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Novel approaches and practices to sustainable agriculture

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ABSTRACT

The world population is increasing in a disquieting rate while the quantity of food to gratify this snowballing human population is an annoyance to agrarian scientists and policymakers around the globe. Today's population is snatching natural resources from the future which can endanger the future generation's right to have nutritious food and clean air. The causes for this challenge can be enumerated and listed out, but singled out as lack of and/or poor implementation of novel approaches and practices for sustainable agriculture. Some of the novel approaches are but not limited to climate smart agriculture (CSA), organic farming, biodynamic agriculture, sustainable intensification and regenerative agriculture; and novel practices as integrated farming system (IFS), precision agriculture, integrated nutrient management (INM) and integrated pest management (IPM). The adoption of these approaches and practices has been proven to safeguard agricultural sustainability.

1. Introduction

As the world population endures to grow at an exponential rate, much more effort will be mandatory for sustainable proliferation of agricultural produces [1,2] thereby improving global food demands, limiting food losses, and ensuring that all people suffering from starvation and malnutrition have access to nutritious food [3]. The global agriculture system must become more prolific and waste-free [4,5].

According to the most recent UN estimates, the population of the globe could increase to over 8.5 billion people in 2030, 9.7 billion in 2050, and then peak at about 10.4 billion during the 2080s [6,7]. Hence, annual food resource must balance the demand of the cumulative population in a sustainable way. For instance, to keep stride, the annual beef output must climb by nearly from 200 million tonnes to 470 million tonnes, and annual cereal production must increase to over 3 billion tonnes from 2.1 billion tonnes [6,8]. Unless and otherwise, this will definitely create the worst economic crisis in the world, which can trigger people to move around imploring with empty bags/bowls to ensure food supply for their survival. This prompts agricultural scientists and stakeholders to investigate various barriers that hinder crop production and develop strategies to address these issues while making the greatest use of available resources and technologies in order to meet the desired goal [5].

Sustainable agricultural approaches and practices provide solutions for producing food as well as other agricultural products at a low environmental cost that does not threaten food accessibility and availability, as well as future generations' general well-being [9]. Sustainable agriculture can be defined as "an integrated system of plant and animal production practices having a site-specific application that over the long term will satisfy human food and fiber needs, enhance environmental quality and the natural resource base upon which, the agricultural economy depends, make the most efficient use of non-renewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls, sustain the economic viability of farm operations, and enhance the quality of life for farmers and society as a whole" [10].

Sustainable agriculture can also be defined as "an agriculture/farming system in sustainable ways to satisfy people's present food and textile needs, without compromising the ability for contemporary or next generations to acquire their needs based on an understanding of ecosystem services" [11,12].

However, there is a constant discussion about what constitutes sustainability in agriculture. Although some others describe as ecocentric and anthropocentric approaches, the concept could be characterized by two alternative approaches: an ecocentric approach and a technocentric approach. Instead of focusing on no- or low-growth levels of human development, the ecocentric approach concentrates on organic and biodynamic farming techniques with the goal of modifying consumption patterns, resource allocation, and use [13–16].

Technology, planning, and lifestyle are identified as major parts of a holistic approach to the examination of sustainable development in general and the sustainability of the present environment in particular in the technocentric approach [17]. A single factor-based conventional approach to sustainability concerns is incredibly naive and dangerous at

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worst, as it creates conflicts with other approaches and misrepresents the true underlying picture that must be established as the foundation for developing development plans and policies. A interdisciplinary and successful approach to sustainable development has been attempted by integrating all three factors [18].

The technocentric approach asserts that sustainability can be achieved through a range of scenarios, ranging from the belief that state-led industrial system modifications, such as conservation-oriented agricultural system, should be implemented, to the claim that a biotechnological approach is the best way to cater to the increasing for food [19,20].

Furthermore, these viewpoints allow for a more broad distinction between technocentric and ecocentric methods. The former can be further divided into technocentric of abundance and technocentric of accommodation, which are described in this way because they rely on the advancement of technology to solve food scarcity problems. Similarly, the latter is divided into communitarian ecocentric and radical ecocentric subtypes, and aims to achieve a proper balance with environment in a co-evolutionary manner between the social structure and the ecosystem [21,22].

Sustainable agriculture is associated with food security, which requires availability of food or adequate food production, access to food and the opportunity to buy food, nutritional sufficiency (including energy, proteins, and micro - nutrients), safety, and the economic stability of these conditions [23].

Novel sustainable agricultural approaches and practices should be adopted and applied at all scales of agricultural production to address the challenge of long-term food security. With the umbrella of sustainable agriculture, this article aims to examine and highlight various unique approaches and practices for all stakeholders.

2. Novel approaches to sustainable agriculture

Identifying and analyzing some established approaches that are specifically implemented to create a more sustainable agriculture, most of them with a special emphasis on the ecosystem, is critical for agricultural sustainability. This means that most of these approaches had clear principles, environmental, economic, and social goals, and had either developed as methodological approaches over time (e.g., agroecology or sustainable intensification) or were high on the policy agenda from the start (e.g., agroecology or sustainable intensification) (e.g., agroecology or sustainable intensification such as carbon farming) [24,25].

These agricultural sustainability approaches are frequently adaptable to a variety of production methods and conditions, or they consider the entire farm/system in their design. They usually have professionals and, in some cases, a market/label already attached to them (e.g. organic farming). Although they may differ in scope (more "overarching" such as agroecology or sustainable intensification, or more "focused" such as permaculture or perhaps high nature value farming), one commonality is that they are all options that farm owners can make and that will strongly influence how they manage their farm in the long run [26,27].

2.1. Climate smart agriculture

Climate change is posing a significant and increasing threat to global food and nutrition security. In most of the developing world, population growth and rising wages have driven demand for sustainable food security to unbalanced levels. According to the FAO, in order to meet food demand in 2050, yearly global crop and livestock production would need to be 60% greater than it was in 2006 [28]. In developing countries, improved yields and cropping intensity will account for roughly 80% of the required increase, with cultivable land expansion accounting for only 20% [29].

Climate Smart Agriculture (CSA) is an approach to augment the management of agriculture in the era of climate change for sustainability. It's a strategy for introducing new agricultural technologies and practices to boost production, adapt, and mitigate climate change [30,31]. CSA is a relatively recent strategy that helps disadvantaged people enhance agricultural production and revenue by ensuring better agricultural practices while also decreasing greenhouse gas emissions [32]. Since its inception in 2009, the concept has been changed by the inputs and interactions of numerous actors involved in its development and implementation. Climate smart agriculture aims to provide internationally applicable concepts for managing agriculture for food security in a changing climate, which could serve as a foundation for policy support and suggestions from multilateral players such as the United Nations' FAO. The CSA strategy was established in response to current concerns in climate change and agriculture policy implementation for sustainable agriculture [33].

CSA pertains to agricultural methods that can boost production, enhance robustness (adaptation), and mitigate greenhouse gas emissions (mitigation) while also assisting in the achievement of food security and development initiatives (productivity) [34].

Adaptation is a process that involves gaining control over hazards posed by global warming, such as variations in temperature [35]. CSA allows farmers to reduce their exposure to short-term hazards while increasing their resilience by improving their ability to adjust to longer-term challenges. It puts a special emphasis on preserving the ecology that farmers and others benefit from [36]. Climate wise practices can assist boost the ability to mitigate climate change while also increasing productivity. It also maintains the system's flexibility for stress adaptation and restoration [36,37]. Adaptation emphasizes the integration of resources, strengths, and traits through which farmers and others must endeavour to take measures that minimize the worst effects and maximize the benefits available.

CSA's mitigation goal is to reduce or eliminate GHG emissions from food, fiber, and fuel. It controls soils and plants in ways that allow them to act as carbon sinks, absorbing carbon dioxide from the atmosphere. Mitigation, as per the FAO, is the capacity of various systems, communities, groups, or individuals to protect, prevent, minimize, alleviate, or cope with threats and stresses [34].

CSA also aims to improve agricultural techniques and approaches in order to boost productivity and earnings from crops, livestock, and fisheries while minimizing environmental impact. It also contributes to the improvement of food and nutritional security [30]. Sustainable intensification is a key component of CSA for maximizing natural resource utilization. Because of its vulnerability to the detrimental consequences of climate change, agricultural production is largely dependent on environmental conditions. Promotion and strengthening of adaptive ability that can aid in enhancing agricultural productivity can improve production in the long run [38]. As a result, the CSA concept drew a lot of attention on international and domestic agricultural and climate change policy agendas, and it was immediately adopted as a unifying factor for climate and agriculture measures [31].

The CSA concept also calls for attaining three goals: boosting food security sustainably through increased production and incomes, building resilience and adapting to climate change, and reduction of greenhouse gas emissions when compared to a business as usual or baseline scenario [39]. The climate-smart agriculture approach has always recognized the possibility for trade-offs between the three objectives, as well as the ability to increase efficiencies between them via policies, institutions, and financing [40].

CSA is an effective approach to improve soil-water storage (12%) and grain yield (66%) of maize crops [41]. In another experiment, it was reported that profit efficiency in maize production can be improved significantly with the adoption of CSA [42]. In general, CSA can provide an effective way to agriculture and rural development globally in a sustainable way in the presence of changing weather patterns [43]. It's become a framework for capturing the concept that agricultural systems may be designed and implemented at the same time to improve food security and rural livelihoods, as well as enable climate change adaption and bring extra benefits. Nonetheless, the notion of CSA is still developing, and there is little research and extension that looks at the connections between CSA and sustainable agriculture, as well as how CSA practices may be pushed to ensure long-term food and nutrition security [32]. In general, the author selects CSA for sustainability based on three main objectives; increase adaptation, decrease greenhouse gas emissions below business as usual, and sustainably increase production and profitability.

2.2. Organic farming

Organic farming stresses environmental protection, animal welfare, food quality and safety, resource sustainability, and social justice, and use the market to help sustain these aims and pay for internalized consequences [8]. A modern definition of organic farming provided by [44], an authoritative source, states that the aim is: "to create integrated, humane, environmentally and economically sustainable production systems, which maximize reliance on farm-derived renewable resources and the management of ecological and biological processes and interactions, so as to provide acceptable levels of crop, livestock and human nutrition, protection from pests and disease, and an appropriate return to the human and other resources''

At the turn of the century, organic farming was given significant consideration. The term "return to nature" lifestyle has become popular. The deleterious impact of chemo-synthetic agriculture inputs became better known. As a result, organic farming could be a viable alternative to conventional farming. Organic products are preferred by consumers, implying that there is significant room for organic product growth [45]. The desire for a healthy lifestyle has now become a trend for many international and domestic societies, spurred on by the slogan "return to nature." The lifestyle is based on the belief that natural products are safer and better for one's health. People are becoming more conscious that the usage of chemical substances in agricultural production, such as pesticides, can have negative health and environmental consequences [46].

Inorganic agricultural practices and cultivated food have had a global impact on complex issues. The world's attention is turning to organic farming [47]. According to the most recent data, over 186 countries have actively implemented organic farming as of 2018. Organic agriculture land, on the other hand, represents for only 1.5 percent of total agricultural land, which is exceedingly low. As the overall amount of land and market size has grown, farmers have expressed interest in organic farming. As a result, the number of farmers practicing organic farming has increased, reaching 2.8 million in 2018 [48].

Organic agriculture is an efficient and promising agricultural practice for ecological responsibility since it produces consistent yields, improves soil health, has no environmental problems, produces organic food, and uses less synthetic fertilizer. Other agricultural systems can help with environmental issues, but organic farming is without a hesitation the best scientifically proven environmentally benign method for maintaining ecological integrity [49,50]. Environmental health is given considerable care in organic farming. Organic farming helps to reduce soil, water, and air pollution because of its environmentally friendly approach. As a result, it serves as a natural instrument for biodiversity protection and agricultural sustainability [51].

Organic farming has emerged as a sustainable farming approach with important social implications for small farmers in rural areas, especially in developing countries. This farming practice enhances soil and ecosystem health while remaining self-sustaining by reducing the use of chemical fertilizers and pesticides and reusing agricultural waste. As people grow more conscious of their health, as well as food and environmental quality concerns, organic agriculture is becoming more popular [52]. As a result of pressing needs to protect the air, soils, and water, improve the socioeconomic conditions of farmers, farm workers, and rural communities, and provide healthy, safe, and nutritious horticultural products to a rapidly growing global population, organic farming practices are enduring and becoming more important [52,53].

The five major features of the an organic agriculture system are "(1) respect for the environment and animals, (2) promotion of sustainable cropping methods, (3) use of non-chemical fertilizers and pest/disease/weed control means, (4) production of high-quality foodstuffs, and (5) no use of genetically modified (GM) crops" [54]. It can ensure food security through unique combinations of environmentally sound practices with low external inputs [55]. The organic agricultural society has developed a wide range of strategies to boost output without relying on external agricultural inputs, particularly chemicals [8]. Soil fertility control, crop, livestock, farm, and ecosystem management, and nutrient efficiency are all characteristics of organic agriculture [56]. Healthy food is produced through organic farming, which also maintains a balanced ecosystem with little harm. Hence the organic farming is an effective approach with wider social acceptance and environmental concerns. The awareness of consumers about health issue and demand of organic products in the market are opportunities for farmers who produce organic products.

2.3. Biodynamic agriculture

Biodynamic agriculture is a sort of alternative agriculture that combines organic and metaphysical notions based on the teachings of Rudolf Steiner (1861–1925). It was formed in 1924 and became the first organic agriculture movement. Through biodynamic agriculture and horticulture, land cultivators can create a mutually beneficial relationship with their soil. Biodynamic agriculture practices utilize the land's life energy and natural components when growing crops, resulting in a more ecologically harmonious environment and more efficient farming techniques [57,58].

Biodynamic farming is the forerunner of organic farming or a subset of it. Biodynamic farming and organic agriculture have many common characteristics, such as the use of natural fertilizers and the avoidance of conventional herbicides, insecticides, and fungicides. While organic is usually the beginning point for biodynamic growth, the primary distinction between biodynamic and organic agriculture is that biodynamics considers natural rhythms. Biodynamic producers, for example, examine solar and lunar movements to determine the optimal time to cultivate and harvest plants, flowers, and edibles in order to ensure their greatest attributes [59,60]. Because mysticism plays such a large role in biodynamic agriculture, biodynamic farmers are especially aware of the nebulous and invisible forces at work in nature, from the impacts of sun and moon movements to the interconnectedness of all things below and above the soil surface [58,61].

Both organic and biodynamic farming are chemical-free and free of GMOs. Biodynamics, on the other hand, takes a step further. It is a holistic technique in which all live interconnected systems, including animals, plants, and the entire universe, are examined. By refilling the soil and restoring life to the plant, soil, and/or livestock, biodynamic activities promote better plants and heal the planet [62,63].

In addition, due to ecological principles, synthetic fertilizers, insecticides, and herbicides, among other things, are not recommended. Biodynamic agriculture is a style of farming that eliminates the use of pesticides and provides psychological support to farmers [64]. As a result, biodynamic agriculture can be regarded as agriculture's ancient environmental tradition and the most sustainable type of processing, suitable in all climate zones under varying conditions [65]. Generally, its above and beyond organic agriculture [66].

The main goal of biodynamic agriculture is to build a sustainable agricultural production by combining natural and ecological production perspectives gained since ancient times with the celestial impacts of the sun, stars, planets, and moon. In the same way, developing standards for natural sciences employed in manufacturing and observing the impact of spiritual realities (Karada\ug et al., 2019). The knowledge gained during the production stages can be applied to a variety of areas, including education and social life. Within the framework of "anthroposophical" approach, which is characterized as "spiritual development path," they value nature, people, and the environment, as well as protecting the balance and cleanliness of nature [67].

From an ecological and ethical stance, biodynamic agriculture focuses on farming, food, and horticulture. Traditional farming, which encompasses both organic and conventional agriculture, degrades soil quality over time due to grazing animals, crops, and other nutrient-draining vegetation [52]. Biodynamic agriculture maximizes the utilization of farm land's inherent potential while restoring ecological balance and organic harmony to your farm or garden. Hence, biodynamic agriculture produces satisfactory products in a sustainable manner [68, 69].

Furthermore, as people seek healthier foods, demand for biodynamic agricultural products is increasing. Biodynamic products, which have been promoted by a variety of organizations around the world, are gaining appeal, notably in Europe. Biodynamic agriculture is being conducted on a total of 202,000 ha, with 150,000 ha on the European continent as of 2019. There are 5918 recognized farms in different parts of the world, including 3806 in Europe [70]. The "Demeter" brand is used to advertise biodynamic agricultural products all over the world. The Demeter trademark is only available to certified manufacturers. Products can be regulated and monitored at every stage of the inspection and verification process. Holistic Demeter's standards are higher than those of nations [71,72].

Biodynamic agriculture has attracted significant scientific attention in the last 20 years as a potential alternative to conventional farming for long-term sustainability. With roots reaching back to the early twentieth century, biodynamic agriculture is one of the oldest organic farming systems. Despite the scepticism, biodynamic agriculture has evolved through time and is today recognized as a viable solution to a number of environmental, social, and economic issues, as well as a contributor to long-term agricultural sustainability [61]. The goal of biodynamic farming is to maximize the wellness and health of the soil, the animals, the food, and the people. It views the farm as a self-sustaining, thriving ecosystem made up of many different components and acknowledges the influence of lunar and planetary cycles. Hence, biodynamic farming contributes to the sustainability of agriculture by improving soil quality, the amount and nutritional value of products, and insect control. Consequently, biodynamics is seen as a possible path to the integrated and sustainable agriculture of the future [73].

2.4. *Sustainable intensification*

Agricultural intensification is required to feed a growing and increasingly demanding human population. Intensification is associated with an increase in both resource consumption and resource utilization efficiency, i.e. with an increase in both resource consumption and utilization efficiency. Resource use efficiency has agronomic, environmental, economic, social, *trans*-generational, and global dimensions [74].

Sustainable intensification (SI) is a process or system for boosting agricultural production and productivity without damaging the environment or necessitating the transformation of more non-agricultural land [75]. The terms 'sustainable' and 'intensification' are used combined to signify that a variety of strategies can be employed to achieve desired goals in terms of more food and improved environmental goods and services [76].

Although there are different interpretations of sustainable agriculture, the majority of them revolve around three principles: I producing more food, feed, fuel, and/or fiber per unit of land, labour, and/or capital used, (ii) preserving essential ecosystem services, and (iii) resilience to shocks and stresses caused by climate change [75,77].

Agricultural intensification is the process of producing more per unit of input (or maintaining production with less input) in agriculture [74, 78]. However, having such a broad, technical phrase has its drawbacks. An increment in inorganic fertilizers input will ramp up production per hectare, thereby intensifying agriculture productivity by increasing production per unit of land and, most likely, per unit of labour [79]. Meanwhile, if other inputs are not raised (or at least optimized) at the same time, the Law of Diminishing Marginal returns will reduce production per unit of fertilizer or per unit of cash [80]. This has a clear practical significance: intensification does not improve the efficiency of all inputs at the same time, and trade-offs must be considered before intensification [74]. Fertilizers, insecticides, and the vast amounts of water necessary for irrigation have all received a lot of attention [35, 81]. This has led to calls for 'sustainable intensification' [82].

Continuing to build a sustainable intensification of agriculture while protecting the integrity of the land and the people who engage on it is required to ensure future quality and supply of agriculture products [83]. Soil and water management and biodiversity can be enhanced by enhancing farming methods such as how we till, rotate crops, cover the ground, fertilize, and handle various agricultural chemicals [37,84]. Simultaneously, more efficient land use (e.g., zero tillage) can help us cut greenhouse gas emissions in agriculture, reduce future habitat loss, and contribute to soil sequestering carbon [85,86]. Landscape connection can assist minimize fragmentation and species isolation, which can lead to extinction owing to a lack of evolutionary adaption [87].

Sustainable intensification is focused on combining and building synergy amongst existing individual solutions while emphasizing on characteristics that solve a variety of societal issues [88,89]. In recent times, green revolution techniques have built industrial systems geared at productivity gains. Initially, policies were designed to expand markets and give farmers additional opportunities to improve their income and social standing [90]. Environmental policies are becoming more popular in recent years. Production systems that can generate many benefits in response to a variety of societal concerns will have a promising future [87,91,92]. The added value of these new solutions is in deciding the best arrangement of components to achieve this goal [87].

As a result, agricultural intensification serves to enhance farmers' livelihoods and economic and social conditions by increasing food security and employment opportunities for present and future generations [93,94]. It has been proven to be a viable choice for improved living conditions in several countries [95]. Agriculture intensification has benefited the economy, food and nutrition security, employment, decision-making, task division, local institutions, and leadership. Therefore, sustainable intensification provides a method for assessing and balancing agriculture's environmental, economic, and social goals. It's a superior solution for sustainable agriculture in general.

2.5. *Regenerative agriculture*

Regenerative agriculture is a preservation and rehabilitation-oriented food and farming system. It concentrates on topsoil regeneration, biodiversity improvement, improved water cycle, ecosystem goods and services, bio-sequestration support, climate change resilience, and farm soil health and vitality [96]. Regenerative agriculture isn't a stand-alone method; rather, proponents incorporate a number of different sustainable agriculture approaches [97,98]. Recycling as much agricultural trash as possible and adding composted material from outside of the farm are among the techniques. Permaculture, agroecology, agroforestry, restoration ecology, and holistic management are widely used in regenerative agriculture on small farms and gardens [99]. Large farms tend to be less philosophy driven and often use "no-till" and/or "reduced till" practices [100].

Regenerative agriculture has been promoted as a potential alternative method of food production with lower or even net positive environmental and/or social implications [101]. Different stakeholders have made various assertions regarding the potential for regenerative agriculture to improve food production sustainably, including the prospect that this could be used as part of a climate change mitigation approach.

For instance [101], claimed that “regenerative agriculture has at its core the intention to improve the health of soil or to restore highly degraded soil, which symbiotically enhances the quality of water, vegetation and land-productivity”. Project Drawdown claims that “regenerative agriculture enhances and sustains the health of the soil by restoring its carbon content, which in turn improves productivity—just the opposite of conventional agriculture,” and estimates that regenerative annual cropping could sequester 14.5–22 gega tons of CO_2 by 2050. The claims include those that “regenerative agriculture has the potential to reverse climate change” [102] and that “we could sequester more than 100% of current annual CO_2 emissions [100] with a switch to widely available and inexpensive organic management practices, which we call ‘regenerative organic agriculture’” [103] In line with this, some analysts remain more cautious regarding the potential of regenerative agriculture to contribute to sustainability objectives by stating in such a way that “regenerating a soil is regenerating a soul” [104–106].

Despite widespread interest in regenerative agriculture, no legal or governing definition of the term “regenerative agriculture” exists nor has a widely accepted definition emerged in common usage [107]. Some actors engaged in regenerative agriculture have initiated attempts to gather different perspectives on how regenerative agriculture can be defined [108], while some authors acknowledge competing definitions [109]. In the time being, regenerative agriculture has been defined in a variety of ways, and as differently as “a system of farming principles and practices that increases biodiversity, enriches soils, advances watersheds, and enriches ecosystem services” [108], to “a long-term, holistic design that attempts to grow as much food using as few resources as possible in a way that revitalizes the soil rather than depleting it, while offering a solution to carbon sequestration” [101], to “a form of enterprise that incorporates a community of people engaged in producing and consuming the food (and land, landscape and amenity) that they, collectively, decide to grow” [110]. Clearly, there are disparities among different definitions. In part, these differences may be a product of different origins and lineages of the term “regenerative agriculture” [111], though a systematic etymological history has not been developed [112].

Regenerative agriculture has as its central goal the improvement of soil health or the restoration of badly degraded soil, which symbiotically improves water quality, vegetation, and land production [113]. It is feasible to improve the amount of soil organic carbon (SOC) in existing soils by adopting regenerative agriculture technologies [101,114], but also to build up new soil. This reduces carbon emissions while simultaneously improving soil structure and health, soil fertility and crop yields, water holding capacity and aquifer recharge, and so reducing floods and drought, as well as further soil degradation due to decreased runoff [115]. Because smaller-scale agricultural production preserves the soil and its quality, urban food production should be considered as a key contribution to regenerative agriculture in the future, as long as the technology utilized are also regenerative [116,117]. If localisation is to become a dominant strategy for dealing with a vastly reduced use of fossil fuels and preserving soil quality while increasing food production in towns and cities, it will be necessary to incorporate integrated (‘systems’) design approaches within the established urban infrastructure. Apart from urban farming, draught-proofing and thermal insulation existing buildings, as well as living and working on a more local scale, would all assist to lower our overall energy use [118,119]. In order to reduce our usage of fossil fuels, methods for reducing overall energy use must be deemed at least as important as increasing low-carbon energy generation. In conclusion, we will only be able to meet future demands if we change from the old linear ‘take, make, dispose (waste-creation)’ resource-consumption paradigm to the systemic, circular alternative to ‘reduce, reuse, recycle, regenerate [101,120].

Overall, regenerative agriculture systems are a type of sustainable agriculture that aims to increase soil quality and biodiversity while also generating healthy agricultural goods at a profit [100,121]. Unifying principles consistent across regenerative farming systems are but not limited to abandoning tillage or actively rebuilding soil communities [109], avoiding spatio-temporal events of bare soil [122], enhance crop diversity on the farm, and integrating livestock and cropping management on the land [123]. Tillage can ruin the habitat of beneficial species, disrupt soil structure, hasten the decomposition and loss of organic matter, increase the risk of erosion, and compact the soil. However, farmers may resist acquiring new knowledge and skills. Less tilling may also lead to more unwelcome plants, and some farmers compensate by increasing their use of herbicides. Further categorization of a regenerative system may be difficult due to the diverse array of farming practices that make up a system aimed at achieving the regenerative goal [121]. As a result, regenerative farming systems can provide higher ecosystem benefits and profitability to farmers in a sustainable manner than an input-intensive crop production model [97,121]. Regenerative agriculture is more than just a sustainable method of farming because it places a strong emphasis on regenerating the soil and working with rather than against natural systems. It can heal the damage done by industrial farming and create a food system that is better for people, animals, and the environment.

3. Novel practices to sustainable agriculture

Sustainable agriculture has the potential to directly contribute to achieve several Sustainable Development Goals (SDGs), including those related to poverty, starvation, inequality, responsible consumption and production, climate change, and ecosystems, as well as local and national development and environmental goals [124,125].

Sustainable farming practices are those that allow for more efficient use of natural resources, reduced environmental impact of agriculture, and improved climatic change and variability, as well as adaptive capacity [40,126,127]. Crop rotation, increased crop diversity, cover crops, no-till and reduced-till systems, integrated pest management (IPM), livestock and crop integration, sustainable agroforestry technologies, and precision farming are all examples [128,129]. Agricultural sustainability entails effective management of the natural systems and resources that farms rely on, which can result in significant public benefits, particularly in the form of ecosystem services [130]. Agriculture that is sustainable has a multitude of economic, social, and environmental benefits. Understanding farmers’ risk attitudes is essential to understanding their behavior and coping mechanisms in the face of environmental challenges [131]. In this review paper some of the novel practices for agricultural sustainability are discussed as follows.

3.1. Integrated farming

The phrase “integrated farming system” (IFS) refers to a more integrated approach to farming as compared to monoculture farming [132]. Integrated framings are agricultural practices that combine livestock and crop production, or fish and livestock production [133,134]. In this system, a network of interconnected businesses is employed in such a manner that “waste” from one component becomes an input for another [99,135]. This reduces costs while improving productivity and/or revenue. Farmers not only reduce waste by repurposing rubbish, but they also increase overall production for the entire farming system [134,136].

Integrated farming attempts to simulate nature’s idea of producing food by combining plants, animals, birds, fish, and other aquatic flora and fauna with crops [133]. The main idea is to improve biological diversity by reducing competition for water, nutrients, and space by using mixed cropping, crop rotation, crop combination, and intercropping, as well as implementing ecologically friendly practices [137,138]. It also improves diversity through the use of a multi-story architecture, which allows for the most efficient use of available space and a high level of interaction between biotic and abiotic components [139]. It can also connect subsystems in which the various components work together to improve farm productivity [140].

The integrated agricultural production is also a long-term strategy for increasing agricultural production through crop diversification, resource integration, and market linkage [4,141,142] Thousands of small and vulnerable family farmers in resource-poor Asian and African countries have moved to this sustainable farming system to diversify farm produce, increase cash income, improve food quality and quantity, and exploit underutilized resources [97,143]. Building a well-integrated farm with good market ties to offer food and nutrition security for a family's livelihood could take three to four years. The benefits of using an integrated farming system include: a) introducing a change in farming practices for optimum production in cropping patterns and ensuring optimal resource utilization; b) farm waste can be recycled for productive purposes in the integrated system; c) judicious combination/integration of agricultural enterprises such as dairy, poultry, fishery, sericulture, and others suited to the given agro-climatic conditions and socio-economic conditions [68,144,145].

Many farmers, if not entire nations, are implementing the integrated farming system, which incorporates practices that include present and future climatic conditions, soil properties, population eating patterns, and anticipates future nutritional needs of an ever-growing human and animal population [50,146,147]. Developing an integrated farming system, on the other hand, involves the use of appropriate technology, which is crucial for long-term farming and food security. It's crucial to think about how to help farmers improve the quality of their crops as a tool. Technology must also be considered as a means of mitigating and balancing the reduction in food production brought on by the loss of agricultural land [148,149]. But there are several obstacles to the IFS system's adoption, including: a) farmers' lack of comprehension of IFS; b) their restricted ability to use agricultural technology; and c) inadequate financial assistance. In order to generate chances to raise farm scale in line with farmers' incomes, the implementation of IFS requires government support.

3.2. Precision farming

Precision agriculture (PA), also known as satellite farming or site-specific crop management (SSCM), is a farming management methodology based on seeing, measuring, and responding to crop variability both within and between fields. Precision agriculture research aims to develop a decision support system (DSS) for whole-farm management that maximizes input returns while conserving resources [150,151]. It is the science of improving crop yields and assisting management decisions through the use of high-tech sensors and analysis tools.

Site-specific management (SSM) is defined as doing the right thing at the right time and in the right place. Although this concept is as old as agriculture, during the twentieth century's industrialization of agriculture, there was great economic pressure to treat large fields with comparable agronomic processes. Precision farming allows SSM to be computerized in intensive agriculture due to information technology [152]. Variable rate application (VRA), yield monitors, and remote sensing are examples of agricultural production practices or systems that use information technology to customize input utilization to achieve desired outcomes or to measure those outcomes [153,154]. With the availability of GPS and GNSS, precision agriculture has become a reality. Maps demonstrating the geographical variability of as many variables as can be measured can be constructed since a farmer or researcher can pinpoint their specific location in a field [155,156].

Furthermore, precision agriculture makes extensive use of data and information to increase the efficiency of agricultural resources, yields, and crop quality [157]. It is a cutting-edge innovation that can aid in the optimization of agricultural field level management strategies aimed at increasing the productivity of resources/inputs on agricultural fields [158]. It comprises controlling spatial and temporal variation in all elements of agricultural production utilizing technology and agronomic ideas in order to increase crop performance and environmental quality (Oliver et al., 2013). It also makes use of technology to promote sustainability by making better use of vital inputs including land, water, fuel, fertilizer, and pesticides. Farmers that employ precision agriculture technology are said to "use less to grow more" [142,159].

PA has some limitations such as; initial capital costs may be high and so it should be seen as a long-term investment, it may take several years before you have sufficient data to fully implement the system, extremely demanding work particularly collecting and then analysing the data. However, PA is beneficial to the preservation of a healthier ecosystem. According to research, legislation and technological advancements can help farmers achieve better results. Higher yields, fertilizer reduction through more precise placement, pesticide reduction through more efficient utilization, fuel savings through less intermingle and better surveillance, and water savings through more accurate detection of needs are all advantages of precision agriculture technology adoption [160].

3.3. Agroforestry

Agroforestry, which is the intentional mixing of agricultural and forestry-based land-use systems, provides numerous benefits that contribute to the long-term sustainability of agroecosystems [161]. Agroforestry has the potential to address the country's land stewardship demands by converting degraded land, conserving sensitive lands, and diversifying farm production systems [162]. When utilized in conjunction with an ecologically oriented land management system, agroforestry methods can aid in the preservation of ecosystem diversity and processes that contribute to long-term sustainability and environmental quality [163–165].

Agroforestry can have long-term economic, environmental, and social implications, given the environmental limits that threaten modern agriculture and the emphasis on establishing sustainable agricultural and natural resource systems [166]. Agroforestry practices can make a significant contribution to ecosystem diversification and processes, which are critical for long-term sustainability, when used as part of an ecologically oriented land management system [97,167]. In other words, agroforestry bridges the gap between agriculture and forestry by developing integrated systems that serve both environmental and economic aims. It can assist agricultural systems adapt to climate change and mitigate its consequences (S. [168]; S. E [169,170]. Wind and water erosion are successfully protected by agroforestry systems. They can also help with the maintenance and improvement of yearly plant yields. Plants and animals use strips of land planted with shrubs and trees as living places and refuges [171,172].

Agroforestry on agricultural land contributes greatly to climate change mitigation, but it is not accounted for in a systematic fashion in global carbon budgets or national carbon accounting. Agroforestry has long been a significant feature of temperate regions worldwide [173–175]. This method has a lot of benefits, including providing food security, enhancing biodiversity, enriching an ecosystem with more resources, and satisfying various environmental goals, such as maintaining CO2 levels in the atmosphere below specific thresholds [176,177]. Hence, agroforestry has a number of benefits, including improved soil fertility that boosts vegetable yields, an extended harvest season, improved produce quality, and increased revenue for rural populations.

3.4. Integrated nutrient management

Integrated nutrient management (INM) is a strategy for safely disposing of crop residues and producing high-quality compost through a balanced and integrated use of both organic and inorganic fertilizers in combination (organic and inorganic fertilizers) for maintaining soil fertility and providing plants with an optimum level of nutrients required throughout the cycle life to sustain the yield [178–180]. INM is a technique for maintaining agricultural productivity while simultaneously protecting the environment for future generations. It is the application of soil fertility management technologies to increase agricultural yield by maximizing fertilizer and organic resource utilization efficiency [174]. This approach entails the careful application of chemical fertilizers as well as organic resources [181]. It combines organic and inorganic fertilizer sources to maximize crop yield, reduce soil degradation, and promote soil-water infiltration, all of which contribute to the future food supply (C. [182]; X.-P [183]. Achieving long-term food security necessitates striking a balance between crop productivity and environmental sustainability.

Scientists have identified four major components of the INM system: A) All conceivable nutrient sources that can be employed as a tool of nutrient sources in developing nutrient input programs for higher nutrient-use efficiency and high yield production must be given great consideration [180,184]; B) the types and quantities of soil nutrient content around the root zone, also known as soil balance, and its temporal and spatial availability to cover nutrient requirement; C) reducing nutrient losses, particularly in intensive agriculture (X.-P. [145,183,184]; D) taking into account all elements affecting the plant/nutrient connection in order to produce high yield production, which is the main goal and key benefit of INM, as well as water use efficiency, grain superiority, high economic return, and sustainability [185].

INM's goal is to integrate the utilization of natural and man-made soil nutrients to boost agricultural output and conserve soil productivity for future generations, according to the same presentation. Rather than emphasizing nutrition management strategies on a single crop, it tries to maximize nutritional resource usage across a cropping system or crop rotation, which might encourage farmers to think long-term and consider environmental consequences [178,180]. In general, integrated nutrient management helps to maintain economic yield for a long time with minimal impact on native soil fertility and pollution, as well as to raise farmer awareness of environmentally friendly techniques (organic farming system) for producing healthy, contaminant-free food while ensuring satisfactory economic returns.

3.5. Integrated pest management

Integrated pest management (IPM) is an old concept that is focused on environmentally friendly pest management tactics. This is going to change, thanks to the creation of a new integrated pest management model. By balancing three critical factors: economic viability, environmental safety, and social acceptability, the new strategy aims to create sustainable food production and food security. It already has worldwide clout and the potential to transform IPM in the twenty-first century [186,187]. Scouting and thresholds are the fundamental ideas, which minimize pesticide use by 50%. Biological, cultural, mechanical, physical, and chemical processes are combined in a sustainable manner to minimize economic, health, and environmental risks [188].

Despite its many benefits, integrated pest management (IPM) is not generally understood or commonly used as a sustainable agriculture strategy. This is set to change with the development of a revised model that redefines IPM for the twenty-first century and incorporates all aspects of sustainable crop production. It encourages more accessible IPM-based agricultural production that reflects current global food production and consumption trends, as well as environmental and social considerations [189,190].

Integrated Pest Management is the employment of a variety of pest management strategies to supplement, decrease, or replace the usage of synthetic pesticides. IPM includes methods such as simultaneous management and integration of tactics, regular monitoring of pests and natural enemies, and the use of decision thresholds, as well as pesticide product management/substitution and entire agroecosystem redesign [191,192]. Reduced use of synthetic pesticides improves on- and off-farm sustainability while saving the farmer money. In addition to pest management, IPM systems may supply a number of ecosystem goods and services, boosting overall farm and landscape resilience. IPM is one of the strategies that can help achieve sustainable intensification, which is described as "creating more output from the same amount of land while minimizing negative environmental impacts and enhancing contributions to natural capital and the flow of environmental services" [191,193,194].

IPM is a pest-control method that uses a range of common-sense techniques and is both cost-effective and environmentally beneficial. IPM strategies rely on current, thorough data on pest life cycles and interactions with the environment [195,196]. Before taking any pest management action, IPM develops an action threshold, a point at which pest populations or environmental factors indicate that pest control intervention is required. The presence of a single pest does not always indicate that control is required. When determining future pest treatment decisions, the point at which pests become a financial risk must be considered [53,197].

IPM systems work as a first line of defence against pests, preventing pests from becoming a problem by managing the crop, lawn, or interior space. In the case of a crop, this could suggest using cultural approaches like crop rotation, pest-resistant cultivars, and pest-free rootstock planting. These management strategies can be incredibly successful and low-cost, with little to no damage to humans or the environment [128,188].

IPM is an environmentally friendly approach [198], that aims to keep pest populations below economic threshold levels by implementing all affordable alternative pest control methods and techniques, such as cultural, mechanical, and biological, with a focus on plant-based bio--pesticides and pesticides like neem (*Azadirachta indica*) formulations. When the insect population in the crop exceeds economic threshold levels, chemical pesticides are recommended as a last resort [199–201]. Pest population suppression below economic threshold levels can be achieved by implementing practicable and inexpensive agricultural measures that cause the least amount of disruption to the ecosystem and environment, allowing agricultural output to continue in a sustainable manner [197]; E [202,203]. Therefore, it can be argued that integrated pest management (IPM) is a proven, cost-effective strategy to combat pest problems without unnecessary pesticides.

4. Summary

Agroecology, nature-inclusive agriculture, permaculture, biodynamic farming, organic farming, conservation farming, regenerative farming, carbon farming, climate-smart farming, high nature value farming, low external input farming, circular farming, ecological intensification, and sustainable intensification are just a few of the approaches to sustainable agriculture. These methods appear to be more comparable to one another than to traditional agriculture practices. The approaches all aim to achieve sustainability, which takes into account both socioeconomic and environmental factors. Novel farming practices have also proven to be effective in achieving sustainability, particularly when implemented in harmony. Rotating crops and embracing diversity, planting cover crops and perennials, reducing or eliminating tillage, applying integrated pest management (IPM), integrating livestock and crops, applying integrated nutrient management, applying precision agriculture, and adopting agroforestry practices are some of the activities in sustainable agricultural practices.

Implementation of novel agricultural approaches and practices should be implemented for ecological sustainability and food security for the alarmingly increasing human population. Only radical change towards a sustainable global economy will ensure the preservation of nature and its benefits to humanity. These approaches and practices have been proved about their eco-friendly approaches. Hence, implementing these approaches and practices is the most significant step we need to take for our shared future right now since providing good food at reasonable prices while protecting the environment is essential for our survival.