Review Article

A review of present advancement in climate smart agriculture Techniques: Adaptation for Sustaining Crop Production under climate change

Abstract

The growing global population is driving up demand for agricultural goods at a never-before-seen rate. Improving crop yield and quality is essential to meeting this growing demand. The yield and quality of agricultural crops may be greatly increased by using agronomic techniques. Although it is known that changing climate circumstances have a detrimental impact on crop development, yield, soil quality, and ultimately the nutritional content of agricultural food, such agronomic methods under changing climate conditions are insufficient to boost crop productivity. In order to increase the production potential of agricultural crops, several agronomic improvements have been made in the previous few decades. These include the application of resource conservation technology and conservation agricultural methods. Therefore, it is essential to adopt various adaptive agricultural practices that are specifically resource-conserving, such as crop diversification, mulching, crop rotation, agroforestry, intercropping, and the push-pull system of crop pest and disease management, etc. in order to effectively deal with such unfavourable situations. These agronomic approaches, which are being advocated to increase agricultural production and profitability, are described in the review along with their methods for enhancing crop performance and quality.

Keywords: climate resilience, adaptive practices, crop productivity and sustainable agriculture

1. Introduction

The foundation of human civilisation is agriculture, which gives us the food, fibre, and a host of other resources we need to survive and thrive. The growing global population is driving up demand for agricultural goods at a never-before-seen rate. Improving crop yield and quality is essential to meeting this growing demand. Sustainability is becoming more and more significant in agriculture [1]. Over time, crop quality and yield can be enhanced by the use of sustainable agricultural practices. Sustainable crop production offers a paradigm change in agricultural operations, concentrating on long-term agricultural health and productivity [2]. It incorporates social and economic equity, economic profitability, and environmental health as its three primary objectives [3]. Sustainable farming methods address growing concerns about resource depletion, climate change, and environmental degradation. Examples of these methods are integrated pest management, organic farming, and precision agriculture [4]. The Sustainable Development Goals of the United Nations, especially Goal 2: Zero Hunger, which highlights resilient agricultural methods and sustainable food production systems, highlight the need of sustainable crop production [5].

Primitive tools and shifting cultivation were the main means of subsistence for early agricultural communities [6]. With the advent of high-yield cultivars and synthetic fertilisers, the Green Revolution of the 1960s and 1970s represented a crucial turning point [7]. Because of the short-duration cereal types, the green revolution also increased cropping intensity. Additionally, water demand for crop cultivation increased globally. Although there haven't been any notable genetic improvements to increase agricultural yields, a number of agronomic innovations have made a substantial contribution to maximising farmer income, enhancing crop yields and soil quality, and improving crop responsiveness to climatic shocks. The new emphasis on more sustainable practices has been influenced by the long-term effects of these activities, which include soil degradation and decreased biodiversity [8]. The expanding worldwide population has raised concerns about food security, which has been addressed in large part by advances in agronomy [9]. These methods, which together lead to increased agricultural yields and quality, include crop rotation, soil management, and fertiliser and pesticide usage [2].

The cornerstone of sustainable and productive agriculture is agronomic techniques. Land reclamation, or agronomy, is the science and technology of growing and using plants as food. It includes a wide variety of techniques necessary for crop growth [10,11]. Beyond only producing crops, agronomic practices are important because they incorporate techniques that guarantee social responsibility, economic viability, and environmental sustainability [12]. The development of agricultural practices has been a journey from traditional to modern techniques that preserve overall crop productivity and quality, improve soil health, and ensure that land will remain productive for future generations [13]. In this article, we examine different approaches and technologies that can assist us in achieving this goal. One of the most promising ways to improve crop yield and quality is through agronomic advancements. This review aims to thoroughly examine the advancements in agronomic practices, with a focus on sustainable crop production.

2. Important Domains for Agronomic Practice Advancement

Given that soil is the basis of agriculture, it has received a lot of attention lately. Soil conservation methods, such no-till farming, have become more popular because of their capacity to lower erosion and increase soil organic matter [14]. These methods improve biodiversity and water retention while maintaining the structure of the soil [15]. It has been demonstrated that using organic additions, such as compost and green manure, improves soil fertility and structure and promotes a sustainable agricultural environment [16]. For the soil to remain healthy and productive over the long run, these organic inputs are essential [17]. Technological developments in soil testing and monitoring have also been extremely important. Farmers may now use site-specific nutrient management techniques thanks to the availability of precision instruments that enable thorough analyses of soil composition [18].

Crop varieties and Genetics: Agronomic research has placed a lot of emphasis on creating hardy crop types. Biotechnological innovations combined with conventional breeding methods have produced cultivars resistant to pests, illnesses, and harsh weather [19]. Crop breeding has undergone a revolution thanks to CRISPR technology and genetic editing. With the use of these technologies, precise gene editing is possible, leading to the creation of crops with desirable characteristics like pest and drought resistance [20]. Significant breakthroughs have also been made in seed technology and preservation. Crop yields have increased and genetic diversity has been preserved thanks to methods like cryopreservation and the use of seed coatings to increase germination rates [21].

Water Use Efficiency and Irrigation: Water is a necessary but frequently limited resource, hence improvements in irrigation methods have been crucial. For example, drip irrigation greatly reduces waste by delivering water straight to the roots of the plants [22]. This approach has shown to be particularly successful in dry areas, where conserving water is essential [23]. Using drought-resistant crop types and other water-saving techniques, such as rainwater gathering, has also proved essential to increasing water usage efficiency [24]. These tactics offer resistance against climatic unpredictability in addition to water conservation [25]. In order to optimise irrigation schedule, climate-smart irrigation techniques have arisen, combining soil moisture sensors with weather predictions [26]. By ensuring that crops are watered at the most advantageous periods, this method lowers water use and increases agricultural yields.

Management of Diseases and Pests: Biological control techniques, which employ natural predators or parasites, are becoming more and more popular as a sustainable substitute for chemical pesticides in the management of pests and diseases [27]. IPM (Integrated Pest Management) techniques have proven to be successful in controlling pests while reducing their negative effects on the environment because they integrate chemical, cultural, and biological instruments [28]. There has also been an increase in the usage of biopesticides, which are made from naturally occurring substances including bacteria, plants, and certain minerals. These insecticides provide a more ecologically friendly way to manage pests [29].

3. An Overview of Adaptive Practices

The improvement of any country's agriculture sector mostly depends on the management of agricultural systems, technical and equipment assistance, policy and economic reform, and infrastructure upkeep. But immediately adopting climate-resilient and adaptable agricultural techniques is necessary to manage agricultural output in the face of both current and projected global warming [30,31]. According to Abhilash [32], implementing climate-resilient, adaptive, and resource-conserving agronomic practices can guarantee high productivity, profitability, crop biodiversity, low greenhouse gas (GHG) emissions, and decreased environmental risks related to the agriculture sector. Below is a detailed explanation of many interesting agronomic techniques (Table 1) along with their advantages.

Table 1. Agronomic adaptive agricultural practices employed for sustainable food production under changing climate

Sl.No.	Agronomic practices	Advantage	Reference
1.	Integrated soil crop management system	Higher crop yield and N use efficiency; low environmental risk	[33]
2.	Crop residue management strategies	Maintains SOC over a long period of time; higher crop productivity	[34]

3.	Transition from conventional agriculture practice to agroforestry practices	Improved soil quality, soil fertility, and productivity	[35]
4.	Selective irrigation practices; zero tillage; use of FYM and domestic sewage sludge	Enhanced soil quality; optimized water and fertilizer use for rice and wheat	[36]
5.	Climate-adapted push-pull system in a companion cropping system as a pest and weed management strategy	Enhanced pest and weed control; better growth; higher soil fertility and soil microbial diversity; higher grain yield by companion cropping	[37]
6.	Use of biofertilizer (*Rhodopseudomonas palustris*) in organic and saline flooded paddy field	Higher grain yield with reduced CH_4 emission	[38]
7.	Integrated agronomic practices, i.e., mixed crop rotation; use of cover crops; rational use of agrochemicals; integrated pest, weed, and disease management; no-tillage	Enhanced faunal diversity; increment in litter and soil quality	[39]
8.	Reduced tillage and strip tillage under fresh and permanent beds in rice–maize system	Higher yield; higher profitability from reduced production cost and labour input under permanent beds crop establishment	[40]

9.	Integrated pest management (IPM) practices	Controls fruit fly infestation and reduces yield loss; thereby increases net income	[41]
10.	Legume-based double cropping system under conservation tillage practice	Increases residual and fixed nitrogen and thus increases net benefit and cost–benefit ratio	[42]
11.	Minimum tillage and intercropping (sunflower + 60% soybean)	Increases energy use efficiency, land use efficiency (LUE), and total yield	[43]
12.	Integrated nutrient management (long-term balanced fertilization)	Increases crop yield, lowered yield-scaled global warming potential and reduced N_2O emission to some extent	[44]
13.	Conservation tillage and residue mulching	Soil organic carbon increased. Soil physicochemical, hydrophysical, and biological qualities improved and crop yield increased	[45]
14.	Dry seeded rice with increased seeding rates	Crop competitiveness increases suppressing weed growth and sustaining grain yield	[46]
15.	Optimised nitrogen fertilization in cropping system	Nitrogen use efficiency increased	[47]
16.	Inoculation of plant growth-promoting rhizobacteria (PGPR) and arbuscular mycorrhizal	Grain yield increased, phosphorus use efficiency increased	[48]

	fungi (AMF) in a field having history of wheat, rice, and black gram cropping system during past 10 years		
17.	Integrated disease management (IDM) and deficit irrigation under water shortage in tomato crop	Managed crop disease. Compensated negative effects of water stress on plants by increasing yield and water use efficiency (WUE). Fruit quality is also improved	[49]
18.	Alteration in planting configuration (Bed/Ridge) and drip irrigation scheduling	Irrigation water use efficiency and yield is increased	[50]

3.1 Crop Diversification

Crop diversification is the process of moving away from single- or mono-cropping and towards intercropping, double-, companion-, or multiple-cropping, crop rotation, or perenniation, among other techniques [51]. This is a more effective way to use natural resources like soil, water, and light energy for agricultural production. By fostering interspecific interactions between several crop species both above and below ground, crop diversification techniques simultaneously improve soil health and boost net crop output [52]. While belowground diversification helps improve the utilisation of water and soil macro- and micronutrients like phosphorus (P), iron (Fe), and zinc (Zn) by increasing soil microbial load and activity, aboveground diversification increases canopy heat and light capture [53].

3.2 Intercropping

Two or more crops are cultivated together at the same location in a method known as intercropping, which is traditional but frequently ignored in agriculture [17]. By modifying soil temperature and moisture, intercropping modifies the microclimate of the soil and affects the way that seeds are dispersed by wind, rain, or other vectors, all of which are advantageous to the intercropped plants in one way or another. It raises the rhizospheric soil's nitrogen and carbon content, allowing subsequent crops to better use those resource pools [54]. Increased iron (Fe) content was observed in the rhizosphere of a peanut–maize intercropping system, according to Xiong et al. [55]. Intercropping tactics have also led to a new invention in crop pest and disease control: the push-pull system. By changing the morphology and physiology of host plants, intercropping protects them from pest invasions and inhibits diseases directly. Additionally, intercropping techniques greatly improved soil fertility and health as well as crop output when carried out with an appropriate quantity of nutrient inputs in the soil [56].

3.3 Crop Rotation and Double Cropping

Crop rotation and double cropping techniques contribute to the restoration of soil fertility and increase farmers' net yearly income by offering a variety of crop varieties [57]. Agronomic methods that are evolving in response to changing climatic conditions include crop-crop rotations, such as the rotation of corn and soybeans, as well as the rotation of prawns and fish with rice [58]. In particular, crop-crop rotation yields greater benefits when combined with decreased tillage techniques. Double or companion cropping, which raises an agricultural landscape's total productivity, is a sustainable agronomic method, much like crop rotation.

3.4 Agroforestry

Agroforestry is a contemporary agronomic technique that is being applied at the farm/field and landscape levels throughout the world's agro-climatic zones. Agroforestry techniques improve the livelihood of resource-poor farmers by increasing crop productivity, farm revenue, and environmental benefits (in ecosystem services through crop and tree diversification) [32]. As a result, it is regarded as a potential sustainable farming method that can protect global food security and double farmer income [59]. The traditional methods used by the native peoples long ago to preserve their agro-ecosystem for social, cultural, economic, and ecological reasons are the roots of modern agroforestry.

These classical or traditional methods, which involve growing agricultural plants alongside commercial/perennial trees like cocoa or rubber, are only expanded upon by modern agroforestry. As an adaptive tactic for managing soil carbon sinks, the conventional methods are still used in some areas. The current situation calls for a lot more agroforestry promotion since it has been shown that the younger agroforestry system has advantages due to its considerable rise in the organic carbon stock [60]. In addition to the benefits of agroforestry that were previously discussed, sustainable agroforestry techniques can help to mitigate the negative consequences of deforestation to some degree. Consequently, the World Bank views agroforestry as a means of subsistence for the impoverished in order to reduce poverty since it allows them to work on large-scale initiatives aimed at establishing agroforestry in an area [61].

3.5 Mulching

Mulching is a novel approach to minimising water loss from agricultural fields in the context of warming climates. This is because evaporation accounts for more than 65% of water loss in agricultural fields, with a 2:1 ratio during growth and fallow seasons, respectively, leaving less water available for crop plants [62]. Only the remaining water, or less than 35% of the total water, may be used by the crop plants for growth and development [62]. As a result, maintaining soil moisture and water content is essential. Mulching helps prevent abiotic stressors like heat or cold, increase soil nutrients, decrease weeds, maintain soil moisture content, and enhance soil microclimate [63]. The most crucial benefit of mulching is that it keeps the soil at a temperature that supports crop development and survival.

Additionally, it improves crop plants' production, water and nitrogen use efficiency. Mulching, for example, has been shown to more than 1.5-fold increase in yield, water and nitrogen use efficiency, and production in cereal crops including wheat and maize [64]. In agricultural areas, a variety of mulching techniques have been employed, including film mulching, straw mulching, flat mulching, ridge-furrow mulching, mulching with the use of certain materials like polyethylene, and mulching with two materials mixed. In general, there are two kinds of mulch materials used in agriculture: (1) synthetic, such polyethylene, plastic sheets, and geotextiles, and (2) organic, like straw, wood, shells, hay, leaves, and needles [65]. These mulches are utilised for a variety of reasons and in a variety of locations, making their use completely location-specific.

3.6 Organic Farming

Organic farming refers to agricultural methods that employ various forms of organic input in place of synthetic agrochemicals, such as pesticides, fertilisers, additives, preservatives, and genetically engineered seeds and breeds. This method reduces agricultural pests and illnesses while boosting soil fertility and water retention capacity [67]. This kind of adaptation boosts the nutritional value of agricultural products while also increasing the agro-biodiversity of farm lands. Most significantly, according to FAO [68], such approaches have good effects on guaranteeing the nutritional security and well-being of resource-poor farmers in developing countries. Organic farming focuses on crop rotation, biodiversity preservation, eco-friendly seed invigoration techniques [77]. Using locally available resources, this subject led the current inquiry to concentrate on old (or traditional) methods that improve agricultural growth and development without harming the environment [78, 79].

3.6.1 Integrated Farming System with Livestock

One of the main and most sustainable agronomic approaches under organic agriculture is mixed crop–livestock production. In the majority of countries in the world, organic farming methods were traditionally used with investments (about 10 times more than they are now) from the public and private sectors [68]. As a result, it currently makes up close to 50% of the world's total food output, and organic farming is widely implemented at the farm, field, and landscape levels in many developing countries [69]. on the past, animal manure was not moved or applied on farm fields in a way that was well-mechanized, losing nutrients that may have benefitted the soil and crops there [70]. In areas where the majority of farmers own cattle, have a sizable amount of farmland, and have access to resources, integrating animals into farmlands is a more adaptable method. These farmers can prudently feed their cattle with crop leftovers and straw produced on their farms (so long as the amount of straw produced does not exceed the level needed to be utilised as cover crops). By doing this, a sizable amount of manure in the form of FYM may be obtained, which could then be applied to agricultural areas to enhance crop yield and soil health [71].

3.6.2 Chemical Fertilisers to Be Replaced with Organic Inputs

The fertility and health of the soil have suffered greatly as a result of the overuse of agrochemicals in previous decades [72]. Millions of people across the globe are facing the potential threat of heavy metal arsenic contamination through groundwater-soil-crop systems [76]. The timing is perfect to employ organic inputs in agricultural areas in a sustainable manner. For organic agricultural operations, a variety of organic inputs have been employed, including farm yard manure (FYM), green manure, compost, vermicomposts, bio-fertilizers [73]. Among the important materials utilised in organic farming operations are FYM, green manure, sheep manure, and household sewage sludge, which reduces the need for inorganic nitrogenous fertilisers and offers a number of additional advantages and improve sustainability and enhance ecosystem services [74, 75].

4. Future Perspectives and Emerging Trends

An increasing awareness of sustainable methods, changing environmental circumstances, and technology breakthroughs are driving substantial changes in agriculture. Agronomy's future is being shaped by these shifts, and a number of significant trends and breakthroughs are developing. The future of agronomy and predictions for developments in agronomic practices point to a greater focus on efficiency and sustainability. It is anticipated that techniques like precision agriculture, which maximise resource usage and reduce environmental effect, would proliferate. The increasing demand from consumers for sustainable and healthful food alternatives is also anticipated to encourage the adoption of organic agricultural methods. Urban and vertical farming are two newer, growing concepts that will probably become more popular. These methods, which use the least amount of area possible to produce the most, provide answers to the problems of urban food security and lack of land.

The implementation of water-efficient irrigation systems and the development of crop types resistant to drought are examples of critical adaptation measures. It is anticipated that climate-smart agriculture, which incorporates both adaptation and mitigation of climate change, would become the foundation for agricultural methods in the future. This strategy minimises the environmental impact of agriculture while ensuring food security. It is anticipated that technological innovation will keep being essential to the development of agronomic techniques. Precision farming methods will be improved by developments in AI, machine learning, and IoT devices, making them more practical and approachable. CRISPR and other gene editing technologies have the potential to completely transform crop breeding. With the use of these technologies, crop varieties with improved nutritional value, disease resistance, and climate resilience might be developed quickly. Furthermore, supply chain management using blockchain and other digital technologies could boost efficiency and transparency in the agriculture industry.

By offering traceability from farm to table, these technologies help improve food safety and quality control.

5. Conclusion

The thorough analysis highlights the revolutionary path of agronomic methods, emphasising the crucial transition from conventional techniques to cutting-edge, technologically driven approaches. As sustainable resource management techniques, precision agriculture, and cutting-edge genetic innovations become more prevalent, agronomy is evolving to meet the growing needs of food security, ecological sustainability, and economic viability. The future direction of agronomy is heavily impacted by technology advancements and the need to adjust to changing climatic conditions. With a focus on the integration of environmental preservation, technological innovation, and socio-economic factors, a multidisciplinary approach is necessary for the future of agronomic practices. In order to support a resilient, sustainable, and productive agricultural environment to meet the demands of a growing global population, this strategic integration is essential.

Disclaimer (Artificial intelligence)

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