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# Circular economy in agriculture: unleashing the potential of integrated organic farming for food security and sustainable development

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Food is a basic human requirement which sustains the dynamics of the Earth's inhabitants by satisfying hunger, providing nutrition and health, and catering to culture, tradition, and lifestyle. However, the rising global population coupled with climate change including calamities, diseases, conflicts, as well as poor agricultural practices put a huge constraint on the quantity and quality of food. Modern agriculture propelled by the green revolution has somehow been able to meet the food requirements of the ever-increasing population and is heavily dependent on chemical fertilizers, pesticides, and machinery, reducing the quality of food, and simultaneously posing a great risk of environmental quality degradation and genetic diversity reduction. The Integrated Organic Farming System (IOFS) is a novel approach that holds the potential in addressing the challenge of reconciling food production with environmental preservation. As this approach embraces zero or minimal chemical use, adopting the reprocessing and reuse of agricultural residues has led to a sustainable system that can be viewed as the closest approach to nature and a circular economy. However, certain constraints need to be addressed, such as ascertaining the effectiveness of organic fertilizers, the complexities associated with weed management, and the inadequacy of proficiency, financial resources, and technical expertise required to implement the IOFS. Therefore, this study emphasizes the comprehensive benefits that could be derived from IOFS, particularly agroforestry, including efficient food production, improved food quality, biodiversification of crops by the adoption of lesser-known crops to cater to cultural requirements and minimal capital input to achieve environmental sustainability and a carbon neutral economy.

## KEYWORDS

crop, biodiversification, lesser-known crops, sustainability, 5R-concept, Circular-Organic-Agroforestry, organo-agroecosystem, agroforestry

## Introduction

Agricultural systems are the foundation of human civilization, providing food, fiber, and fuel (Sharma U. et al., 2022). However, traditional farming practices have come under scrutiny due to their negative environmental impacts, involving soil degeneration in soil, water, and air with emissions of GHGs. This steered a proliferation of sustainable farming practices that balance food production with environmental conservation. Integrated Organic Farming Systems (IOFS) is an innovative approach that offers a promising solution to this challenge. Agricultural systems must have multi-functionality to achieve food security, economic gains, social functions, and environmental sustainability (Groenfeldt, 2005). In addition, an increase in the number of components and functions tends to enhance the stability of the food production and land use system (Price, 2000).

In the Indian context, IOFS is a novel concept of on-farm resource management strategy developed under the scheme (AL-NPOF)<sup>1</sup> All India Network Program on Organic Farming (IIFSR-ICAR, 2014), designed to realize remunerative and sustained agricultural out-turn to satisfy the heterogeneous needs of the farmers as well as the consumers. IIFSR-ICAR (2016) developed the IOFS model for Meghalaya and Tamil Nadu. The model for Meghalaya is [(Cereals + legumes + vegetable crops + fruits + fodder) + Dairy (1 cow + 1 calf) + fishery]. While the IOFS model for Tamil Nadu is [(Green manure-cotton-sorghum; okra + cilantro-corn + cowpea (fodder), *Desmanthus*, 1 dairy cow with heifer and young bull + biofence of *Gliricidia sepium* and coconut)].<sup>2</sup>

IOFS is a holistic approach that integrates various agricultural practices, such as crop cultivation, livestock rearing, and tree farming, in a synergistic manner. An integral feature of an IOFS involves two fundamental attributes: residue recycling, whereby the waste or byproducts produced by one constituent are utilized as inputs for the other constituent, and improved land-use efficiency, i.e., two subsystems occupying a portion, or the entirety of the space required for each subsystem (Paramesh et al., 2022). The goal is to maximize resource utilization and reduce waste, leading to improved soil health, biodiversity, and enhanced ecosystem services. IOFS also emphasizes the application of organic resources and minimizes the application of chemical pesticides and fertilizers, promoting soil fertility with the reduction of environmental pollution. Several authors outline the benefits of IOFS for food production and environmental sustainability (Garima et al., 2021; Sharma U. et al., 2022; Kumar et al., 2023; Verma et al., 2023a,b).

For instance, a study conducted in India found that IOFS increased crop yields, reduced input costs, and improved soil quality compared to conventional farming practices (Das et al., 2017). Another study in China showed that IOFS improved soil organic matter content, reduced nitrogen losses, and increased biodiversity (Chen et al., 2019). Thus, the adoption of IOFS has

the capacity to propel toward food and nutritional soundness through the systematic employment of available assets and the incorporation of essential components such as agricultural crops (Altieri et al., 2012; Wezel et al., 2014). However, understanding the distinct functions performed by different elements of IFOS is crucial in catering to the unique requirements of smallholder farmers, as this knowledge is pivotal in fulfilling the dietary and sustenance needs of agricultural households. Simultaneously, due to the intricate nature pertaining to the projected growth of food and nutritional demand, it is imperative to recognize the paramount significance of region-specific IFOS systems throughout the globe. These IFS initiatives play a pivotal role in effectively catering to and satiating the demand, thereby assuming a critical position in the overall food security framework (Paramesh et al., 2022).

Specialized agroecosystems tailored to cope with climatic stress are vital to expedite food security and sustenance. IOFS also has the prospect to attenuate climate change by impounding carbon into soil and limiting GHG emissions. The carbon captured by primary producers during photosynthesis practically nurtures each ecological consumer-resource system by serving as the channel for the transmission of solar energy in the biosphere (Pelletier et al., 2011). A study in Italy showed that IOFS had a lower carbon footprint than conventional farming practices due to reduced use of synthetic fertilizers and lower energy consumption (Chiriaco et al., 2017). Similarly, an investigation in China reported that IOFS minimized greenhouse gas emissions by 13.4% compared to conventional farming practices (Zhou et al., 2019). If all agricultural systems adopt IOFS, the oversight in manufacturing synthetic fertilizer and application can curtail agricultural emissions by about 20%, of which 10% will be due to reduced NO<sub>2</sub> release while about 10% to low energy requirement (Niggli et al., 2009). Furthermore, these emissions reduction is again complemented by emission reparation by carbon sequestration of around 40–72% of the annual greenhouse gas emitted from food production systems. Overall, Barbosa et al. (2015) expressed that the adoption of IFOS presents a viable and encouraging approach for reducing greenhouse gas (GHG) emissions and curtailing nutrient loss. The optimization of available resources is achieved by implementing improved nutrient recycling techniques and utilizing crop residues as animal feed.

Despite the potential benefits of IOFS, its adoption has been limited due to several barriers, including a lack of knowledge and technical expertise, inadequate policy and institutional support, financial, sociocultural, and biophysical constraints, and market demand. Specifying the finitude of energy capital supporting food logistics combined with a restricted range of ecosystems to appropriate residues from energy production along with conversions, the ramifications for food systems deserve critical deliberation (Pelletier et al., 2008; Paramesh et al., 2022). Therefore, there is a need to undertake research and development in IOFS to universalize adoption. This review article intends to provide a conspectus of IOFS and its potential benefits for food production and environmental sustainability. The article will discuss the key principles of IOFS, its potential benefits and limitations, and the current state of research and development in this field. The article will also highlight the guide to the conversion of agrisystems to

<sup>1</sup> <https://iifsr.icar.gov.in/icar-iifsr/npof/>

<sup>2</sup> <https://iifsr.icar.gov.in/icar-iifsr/npof/data/uploads/files/Tecnologies%20developed.pdf>

IOFS that can promote the adoption of IOFS and the challenges that need to be addressed.

## Approached methodology

### Data collection

For identifying relevant studies for this review, we carried out a systematic search of electronic databases, including PubMed, Scopus, Web of Science, and Google Scholar, using the following keywords: “Integrated organic farming,” “Organic farming systems,” “Sustainable agriculture,” “Food production,” and “Environmental sustainability.” We also hand-searched the reference lists of selected articles for additional relevant studies. The search encompasses appropriate literary materials from as early as 1713 to February 2023.

### Data analysis

The authors TS and LP individualistically partitioned the titles and abstracts of the articles identified to assess their relevance to the review topic. The full texts of potential articles were obtained and evaluated for eligibility. Eligible studies were those that reported on the implementation and outcomes of integrated organic farming systems in different regions of the world. Overall, this review article provides a meticulous audit of integrated organic farming systems with their potential to provide a sustainable and efficient approach to food production and mitigate environmental impact.

## The crisis and constraints in food production and food security

Before the beginning of the 19th century, the human population's growth was relatively slow. It took over 2 million years to reach the 1 billion milestone (Population Division, UN); now, the worldwide total population is about 8 billion (countrymeters.info). UNDESA (2021) forecasted that there will be 9.6 billion people by 2050, and providing food for humans sustainably will become a goliath task as total food production volumes are expected to increase appreciably through 2050 to nourish the population (FAO, 2006; Godfray et al., 2010). Taking 2000 as the base year, the FAO (2011) projected that it is mandatory to surge food production by 70% globally and 100% in cash-strapped countries. Sustainable nourishment of the human population is an impending obstacle as resources are finite.

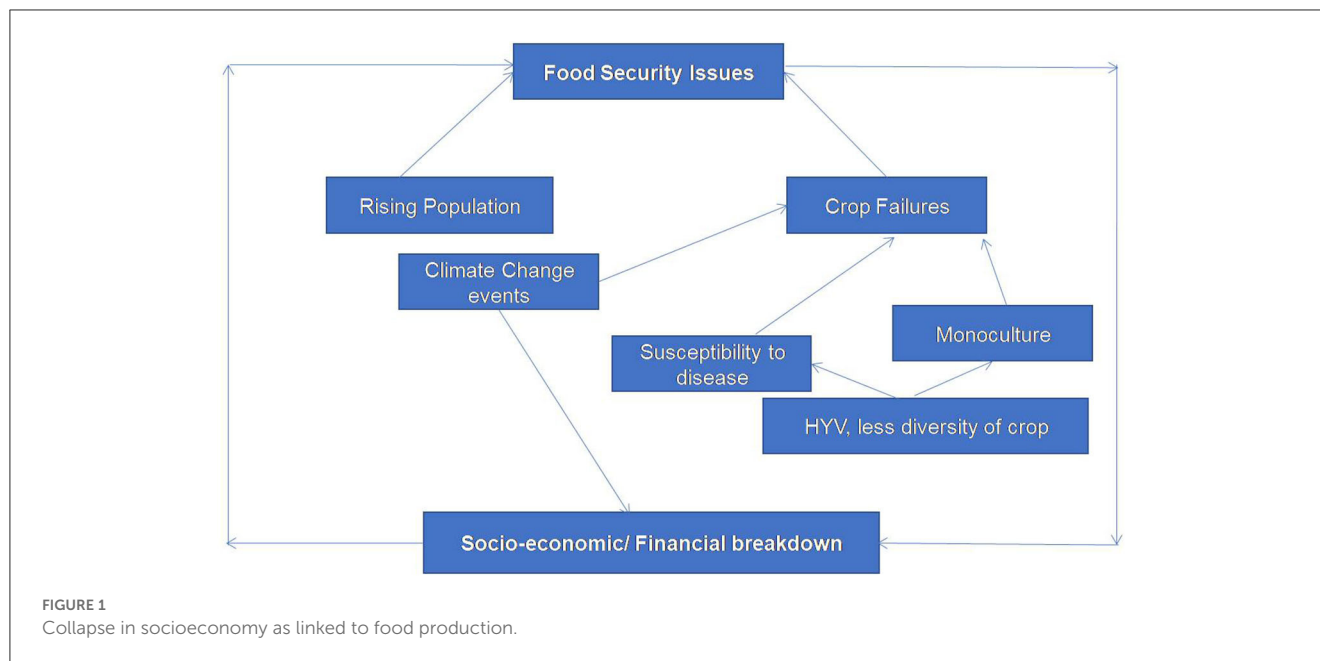
The rapid growth of the human population in such a short period, combined with natural calamities, poor agricultural practices, and World Wars I and II, has put a mammoth impediment on the food supply, causing widespread famine and malnutrition. The end of the Second World War marked the emergence of several agricultural improvements termed the Green Revolution (Gaud, 1968), which was hastened by the efforts of

Dr. Norman Borlaug through the creation of HYVs along with disease-resistant varieties of cereals especially wheat and rice which have been genetically modified from the purebred (Borlaug, 1953). The introduction of the multiline and the intensification of agriculture practices have produced huge agricultural output and saved a billion people from starvation (Easterbrook, 1997). Specialization of agriculture with a focus on incremental production was undertaken with reparations of agroecological principles including crop diversity, especially pulses that could reduce synthetic inputs (Watson et al., 2017).

Reliance on a few crops has resulted in a narrow genetic base, and diseases combined with hanging environmental scenarios such as land degradation and climate change have made such crops susceptible to devastation. Mention may be made of the Irish potato famine of the 1840s, where one in eight Irish people died of starvation as the potato was their main staple, and potato blight disease caused major crop failure. Moreover, the Southern Corn Leaf Blight in 1970 due to an attack of race T of fungus *Helminthosporium maydis* on the Southern and Mid-West US Corn Belt brought frantic turmoil in the economy of America as 15% of the crop was wiped out. The farmers and lenders who suffered the ripple effect of the blight had to endure the consequences of trying to recover from their losses (Doyle, 1985). During the 1980s in California, USA, 2 million acres of grape vines were replanted in Napa Valley as the same high-yielding clonal variety was unable to withstand attacks by aphid (*Phylloxera vastatrix*), which had devastated England and Europe from the grafts brought from California in the late 19th Century (New York Times, 1985). These have led to an economic breakdown, as depicted in Figure 1.

To discourse the issue of food insecurity in several regions by famine, the first-ever World Food Summit of 1974 convened by FAO promulgated that every human has the absolute right to be free from hunger and malnutrition to develop their physical and mental faculties (UN, 1975). In subsequent years, concerted efforts from multiple agencies and governments have discussed the issue of food insufficiency to some extent. However, most of these movements have been incremental that have failed to bring about a transformative mode of agroecological approaches considering the dynamics and interactions with the cropping systems, producer, and consumer (Rosati et al., 2021).

Conventional modern agricultural practices have also been criticized for being intensive and having high dependence on non-renewable resources, chemicals, and fuels (Carson, 1962; Pimentel, 1996; Geiger et al., 2010; Winqvist et al., 2012), degradation of land and water resources (Carson, 1962; Pimentel, 1996; Winqvist et al., 2012; Petrosillo et al., 2023), negative impacts on the native bio-resources through reliance on a few staples (Jennings, 1988; Fischer et al., 2014; Petrosillo et al., 2023) along with the higher output of greenhouse gases especially methane (UNDESA, 2021), and compromised nutritional quality (Sands et al., 2009). The input on agriculture to bring about enough food for all is so high that 70% of global freshwater withdrawals from both groundwater and freshwater are attributed to the irrigation of farmlands or processing of food produces (UNESCO, 2020). And an input



of over 110 million tons of chemical fertilizers was made in the year 2018 (UNDESA, 2021). Kissinger et al. (2012) have attributed 80% of deforestation to agricultural land use. This projection was estimated using FAOSTAT (2009) deforestation values of 2005–2009 as a base, corresponding to the change in cropland areas in each country. The resulting ratio was furthermore employed to estimate deforestation values from area changes in the outlay. Meanwhile, half of the world's terrestrial habitable lands have been utilized for agricultural purposes, involving the conversion of huge areas (about one-third) of global forest lands (FAO, 2020a). The conversion of forests and thereby change in LULC to agroecosystems additionally poses a huge risk of loss of local biodiversity through habitat fragmentation and alteration (Gibbs et al., 2010).

AFOLU accounts for 25% of global human-induced GHG emissions (Ripple et al., 2014; Smith et al., 2014) of which 14.5% is contributed from livestock production. As specified by the IPCC, the agricultural industry was responsible for emitting an estimated annual quantity of greenhouse gases ranging from 5.1 to 6.1 gigatonnes of CO<sub>2</sub> (Barker et al., 2007). The estimate which does not include emissions coming from post-harvest processing and distribution as the greatest consumption of energy and emission of GHGs in the food system is regional and global food trade upshot “food miles” (Pretty et al., 2005).

Moreover, conventional modern farming practices exacerbate soil quality degradation through topsoil runoff and loss of SOM, forbidding the future sustainability of crop production already facing peril under extreme climatic events (Pimentel et al., 1995; Ashby, 2001; Gomiero et al., 2011; Porter et al., 2014; Petrosillo et al., 2023). There is a strong correlation between agriculture and climate change as agriculture is very much responsible for producing GHGs, and prevailing climatic conditions highly

influence the success of an agricultural food production system. Climate change-associated events such as rising temperatures, erroneous precipitation patterns along with the increased frequency of extreme weather occasions imperil agricultural fecundity, the feasibility of farming spiraling vulnerability, and ultimately leading to food insecurity (FAO, 2007).

Food security is indispensable to achieving sustainable development (Popkova and Shi, 2022; Sharma U. et al., 2022) especially MDG1-Hunger, i.e., Eradicate extreme poverty and hunger. But if people engaged in the agricultural sector do not strive to “ensure environmental sustainability”, i.e., MDG7- Environment, the efforts to increase food production are unsustainable (Rosati et al., 2021). Regrettably, the higher frequency of occurrence of climate change-associated hydro-meteorological uncertainties combined with rising global temperatures is exacerbating the existing food crisis (FAO, 2017). The predominant subsistence of over 60% of the population in Africa's Sub-Sahara region including 40–50% in Asia-Pacific regions is projected to be from the agriculture sector till 2030 (ILO, 2007). IPCC (2007) has also stated that by 2050 all global agroecosystems, inclusive of croplands, pastures, and meadows in temperate areas, are contemplated to be strained due to climate change. These can be supported by several reports of predictions on climate impacts and risks on agroecosystems by climate change through Table 1.

Additionally, The State of Food Security and Nutrition in the World 2020 and 2021 (FAO, 2020a; FAO et al., 2020) has pointed out that the world is “not on track” to realize Zero Hunger by 2030. As per this report, nearly 690 million people are hungry, ~8.9% of the total human population. It has also been highlighted that a global pandemic like COVID-19 can put pressure on health and nutritional security as the pandemic has disrupted production, supply chain, and adequate and appropriate food consumption (WHO, 2020).

TABLE 1 Regional impacts and risks of climate change to agriculture.

Region	Impacts	Risks to Agriculture and Food Security	Source
Africa	Temperature increase (x1.5) Precipitation is erroneous and scanty Increased intensity and incidence of droughts and floods	Agricultural productivity relinquished as a consequence of loss in cropland, shorter growing season, vacillation in crop choice Worsening food insecurity due to low crop yield, more people hungry Net returns from crops are projected to decrease by 90% by 2100	Boko et al., 2007; Christensen et al., 2007
Asia	Warming above the global mean in major portions of the continent, rapid glacier melts Longer Heat waves/hot spells in summer Increased precipitation—landslides and severe floods Increase in extreme events combined with El Nino events causing droughts during the summer month	Decreased crop productivity in Asia, risk of food insecurity Reduced soil moisture, land degradation, and desertification	Christensen et al., 2007; Cruz et al., 2007
Latin America	Warming above the global mean in Latin America, heat waves dry spells and droughts in Brazil Uncertainty in rainfall frequency, intensity, and distribution, tropical cyclones, glacier melts in the Andes due to El Niño Southern Oscillation (ENSO), landslides, and severe floods due to intense rainfall in some regions	Reduction in crop yields in some areas, although other areas may see increased yields. By 2050s, 50% of arable lands are likely to be subjected to desertification, erosion, and salinization leading to food security problems	Christensen et al., 2007; Magrini et al., 2018
Small Island Developing States	SIDs in the Caribbean, Indian Ocean, and North and South Pacific have warming lower than global. 10% reduction in average precipitation in and around the Pacific Increasing intensity of tropical cyclones, storm surge, and land inundation	Agricultural land loss by sea-level rise, seawater incursion causing inundation, salinization Risking farming viability-leading to food insecurity Fisheries affected by extreme events especially cyclones and rise in sea surface temperature	Christensen et al., 2007; Mimura et al., 2007

Adapted from UNFCCC (2007).

## Integrated organic farming systems and circular -organo-agroforestry practices

### Existing sustainable land use/farming practices

#### Organic farming system

“Organic agriculture promotes and enhances agro-ecosystem health, through a holistic production management system by emphasize the use of management practices in preference to using off-farm inputs, considering the use of locally adapted systems at regional level. This is carried out by means of, possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfill any specific function within the system.” (FAO, 1999; IFOAM, 2002). Organic farming strives to eliminate the dependence on chemical inputs and, since being labor intensive, provides rural employment and development opportunities. IFOAM (2010, 2020b) recognizes, “Organic Agriculture as the producing system which sustains the health of soils, ecosystems, and people”. These farming practices rely on the interactions between the components, promoting fairness of all life forms involved with the environment. It is distinguished by the prohibition of the input of chemical fertilizers and pesticides, particularly emphasizing soil health and

cropping patterns, nutrient transfers, and oscillations within the agroecosystem (IFOAM, 2012). According to Pretty and Ball (2001), sustainable and organic systems in the United States demonstrated comparable yields to high-input industrialized systems while consuming 22–120% less energy. Simultaneously, according to several studies (Muller et al., 2012; Pimentel and Burgess, 2014), organic farming systems have been found to consume 20–50% less energy as compared to conventional farming systems (Zikeli et al., 2014). Moreover, the worldwide implementation of organic farming practices has the capacity to sequester an amount of greenhouse gas emissions equivalent to 32% of the total current human-induced emissions (Jordan et al., 2009; Zikeli et al., 2014).

#### Conservation agriculture (no-till agriculture)

At present, the cultivators-led transformation of agricultural land-use systems from tillage-based to conservation agriculture has garnered much thrust as a novel paragon for sustainable intensification in food production (Kassam et al., 2015). FAO (2014b) defined Conservation Agriculture as the approach of managing agroecosystems for greater and continuous productivity, improved profits, and food security while preserving and enhancing the resource base and the environment. This food production system is characterized by zero or minimal tool of soil

to avoid disturbance of soil from cultivation, upkeep of permanent organic mulch over the soil with residues, crops, and cover crops, and enhanced crop diversity through mixing and sequencing of rotations especially of legume along non-legume. Kassam et al. (2015) have further added that CA can be complemented by the use of quality seeds, integrating management of water, pests, and soil nutrient. This particular land-use system can be executed on all land dimensions from an acre to some hectares (FAO, 2014c) and allows for maximum utilization of soil's ecosystem services with the use of locally adapted species. Simultaneously, conservative agricultural practices improve food accessibility and enhance the plasticity of the cropping systems against the perils of climate systems (Kassam et al., 2009; Friedrich et al., 2012; Farooq and Siddique, 2014; Jat et al., 2014; Sharma et al., 2020; Joshi et al., 2021; Sharma P. et al., 2022).

### Natural farming system

In the Indian context, natural farming, an emerging practice, is providing new opportunities for efficient food production and environmental sustainability. The natural farming approach is a diversified farming system that incorporates crops, trees, and livestock, with a focus on functional biodiversity (Rosset and Martínez-Torres, 2012). According to Palekar (2005), the implementation of intercropping and mulching techniques, along with the substitution of chemical fertilizers and pesticides with locally produced alternatives such as Jeevamritham, Beejamritham, and Neemastra, results in a noteworthy reduction in production costs. Natural farming, which can also be referred to either as Eco-Agriculture or Eco-friendly Agriculture, is a modern methodology that seeks to improve both conventional and contemporary agricultural techniques while prioritizing the conservation of the environment, public health, and local communities (Mishra, 2013). Natural farming is a concept that is rooted in the principles of Masanobu Fukuoka, a Japanese farmer. It is based on the belief that it is essential to align oneself with the natural cycles and processes that exist in the environment. The potential effects of the extensive adoption of natural farming on greenhouse gas emissions are currently unclear. The anticipated outcome is a reduction in agricultural emissions per unit of land through the mitigation of fuel consumption, emissions from manufactured inputs, and N<sub>2</sub>O emissions resulting from a decrease in fertilizer use. According to CSTEP (2020), the implementation of natural farming systems has resulted in notable reductions in water consumption (50–60%), input energy (45–70%), and greenhouse gas emissions (55–85%). Similarly, Rosenstock et al. (2020) and Lohith et al. (2021) as well relayed a significant reduction in the GHG emission ranging from 23 to 60%.

### Integrated farming system

Efforts for improvisation of agricultural methods to increase food production and enhanced income from the farm has led many smallholder farmers to explore the integration of animal husbandry into traditional crop-based agricultural practices. Such efforts for efficient land use, to achieve sustenance and sustainability where the byproduct of one component became the input for another component and vice versa came to be known as Integrated Farming Systems. Several authors have defined IFS (Jayanthi et al., 2000;

Singh and Ratan, 2009; Panke et al., 2010) but the core rationale of the definitions provided are maintenance of cropping patterns and combination along with optimal utilization of resources that accords in food security with income generation (FAO, 2001; Tipraqsa et al., 2007; Sasikala et al., 2015; Kumar et al., 2023). However, it ought to be reminded that the contradistinction between the integrated farming system and the conventional intensive farming system is not outright but is rather a matter of the degree of integration of resources in the farming practices (Tipraqsa, 2006) and hence environmental sustainability of IFS is not well-established.

### Agroforestry

Agroforestry can be defined as the system of land usage or acreage where arboraceous perennials, such as trees, are raised along with herbaceous food crops in the same plot or piece of land that result in significant ecological interactions that further aid in maximizing financial returns to the practitioners (Young, 2002). In Lundgren's "Agroforestry Systems" (Lundgren, 1982), Agroforestry was defined as "a collective name for various land-use systems in which woody perennials (trees, shrubs, etc.) are grown in combination with herbaceous plants (crops, pasture) or livestock, in a spatial arrangement, a rotation, or both." Agroforestry systems provide the optimum output of food crops and animal husbandry, even in the face of shortages in wood produce (Mantel, 1990). FAO (2004) states that, "organic agriculture and sustainable forest management produce commodities and build self-generating food systems and connectedness between protected areas." The ubiquitous augmentation of these perspectives and their incorporation in landscape design is supposedly a cost-effective policy alternative for biodiversity conservation. A report of trial investigations by Ramesh et al. (2022) revealed that the inclusion of fodder in conjunction with the fodder trees is highly productive and could generate more effective farm income along with feed for livestock components.

The true essence of agroforestry lies in the anticipated position of on-farm and off-farm production from perennial woody components for facilitating sustainable land use and primal resources and maximizing economic returns for the farmers, which may be summarized as enhancing connectivity and stability among biodiversity, forests, landscape, and watershed (FAO, 2010; Nair, 2011; Murthy et al., 2016). An appropriate agroforestry system that usually follows organic norms can check against soil erosion with the help of the tree component and crop cover, maintain soil organic matter and augment nitrogen build-up through soil microbes and nitrogen-fixing species, and efficiently cycling of nutrients and energy within the system (Patiram and Bhaudauria, 2003).

### Conforming and transforming agriculture systems to organic

Several organizations have given recommendations and suggestions to conform traditional and other sustainable agriculture systems to purely organic food production systems through conversion practices. PGS (Participatory Guarantee

System) of the IFOAM provides an alternative to third-party certification systems (characterized by complicated regulatory procedures) for better on-farm practice and marketing strategies for smallholder agriculture practitioners such that food produce by such practices is guaranteed giving consumer satisfaction (IFOAM, 2020a). PGS allows for purchasers and growers assent on the circumstances in existing local food systems and the scheme; these are substantiated through the direct participation of all stakeholders especially in the options and descriptions of the norms along with the review and decision process to recognize farmers as organic. This system ensures transparency and integrity (IFOAM, 2009), that is, particularly *adapted to local contexts and short supply chains*, and which is sometimes referred to as “participatory certification” (IFOAM, 2020a). Detailed step-by-step conversion from existing food production land use to 100% organic production system especially applicable to larger conventional agricultural practices can be achieved by following FAO/TECA ID 8364 Step-by-step conversion to organic agriculture (FAO, 2020b). In the simplest words, it has three steps, viz., (1) Collecting information, (2) Trying out identified promising practices on a small scale, and (3) Implementing the organic practices to the entire farm. Initially intending farmers must collect reliable information from successful farmers, agriculture departments, and through websites such as those listed in Table 2. This should be followed by choosing practices that are simple and within the financial, intellectual, and technical grasp, which would also show results in short rotation/duration. These chosen practices are to be tested in designated plots within the farm and during such phase, the operation taken should be purely organic. When success is achieved, the farmer may proceed to convert the entire farm to the chosen organic practice. This allows for a certain period of observation and choice of combination of crop/livestock/woody components/horticultural crops/aquaculture/fodder grass/cover crops, etc., to be adopted in the IOFS to enhance maximum output with minimal external input. This would make preparations for sustainable food production systems that could mitigate food insecurity and are environmentally friendly.

Gliessman's (2015) description of the transition of agricultural systems toward sustainable agrifood systems has described five phases during the transition from conventional to sustainable agriculture systems. The first three phases operate at the agroecosystem level, while the last two phases involve more interaction between the producer and consumers, as well as involving the active participation of locals during food species selection and diversification of the agricultural systems' components. Rosati et al. (2021) have argued that despite the efforts to enhance sustainability, even organic farming systems could be just considered incremental in nature as they focus more on refusing chemical inputs and replacements by agroecological alternatives and fail to be transformative. They added that integrating agroforestry practices into organic farming systems can bring about a wholesome, sustained agroecological system inclined toward diversification of crop components with amplified interrelationships between the farm system and nature. Their argument stands true when we look at the various workers' descriptions and definitions of agroforestry, as discussed in the previous paragraph. Thus, we can safely declare that including agroforestry as part and parcel of organic farming systems has a

duality in being transformative as well as incremental in nature and can address improved food security that gives a minimum cynical impact on the environmental health. The positive impact of organic practice in agriculture practice diversification, including poly-cropping, agroforestry, and integrated farming systems of crop and livestock with local varieties and breeds, produces good quality organic food. Moreover, certified organic products provide for increment in revenue for growers thereby forming a market-based incentive for ecological stewardship (Scialabba and Muller-Lindenlauf, 2010).

UNFCCC (2007) has compiled reactive and anticipatory adaptation means for Agriculture to ensure food security, which is coherent with the IOFS approach. The adaptation measures for agricultural and food security are laid out in Table 3. It is evident that adaptation for sustainability and resilience of agricultural systems may be enhanced through organic conversion, promotion of agroforestry, and water management.

## Concept of circular economy and sustainability in integrated organic farming systems

Geissdoerfer et al. (2017) defined Circular Economy as “a recovering system in which resource input and waste, emission, and energy leaks are curtailed by slowing, closing and reducing material and energy loops”. The study adds that “a circular economy can be achieved through durable design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.” An integrated organic farming system follows the 5R-concept: Reduction of inputs, Reuse agricultural residues, Recycle water, Refuse inorganic fertilizers and pesticides, and Replace conventional practices with closer to nature practices. For an efficient circular economy, agriculture should be taken as a primary sector with sustainability as its prerequisite, forming the fundamental of the economy and the living system involved (Jurgilevich et al., 2016). Agricultural systems adopting a circular approach such as IOFS circulate waste from one process to create resources for other means. The feedback-rich systems inspire the circular economy in the biosphere, that there are no wastes that would remain as wastes as decomposers process them, and the nutrient made available for use by producers is thus the system providing for itself perpetually (Pearce and Turner, 1989; Ellen MacArthur Foundation, 2013; Nattassha et al., 2020).

Circular agricultural practices as multifaceted sustainability efforts (Govindan and Hasanagic, 2018) are designed in such a way that all key elements involved in food production, from cultivation, harvesting, post-harvest activities, transportation, marketing, consumption, and disposal (Irani and Sharif, 2018) promote sustainable development through food security and sustainability across all the elements (Fassio and Minotti, 2019; Nattassha et al., 2020; UNDESA, 2021). This process can be considered to follow a rigid Cradle-to-Grave or Life Cycle-Assessment (LCA) approach as agricultural systems follow organic farming protocols with agroforestry and residue recycling that can reduce carbon emissions and efficiently deploy natural resources significantly by curtailing material and capital inputs. Integrated farming systems,

TABLE 2 List of prominent NGOs, other official government organizations, and academic institutions promoting OA.

Name	Region/scale of operation	Function/role in OA	Website
BioTrade Initiative, United Nations Conference on Trade and Development (UNCTAD)	Switzerland, Global	Production, collection, and commercialization of goods and services from local and endemic biodiversity Trade- genetic resources, species, and ecosystems—coherent to the sustainability of the environment, society, and economy	<a href="http://www.biobtrade.org/">http://www.biobtrade.org/</a>
CGIAR System-wide Program on Integrated Pest Management (SP-IPM)	Nigeria, Global	Within CGIAR, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and the International Institute of Tropical Agriculture (IITA)—research on organic pest and disease management.	<a href="http://www.spipm.cgiar.org/Web/CGIAR%20IPM%20project.htm">http://www.spipm.cgiar.org/Web/CGIAR%20IPM%20project.htm</a>
Garden Organic	UK, Global	Organic gardening, farming, and food Promotion and facilitation of OA in Africa, Asia, and Latin America.	<a href="http://www.gardenorganic.org.uk/index.php">http://www.gardenorganic.org.uk/index.php</a>
Global Horticultural Initiative (GHI), World Vegetable Center	Tanzania, Global	Remunerative options for growers and food security Focus area—underutilized crops.	<a href="http://www.globalhort.org/">http://www.globalhort.org/</a>
Institute of Organic Agriculture, University of Bonn	Germany	Energy flows—Fruit & Vegetables—Livestock—Pest/Disease Management Nutrition, Quality, Health—Temperate and Irrigated Agroecosystem	<a href="http://www.iol.uni-bonn.de/">http://www.iol.uni-bonn.de/</a>
International Federation of Organic Agriculture Movements (IFOAM)	Germany, Global	Umbrella organization works with UN and multilateral institutions-organic agriculture movements globally. Provides common market guarantee and authenticity for integrity in organic claims—Organic Guarantee System (OGS) and PGS	<a href="http://www.ifoam.org/">http://www.ifoam.org/</a>
(NCOF), Department of Agriculture & Cooperation, Ministry of Agriculture	India	Integrated Nutrient Management (INM) with bio-fertilizer Implementing IOFS in India	<a href="http://www.dacnet.nic.in/ncof/">http://www.dacnet.nic.in/ncof/</a>

Source: FAO-ORCA database in <https://www.fao.org/organicag/oa-portal/orca-database/searchnew/en/>.

when adopting the organic agricultural approaches, make the components of the farming systems synergistic (Csavas, 1992) and curtail risks, ensuring higher food production and economic profits in combination with proper utilization of organic crop residues (Radhamani et al., 2003; EC, 2012, 2014; McCarthy et al., 2019).

An ideal organic farming system assimilates the outputs or residue of one enterprise as feed for another enterprise in the confines of the same tillage (McDonough and Brungart, 2002; Argade and Wadkar, 2013). The long-term application of organic manure (Gomiero et al., 2011) in farms practicing livestock-based integrated organic farming was more stable and sustainable than conventional monoculture farming practices (Fließbach et al., 2007). The Brundtland Commission (Brundtland et al., 1987) defined sustainability as the “development that meets the wants of the current without compromising the capability of upcoming generations to meet their own needs,” and Geissdoerfer et al. (2017) have stated that the notion of sustainability has its origins in forestry. To support their statement, they have used the conceptualization of silvicultural principles of “*Sylvicultura oeconomica*” (Von Carlowitz, 1713), in which the amount of wood being reaped in a cycle should not transcend the regenerative capacity of the woodland. The sustainability of any system may be expressed in terms of the equation “ $I = P \times A \times T$ ”, where I is the Environmental Impact of the system, P is Population (demographic factor), A is Affluence representing consumption, and T is Technologies involved (Holdren and Ehrlich, 1974). According to this equation, we can rate any agricultural land use system for its sustainability. Considering the parameters involved, we can conclude that Integrated Organic Farming Systems,

TABLE 3 Reactive and anticipatory adaptation measures for agricultural systems.

Reactive adaptation	Anticipatory adaptation
Erosion control, dam construction for irrigation, and Educational and outreach programs on conservation and management of soil and water Changes in utilization and application of synthetic fertilizers and maintenance of soil fertility and prolificacy Introduction of new crops, switching to different cultivars, and alteration in patterns of planting and harvesting period to suit the prevailing climate condition. Promoting agroforestry to improve ecosystem service	Progressive utilization of recycled water, upgraded system of water regulation, soil–water regulation. Diversification and intensification of food and plantation crops Identification of species having high resistance to diseases and climate stress Policy measures, tax incentives/subsidies, free market

Adapted from: UNFCCC (2007).

including Agroforestry land use systems (McAdam et al., 2009), can be declared highly sustainable and ideal for substantial food production with the least environmental impact.

Thus, the integration of circular economy principles to organic agriculture system with agroforestry can be expressed with an amalgamated term “Circular-Organic-Agroforestry” as depicted with components and a model in Figures 2, 3 respectively and may be defined as “a system of agricultural farming practice which is organic and has rich species diversity which includes tree components, herb crop components and may include animal husbandry and fishery in which there are synergistic interactions



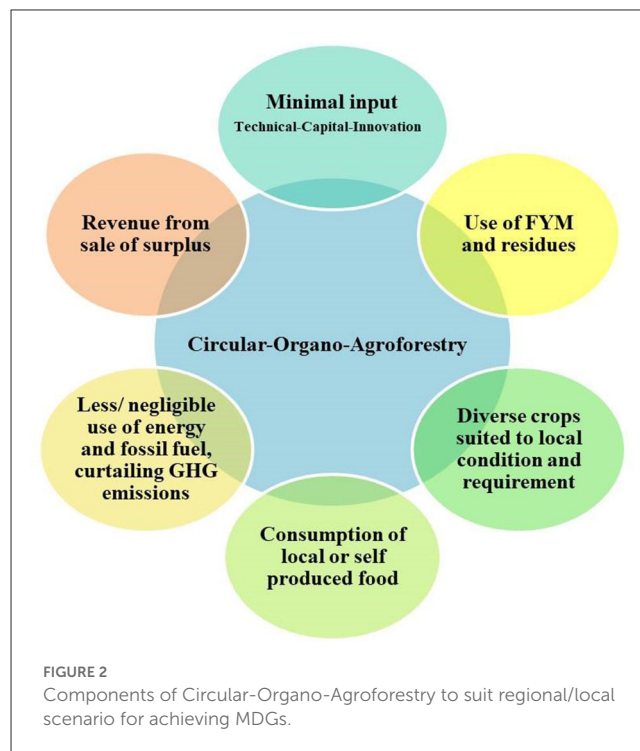
between all components within the system following the principles of a circular economy that results in sufficient food production and helps in achievement of sustainable development.”

## Concept of food biodiversity and nutrition enrichment from organo-agroecosystem

Guidelines on Assessing Biodiverse Foods in Dietary Intake Surveys (FAO Biodiversity International, 2017) defined “food biodiversity” as “the diversity of plants, animals and other organisms used for food, covering the genetic resources within species, between species and provided by ecosystems.” A diverse diet augments the prospective of consuming sufficient nutrients essential to human health (WHO/FAO, 2003). Long-standing efforts to provide basic food for the human population have resulted in a biased focus toward more high-yielding starchy staples (Zhu et al., 2000). This further leads to dramatically simplifying landscape composition and a sharp decline in local biodiversity (Gomiero et al., 2011). This has put massive pressure on the diversity of food species from 5,000 to 70,000 plant species that have so far been documented as human food (Kunkel, 1984; Wilson, 1992; Schippmann et al., 2002, 2006), out of which almost exclusively three cereals, viz. rice, wheat, and maize, furnish 50% of the calories derived or having originated from the plant (FAO, 2015; Bailey, 2017; Futurism, 2017; FAO et al., 2021). Increased focus on the production of staples (Magrini et al., 2018) has generated reverberations in the ecological system and human wellbeing (IPES-Food, 2017). These reverberations can be attributed to the limitations of crop diversity combined with the intensification of livestock production methods (Tilman and Clark, 2014, 2015). Food security is not restricted solely to making food available and nevertheless must address the alarming sum of more than 800 million people in low-income countries suffering from chronic undernourishment and micro-nutrients deficiency (FAO, 2017), while overconsumption in high-income countries has propelled lifestyle diseases such as obesity, type II diabetes, and coronary heart disease (WHO, 2009; FAO, 2017). New solutions must develop solutions to overcome disparities in distribution and availability to food and nutrient requirements (Tilman and Clark, 2014). Healthy diets are unavailable to many people, especially the poor (FAO, 2020a), as over 3 billion people globally still get just adequate to fill their stomachs and do not have enough to purchase nutrient-rich food (FAO et al., 2020). This is very alarming as dietary guidelines that have been put forward in different regions of the world recommend a wholesome diet endowed with a variety of nutrients, which includes green leafy vegetables rich in vitamins, and micronutrients, whole grains and nuts, seeds, and pulses for proteins aside from starchy staples (Fischer and Garnett, 2016).

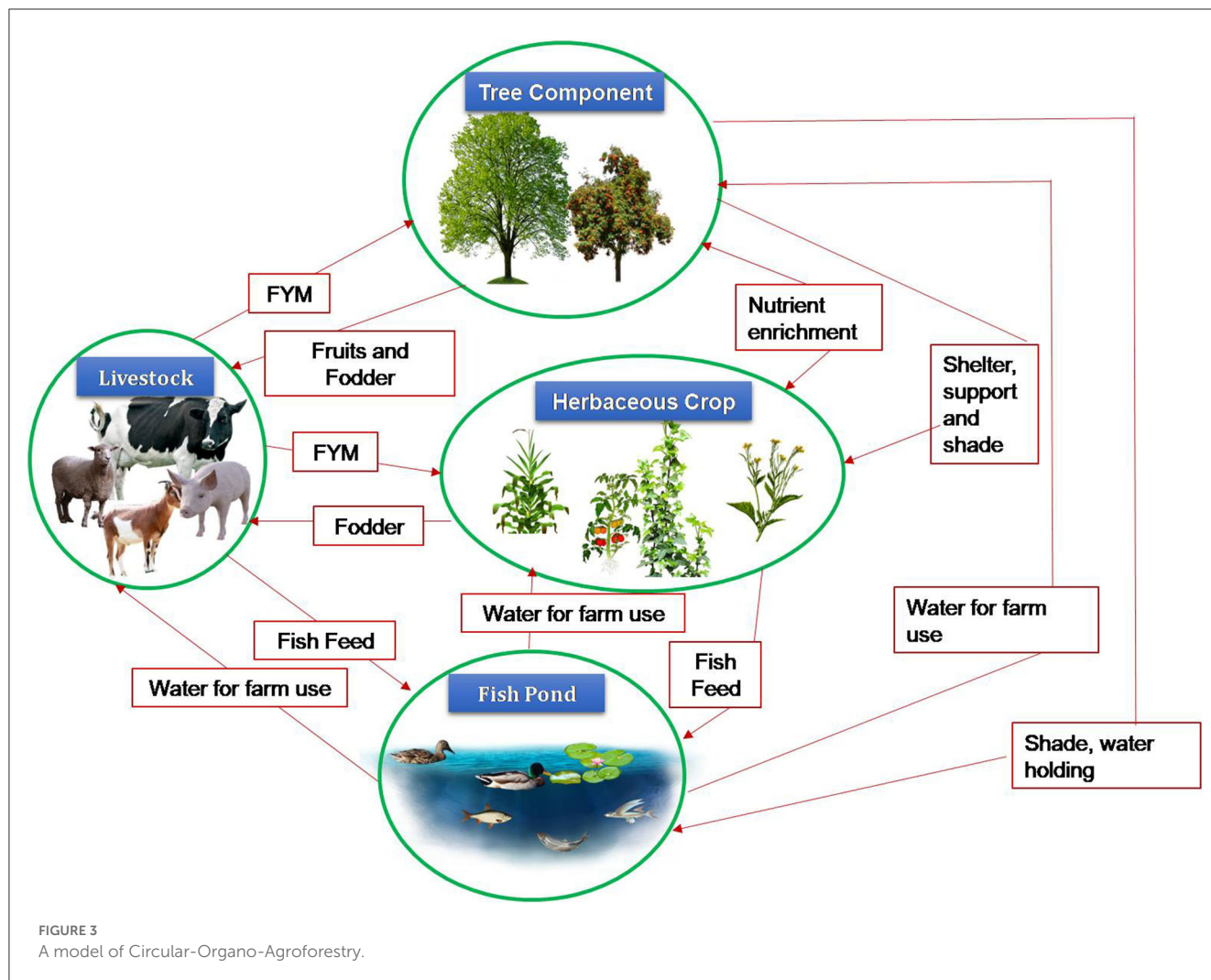
The Convention on Biological Diversity advocates the combination of the conservation and sustainable use of biodiversity in cross-sectoral plans to achieve sustainable development goals that include poverty eradication, adaptation/mitigation to impacts of climate change through sector-specific initiatives such as agriculture and forestry (CBD, 2011).<sup>3</sup> The Pacific

<sup>3</sup> <https://www.cbd.int>



Organic Standard emphasizes biodiversity enrichment through land use by requesting properties larger than five hectares to set aside a base land ratio of 5% of the certified area for wildlife excepting that the estates practice a traditional agroforestry or poly-culture system (Secretariat of the Pacific Community, 2008; Scialabba and Muller-Lindenlauf, 2010).

FAO (2014a) defined a sustainable food system as “a food system that brings food security and nutrition for all such that the economic, social, and environmental bases to create food security and nutrition for future generations are not compromised”. The FAO’s Genetic Resources for Food and Agriculture Commission provided and adopted the Voluntary Guidelines for Mainstreaming Biodiversity into Policies, Programs, and National and Regional Plans of Action on Nutrition (FAO, 2016) supporting countries for incorporation of food biodiversity to encourage knowledge, conservation, promotion, and utilization of varieties and breeds used as food, as well as wild, neglected, and underutilized, underexplored species that could result in a better state of health and nutrition in respective countries. Species such as hanza (*Boscia senegalensis*) are a significant source of carbohydrates, *Jessenia* and *patawa* (*Oenocarpus bataua*) produce high-quality edible oil, Locust bean (*Parkia bicolor*) is rich in protein sources, Mongongo tree (*Ricinodendro rauteneni*) is a source of protein and fats, Bamboo shoots (Selvan and Tripathi, 2017), edible fungus, yams, etc. are significant lesser-known wild foods in which rural/forest dwellers extensively exploit in different areas around the world (Scoones et al., 1992; Selvan, 2022). Their utilization may be seen as signs of local populations’ strategy to cope with food stress, and the incorporation of wild foods into local organic agricultural practices not only fulfills increased food production but enhances diverse nutrient availability (Nurhasan et al., 2022).



According to IFOAM (2002), farmers are to ensure maintenance and improvement of agrilandscape and enhance biodiversity. Organic farming systems, including agroforestry worldwide, use species that caters to the requirements of the local populace that includes but not limited to food staple, medicinal plants, ornamentals, culturally and traditionally important species, and fuelwood species, the inclusion of species that could provide fuel and fodder which may be considered as a step forward (Rosati et al., 2021) and to be aligned with principles of certified organic farming (Maeder et al., 2002). The species and varieties incorporated into these systems have better adaptability and enhanced agroecosystem resilience to environmental factors as well as market uncertainties (Zhang and Li, 2003; Smith et al., 2007, 2014).

IOFS that include animal husbandry considers ethical concerns in the context of the wellbeing of the livestock, and hence, amidst varied animal husbandry systems, encouraging natural grazing in open pastures and meadows, inhibiting synthetic feeds fortified with vitamins, and promoting the use of organically sourced feed (Lund, 2006), which leads to improved consumer health, such as consuming meat from livestock that may contain traces of growth promoters and antibiotics from the artificial feed and

injections. Greater species diversity in these systems is conceived to improve food security (Parrot et al., 2006) and enhance the systems' ability to resist shocks, thereby reducing vulnerability and increasing resilience while maintaining the stability of the natural ecosystem (Fraser et al., 2005; Whitfield et al., 2018; Sherpa, 2023).

The species selected for such land use are often tailored to the local climatic and environmental conditions and involve less technical or zero chemical input, partly due to a lack of finance, knowledge, and resources. For instance, in the Northeastern Region of India, almost all traditional farming systems are usually of agroforestry type. They are organic by default as the farmers lack technical resources and prefer to rely on their traditional methods of agriculture using farmyard manures, green manures, indigenous ways of weed and pest control, and selection of crop species or animal husbandry to cater to their local preferences (Das et al., 2018). Indeed, they practice a different type of organic agroforestry land use systems (Selvan and Kumar, 2017), one of the reasons why the food security problems in the region are not as serious. The careful selection of species by the farmers in the region has also made their land use systems advantageous and sustainable (Pretty and Bharucha, 2014).

TABLE 4 Synthetic inputs of fertilizers and pesticides in the food production systems.

Region	Fertilizer use Kg/Ha		Pesticide use Kg/Ha		Total increment percentage	
	2000	2020	2000	2020	Kg/Ha fertilizer use	Kg/Ha pesticide use
World	90.3	129	1.45	1.81	22.24	19.88
Africa	17.2	26.4	0.36	0.49	34.84	26.53
Americas	91.6	150.6	2.44	3.74	39.17	34.75
Asia	128.6	187.4	1.11	1.15	31.37	3.47
Europe	71.3	83	1.48	1.64	14.09	9.75
Oceania	92.9	82.1	1.42	2.13	-13.15	33.33

Adapted from FAO (2022).

Integrated organic farming uses agrobiodiversity to bring about variety and variability to increase yields, have higher disease resistance, requires less water input, have symbiotic relationship among the components of the system, produces food that has higher nutrient value, and produces more food groups to improve health of consumers (Bailey, 2017). Thus, it results in higher species richness and a greater abundance of taxa (Hole et al., 2005).

## Status of organic food production systems

An area of 72.3 m ha of agriculture is under organic operations of which Australia alone has 35.69 million Ha which is ~50% of the total; followed by Argentina at 3.69 m ha and Spain at 2.35 m ha. The fourth and fifth largest area under organic agriculture is observed in the USA (2.33 m ha) and India (2.3 m Ha). Meanwhile, Europe showed steady growth in organic agriculture possessing 23% of the total. The increase in land under organic agriculture increased 555%-fold in the last two decades, i.e., 1999–2019. The report further showed that Australia showed an increase of 200% in the last decade itself. Despite the increase in organic agriculture areas in all regions of the world, the intensification of conventional agriculture is also growing simultaneously. Entry of synthetic fertilizers and pesticides into the food production systems is showing an increasing trend globally and in all regions of the world. This trend of input Kg/Ha is shown in Table 4. An exception is seen in Oceania for Kg/Ha fertilizer use from 2000 to 2020 which is actually -13.15%. This may be attributed to the proliferation of organic cropland areas.

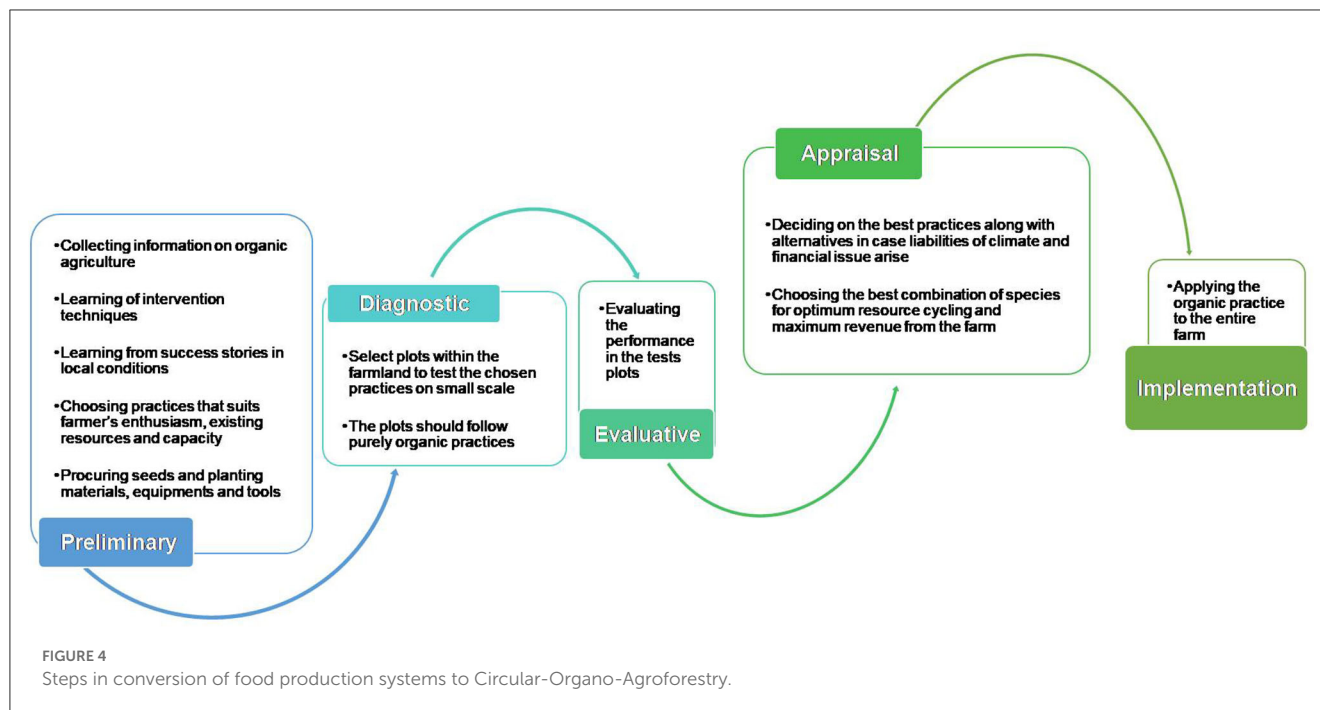
However, it should be noted that only 1.5% of total global agricultural land are following organic practices despite the massive increase. Liechtenstein has more than 41% of agriculture land in organic agricultural practices (Schlatter et al., 2021; Willer et al., 2021).

Furthermore, it is reported that there are above 3.1 million organic producers worldwide of which 91% are concentrated in Asia, Africa, and Europe of which major import and export share is from tropical fruits, organic vegetables, fruit drinks, etc. (Sahota, 2021). An encouraging fact is that India itself has about 1.37 million organic producers (Sahota, 2021). The total organic food retail sale exceeds 106 billion Euros in 2019. The US is the major market for organic food at 44.7 billion Euros, which is even higher than the combined

market share in the European Union, i.e., 41.4 billion Euros. The 3rd biggest market in the world and Asia's largest organic food market is China at 8.5 billion Euros (Sahota, 2021).

## Limitations and constraints in the adoption of IOFS

Application of organic farmyard manures and vegetative residues are often-times proven to enhance sustainable and circular utilization of resources in integrated organic farming practices. Challenges exist in determining the fertilizing efficiency of organic materials as it depends on the mineralization processes, absorption along with losses such as gaseous emissions, and leaching or runoff (Burton and Turner, 2003; Sørensen et al., 2013; Bernal, 2017). A drawback of the organic land use systems is the difficulty in controlling of weeds as weeding is done manually which is labor-intensive increasing operation costs. Meanwhile, the use of vegetative mulches and FYMs with bio/green fertilizers must be taken with proper care as some ingredients may even exhibit allelopathic effects on the crops (Bond and Grundy, 2001). Muller et al. (2017) made a conservative estimate of organic yields exhibiting a median yield gap of 25% from the data in Seufert et al. (2012)'s "Comparing the yields of organic and conventional agriculture". Clark et al. (1998) stated that the increase of soil organic matter after the transition from conventional to organic systems occurs rather too slowly and takes too long to manifest significant positive outcomes. Adoption of novel practices of transformative agricultural practices requires interactive discourse between local farmers and researchers/advisors for better acquisition of knowledge (on the complexity of the species compositions, functions, and services) which is itself a time-consuming and critical challenge (Geels and Schot, 2007; Hauggaard-Nielsen et al., 2021). Bernal (2017) further emphasizes that the contemporary lack of data and limited research on consequences to the agroecosystems due to increased microbial activities associated with organic fertilizers may cast doubts on the sustainability and put constraints on the adoption of IOFS. Moreover, locality factors play a crucial part in ascertaining the accomplishment of any particular farming systems as what is deemed sustainable could unfortunately yield desirable outcome in a different region or even within the same



region (Smolik et al., 1995). FAO (2011) has expressed concerns over adoption of integrated systems as even though incorporation of food crops, animal husbandry, and pisciculture is ordinarily considered progressive, smallholder farmers need to have sufficient proficiency, financial, technical, and labor to operate this system in ways that yield economic and environmental sustainability in the long term. These above points may make IOFS unappealing and rather be viewed as utopian efforts of food production systems for poorer countries that are facing food insecurity as the aim to increase production is of primary importance.

## Conclusion and future prospects

The primary target for escalating food production deprived of consideration for the ecological aspects, or good nutrition, is responsible for the drastic degradation of the environment while at the same time causing a pandemic of non-communicable diseases (Bailey, 2017). It could also be noted that monoculture, along with conventional agriculture practices depending on few staples, has caused a reduction of crop biodiversity. It is expository to scrutinize the correlation of Circular Economy with Sustainability, which can determine any sector's inventory management, trade ideals, and innovative approaches (Geissdoerfer et al., 2017). It is impetuous to develop food production systems characterized by resilience, sustainability, and justice inept in satiating the hunger and providing healthy, nutritious food. There is a need to interlink the essence of local producer–consumer relations and the generation of farm and food waste. IFOAM (2022) realizes the actions to galvanize with market players to ardently increase the value of organic products, creates strong and fair value chains, and allows easy access to wholesome and nutritious organic food and products created from organically sourced materials

for every individual. Organically managed agriculture systems are designed for the production of high-grade, nutritious food that forms the foundation for preventative health management and wellbeing (IFOAM, 2020b). Integrated Organic Farming Systems, considered equivalent to circular agriculture, aim to ameliorate rising concerns of unsustainable global food production, environmental degradation, and the peril of biodiversity loss (UNDESA, 2021). Niggli et al. (2009) emphasized that there are three strategic research priorities in agriculture food production systems (Gomiero et al., 2011), i.e., (1) feasible options in empowerment of rural economy on a local, regional, and global scale; (2) safeguarding agroecosystems employing eco-functional agricultural consolidation; and (3) high-quality foods, a foundation for healthy and balanced diets, and a requisite for uplifting quality of life. It should be noted that Organic Agriculture practice is created on the four principles of *Health, Ecology, Fairness, and Care* (IFOAM, 2020b). All agriculture food producers should prioritize the utilization of organic agriculture diligently in panoramic policy solutions to exigency in climate change, biodiversity loss and food security, and relocate public grants to sustainable farming practices (IFOAM, 2022).

Meanwhile, farmers as well as researchers may explore various other organic agriculture and agroforestry practices such as Biodynamic agriculture, Regenerative agroforestry practices such as Permaculture, and Syntropic agriculture. A systematic step-by-step process of conversion of existing agricultural land use system to IOFS is depicted in Figure 4. These practices take a closer to nature approach by mimicking natural ecological processes in the acreage. In a particular agroforestry system called the *Miyawaki*, system the plots of urban areas are converted to natural forests using native species. This system utilizes the soil's ecosystem service to the fullest by growing several species in confined spaces where the crops grow rapidly in height while

competing for sunlight. Any local fruit-bearing species or crops may be used to provide fertilizer and pesticide-free food options for the urban population. In addition, the mentioned farming strategies are practiced without synthetic inputs and emphasized the proper management and cycling of residues within the farming systems, sustaining the farmers and producing food for local markets. Farmers may follow any organic practices that are suited to farmer's existing conditions, integrating crop, livestock, trees, and fishponds accordingly.

Linkages and interactions between the various component species can considerably improve the sustainability of farming systems (Kumar and Jain, 2005). IOFS is an innovative approach that offers a promising solution for sustainable food production and environmental conservation. Its adoption can succor the global challenges of food security worsened by climate change and environmental degradation. The linear system of an economy based on a take–make–consume and dispose of pattern can only be done away with the adoption of Circular-Organic-Agroforestry practices. However, its implementation requires concerted efforts from various stakeholders, including farmers, policymakers, and researchers, to overcome the existing barriers and promote its adoption at a larger scale through financial and revival of traditional organic practices with technical assistance within a framework that rewards farms as multifunctional systems (Vermeulen et al., 2018; Lipper et al., 2022). Bernal (2017) has also stated that the scientific community needs to develop treatment technologies for ensuring nutrients (N and P), enhancing environmental conservation and sustainability and ensuring food safety as improvisation from directly using manures in traditional methods.

More research and efforts need to be encouraged in looking for sustainable food production systems that are simultaneously low-cost and provide food security in the local, regional, and global

context while attempting to achieve carbon neutrality from the food production systems. A more inclusive form of agriculture system that caters to local requirements and has a shorter supply chain, as well as producing minimum waste, is what the world requires at the moment. Integrated Organic Farming Systems seem to be the right choice of land use that could fulfill all these requirements.

## Author contributions

TS and LP: conceptualization, investigation, analysis, writing original draft, and project administration. TS, LP, KM, VG, KR, DB, CT, DKa, PS, RD, DKu, and HD: methodology, writing review, and editing. All authors contributed to the article and approved the submitted version.

## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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