vertical farming ventures, which employ advanced indoor farming techniques to grow vegetables in vertical stacks. By reducing land and water requirements, these systems offer a sustainable solution to urban food production. Vertical farming employs the recycling of nutrient solution, improving nitrogen (N) and phosphorus (P) use efficiency and effectively reducing the N footprint by 37% and the P footprint by 36% (Liu et al., 2022). More importantly, vertical farming systems have the capacity to produce high rates of locally grown food, without using farmland and regardless the timing and weather conditions.

Nanofertilizers increased rate use efficiency and stress tolerance, have the capability to contribute to sustainable agriculture, while minimizing the environmental impact from nutrient run-off. An experiment conducted in Egypt, compared the efficiency of traditional chemical fertilizer and nanofertilizer (Abd El-Azeim et al., 2020). Foliar application of nanofertilizer showed considerable positive effects on all the yield and yield growth quality parameters examined at rates either equivalent to or lower than traditional fertilizers. Even at lower application rates of 25 and 50% compared to control, nanofertilizers were equal or more effective (Abd El-Azeim et al., 2020). The method of synthetizing nanoparticles is also crucial in the performance of nanofertilizers. Promoting plant growth and enhancing physiological attributes were observed at low to medium concentrations of biological synthetized FeO nanofertilizers in *Zea mays*, whereas chemically synthesized nanoparticles reduced plant growth at medium doses (Hasan et al., 2020).

The extensive use of pesticides can have negative trade-offs in the farming system. In the case of rice-fish farming in Mekong Delta River in Vietnam, farmers often prioritized increasing rice yields while inadvertently neglecting the effects on fish growth and survival rates. Berg and Tam (2018), revealed that reducing the use of pesticides led to significantly increased yields in both rice and fish yield, while mitigating the adverse effects of pesticides on farmers. An additional option for pest control involves the utilization of biopesticides, which are derived from naturally occurring substances, primarily extracted from aromatic plants and microorganisms. Plant essential oils such as cloves, mint and oregano oils can successfully inhibit fungal growth, but cautious is needed in the dosage to not affect wheat seed germination (Karaca et al., 2017). Management of fungi diseases in legume crops can be controlled using different strains of *Trichoderma spp* fungi (Mishra et al., 2018).

Bourke et al. (2018) examined the efficiency of cold plasma (an ionized state of gas), to maintain food quality in different stages of food production. Cold plasma has the capability to break down mycotoxins and pesticide residues, including various organochlorine and organophosphorus pesticides (Misra et al., 2014; Shi et al., 2017). Physiochemical and physiological parameters of seed quality including germination and growth rate are also improved, but the type of seed needs to be considered to choose the proper cold plasma treatment power level (Bourke et al., 2018). In terms of post-harvest treatment, it has the ability to inhibit the growth of fungi, insects and bacteria in stored products, increasing shelf life without affecting the products' organoleptic characteristics (Choi et al., 2017).

Regenerative agriculture focusses on improving soil health through techniques like cover cropping, no-till farming, and crop rotation. These practices sequester carbon, reduce soil erosion, and enhance the resilience of farming systems. Tailor-made practices are a necessity for making regenerative agriculture a success. Cover crops, reduction of nitrogen fertilization and application of soil organic matter and manure improved the overall environmental performance in Dutch farms, as the GHG emissions reduced, pesticide use was limited and soil functions improved. However, this improvement negatively impacted farm profitability, potentially hindering the broader adoption of regenerative agriculture.

Profitability is the biggest concern for a farmer when adopting new practices, as their livelihood depends on it. Therefore, economic incentives are needed to motivate food producers to adopt more sustainable farming practices. Government schemes such as the Common Agricultural Policy in European Union are in place to support the implementation of environmentally friendly practices in Europe. Apart from that, product, marketing, labeling and accreditation (PMLA) schemes, are supported by farmers as they offer economic gains, protect their product from imitation and gain the possibility of reaching new markets (Ilbery & Maye, 2007). The PMLA schemes promote specific agricultural practices, products or regions and is widely used in Europe. PMLA schemes is proven to be a win-win situation, as the farmers' profitability increases, the local community employment is maintained, food supply chain actors improved their relationships and the environmental aspect the scheme is intended to protect is preserved.

Taking an alternative viewpoint, in Australia, research has explored the potential to enhance the sustainability of the food production sector by incorporating environmental considerations into dietary choices. An articulated healthy and sustainable (HandS) diet is outlined, where decisions are guided by health criteria and their environmental outcome (Friel et al., 2013). They recommend that the intake of nourishing food and beverages to fulfill an individual's energy requirements and avoid overconsumption, limit saturated fat, salt and sugar and consume foods from all the categories (grain, vegetables, fruits, meat and dairy).

7 Conclusions

The overfood production origins food wastes and exhausted the soils, increasing the degradation processes due to the increment of inputs and the techniques used for soil management. Far from ensuring the food supply, the excess of fertilizers and the wrong agricultural practices are drawing a negative scenery of sustainability. Soil degradation is limiting the surface available for food production. So, food waste is provoking an antagonism regarding soil health and food yield.

The consequences of overproduction have been showed in this chapter and the effects are notorious in the environment, society and economy. These aspects are the three pillars of sustainability in the planet and all of them are affected by food wastes. Better actions should be implemented to reduce food waste and ensure the food availability to feed a growing population. As FAO recognized (2015), the most widely recognized function of soil is its support for food production and it is estimated that 95% of our food is directly or indirectly produced on our soils. Food waste, excess of food production, poses in risk soils and the environment.

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