

Climate Smart Agriculture: A New Approach for Sustainable Intensification

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Authors' contributions

This work was done in collaboration among all the five authors. Author GS designed the study and wrote the first draft of the manuscript. Authors PPR and SM supervised the study and analyzed the data. Authors SPD and PPP managed the literature search and wrote the final manuscript. All authors read and approved the final manuscript.

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ABSTRACT

World population is increasing day by day and at the same time agriculture is threatened due to natural resource degradation and climate change. A growing global population and changing diets are driving up the demand for food. The food security challenge will only become more difficult, as the world will need to produce about 70 percent more food by 2050 to feed an estimated 9 billion people. Production stability, agricultural productivity, income and food security is negatively affected by changing climate. Therefore, agriculture must change according to present situation for meeting the need of food security and also withstanding under changing climatic situation. Agriculture is a prominent source as well as a sink of greenhouse gases (GHGs). So, there is a need to modify agricultural practices in a sustainable way to overcome these problems. Developing climate smart agriculture is thus crucial to achieving future food security and climate change goals. It helps the agricultural system to resist damage and recover quickly by adaptation and mitigation strategies. Sustainable Intensification is an essential means of adapting to climate change, also resulting in lower emissions per unit of output. With its emphasis on improving risk management, information flows and local institutions to support adaptive capacity, CSA provides the foundations

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for incentivizing and enabling intensification. Since climate smart agriculture is defined along three pillars (productivity increases, building resilience and adapting, and GHG emission reduction), key concepts such as productivity, resilience, vulnerability and carbon sequestration provide indicators for future empirical measurements of the climate smart agriculture concept.

Keywords: Climate Smart Agriculture (CSA); Sustainable Intensification (SI); GHGs; climate change; food security; sustainability.

1. INTRODUCTION

Food systems, from local to global, face a complex set of challenges in the twenty-first century [1]. In addition, food consumption patterns are changing as per the life style of people. Thus, there is an increased competition for land, water, energy, and other inputs for food production. Now a days, climate change is emerging as one of the major threats to agriculture, livelihood and food security of millions of people in many places of the world [2]. At the same time, many current farming practices damage the surrounding environment and as such have been a major source of greenhouse gases (GHGs). Extensive deforestation and land degradation have also reduced the carbon sequestration capacity from the atmosphere. Worldwide, more than a billion of farmers and their families face a great challenge of climate change because agriculture sector is the most vulnerable sector to climate change [3]. This idea makes it clear that Sustainable Intensification (SI) entails increasing food production from existing farmland in various ways that have lower environmental impacts and do not undermine our capacity to continue producing food crops in future. Intensification, without the sustainability focus, has led to numerous problems around the globe [4]. Thus, Climate Smart Agriculture (CSA) helps to deal with these interlinked challenges in a holistic and effective manner. CSA is not a new production system – It is a mean for identifying which production systems and institutions response best to the major challenges of climate change for specific locations and also to maintain and enhance the capacity of agriculture to support food security in a sustainable way.

CSA is an approach to developing the technical, policy and investment conditions to achieve sustainable agricultural development for food security under climate change. The magnitude, immediacy and broad scope of the effects of climate change on agricultural systems create a compelling need to ensure comprehensive integration of these effects into national

agricultural planning, investments and programs. The CSA approach is designed to identify and operationalize sustainable agricultural development within the explicit parameters of climate change [5]. It is defined by three major goals: firstly, increasing agricultural productivity to support increased incomes, food security and development; secondly, increasing adaptive capacity at multiple levels (from farm to nation); and thirdly, decreasing greenhouse gas emissions and increasing carbon sinks (Fig. 1). This approach also aims to strengthen livelihoods and food security, especially of smallholders, by improving the management and use of natural resources and adopting appropriate methods and technologies for the production, processing and marketing of agricultural goods. To maximize the benefits and minimize the tradeoffs, CSA takes into consideration the social, economic, and environmental context where it will be applied. Repercussions on energy and local resources are also assessed. A key component is the integrated landscape approach that follows the principles of ecosystem management and sustainable land and water use. An essential element of CSA is identifying potential synergies and trade-offs between objectives [6]. The concept of Climate Smart Agriculture (CSA) draw attention to linkages between achieving food security and combating climate change through agricultural development, and the opportunities for attaining large synergies in doing so [7]. As a concept, CSA is therefore geared towards guiding the management of agriculture in the era of climate change [8] and achieving food security, while also mitigating climate change and contributing to other development goals [9]. CSA as an approach therefore helps farmers to reduce vulnerability, increase adaptive capacity and to better cope with ex-post risk [7]. CSA integrates climate change into the planning and implementation of sustainable agriculture and informs priority setting. Thus, SI and CSA approaches are complementary, and the degree to which they contribute to global food and nutritional security helps to meet the need of human-being.

2. AGRICULTURE AND SUSTAINABLE DEVELOPMENT GOALS

Feeding the human population sustainably has become an increasing challenge as global populations grow continuously but the resources remain finite. The challenges posed by climate change are as multifaceted as those facing food systems [1]. Climate change is very likely to affect food security at the global, regional and local level. It can disrupt food availability, reduce access to food and affect food quality [10]. It has long been known that increasing climatic variability across space and time, the shifting of rainfall and temperature patterns and increasing frequency of climatic extremes pose challenges for food production. Thus, to overcome the situation, sustainable development goals (SDGs) for food security helps to produce more food by addressing both under and over consumption. Therefore, SDGs are not only tackling food availability but also developing new solutions and approaches to addressing unequal distribution and access to food, changing dietary trends [11] and enabling people to utilize food in safe and nutritious ways. Despite the urgency of the climate-smart agenda, we must be careful not to reduce the priorities of the agriculture and food system for providing food and reducing emissions. The food system must contribute to broader SDGs so that societal needs are met

and environmental limits are avoided at scales that range from global to the individual household; contributing to achieving gender equality, improving health, sustainable use and access to water, meeting energy needs, and conserving biodiversity [1]. SDGs provide technical knowledge on the concepts of sustainable soil management and examines how wide-scale implementation of climate-smart soil and land management practices could enhance climate change adaptation and mitigation.

Most of the GHG emissions of the agricultural sector are directly driven by the use of resources: new land being deforested or turned from grassland to crop land, fertilizers, livestock, energy. Increasing efficiency in the use of resources (i.e. producing more of a given output using less of a given input) is thus key to reducing emissions intensity per kilos of output [12]. It is also key to improve food security, especially in resource scarce areas. Increasing efficiency in the use of resources is also one of the driving principles of CSA. GHG emissions from agriculture are linked to its use of resources. Three production factors have an important influence on total agricultural GHG emissions: (i) area, since converting land into cultivations would require either deforestation or grasslands being converted to croplands, which would induce higher CO₂ emissions;

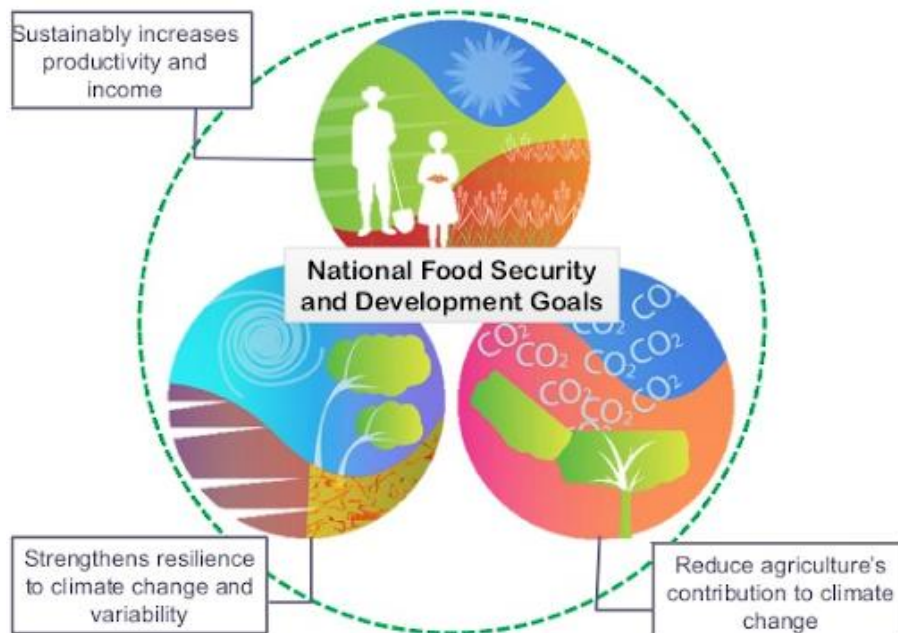


Fig. 1. Goals of climate smart agriculture

(ii) fertilizers, whose production is an important source of CO₂ and which at the field level translate into nitrous oxide emissions; and (iii) livestock, which is an important source of methane and nitrous oxide emissions [13]. Physical capital, such as buildings and machines are also a factor, both directly by energy use and indirectly by their production. Everything else being equal, increasing the efficiency in the use of one of these production factors decreases the emissions intensity of output. As irrigation often demands considerable energy, water efficiency is another key factor for increasing production, adapting to climate change and reducing emissions. Increasing the sustainable intensification of crop production can be done through increasing resource use efficiency and cutting the use of fossil fuels. This saves money for farmers and prevents the negative effect of over-use of particular inputs. Better maintenance of ecosystem services can be accomplished through: adopting agricultural practices that are based on crop rotations, applying minimum tillage and maintaining soil cover; relying on natural processes of predation or biocontrol of pest or weed problems; managing pollination services; selecting diverse and appropriate varieties; and carefully targeting the use of external inputs [14].

3. CLIMATE SMART STRATEGIES

Many agricultural technologies and practices such as minimum tillage, suitable method of crop establishment, nutrient and irrigation management and residue management can improve crop yields, increase nutrient and water use efficiency and reduce greenhouse gas (GHG) emissions [15]. In general, the climate smart agriculture (CSA) options integrate innovative and traditional technologies, practices and services that are relevant for particular location and reduce the effect of climate change and provide the opportunities to stand such changing scenario. Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. CSA identifies synergies and trade-offs among food security, adaptation and mitigation as a basis for informing and reorienting policy in response to climate change. In the absence of such efforts, IPCC projections indicate that agriculture and food systems will be less resilient and food security will be at higher risk. CSA pathways result in higher resilience and lower risks to food security, whereas business as usual leads to higher risks of food security and lower resilience

of food and agricultural systems. The overall aim of CSA is to support efforts from the local to global levels for sustainably using agricultural systems to achieve food and nutrition security for all people at all times, integrating necessary adaptation and capturing potential mitigation.

CSA emphasizes agricultural systems that utilize ecosystem services to support productivity, adaptation and mitigation. Examples include integrated crop, livestock, aquaculture and agroforestry systems; improved pest, water and nutrient management; landscape approaches; improved grassland and forestry management; practices such as reduced tillage and use of diverse varieties and breeds; integrating trees into agricultural systems; restoring degraded lands; improving the efficiency of water and nitrogen fertilizer use; and manure management, including the use of anaerobic bio-digesters. Enhancing soil quality can generate production, adaptation and mitigation benefits by regulating carbon, oxygen and plant nutrient cycles, leading to enhanced resilience to drought and flooding, and to carbon sequestration (Fig. 2). These supply-side changes need to be complemented by efforts to change consumption patterns, reduce waste, and create positive incentives along the production chain [16]. CSA stresses the importance of building evidence to identify viable options and necessary enabling activities. It provides tools for assessing different technologies and practices in relation to their effects on national development and food security objectives under the site-specific effects of climate change.

3.1 Climate Change Adaptation

Climate change will have significant and generally negative impacts on agriculture and growth prospects posing a threat to food access for both rural and urban populations, by reducing agricultural incomes, increasing risk and disrupting markets [17]. As a result of climate change, land degradation and losses in biodiversity, soil has become one of the world's most vulnerable resources [18,19]. Negative impacts can be ameliorated through adaptation, ranging from relatively minor changes in production practices to major, transformative shifts in farming and food systems. Actions to build adaptive capacity are diverse, but an important component entails building ecosystem services in agricultural systems that enhance resilience, through soil, water and plant nutrient management, as well as improved on-farm water

storage and irrigation, access to crop varieties that are more tolerant of heat, droughts, floods and salinity, diversification of farm enterprises [4]. Sustainable intensification also links to adaptation through its effects on farm incomes. Sustainable soil and land management practices that are adapted to the local biophysical and socio-economic conditions providing options for enhancing the interactions among soil, water, livestock and plants. These interactions can prevent, slow or stop soil degradation and mitigate the impacts of climate change [20].

3.2 Climate Change Mitigation

Food systems contribute significantly to global warming and are responsible for 19–29% of global emissions, the bulk of which come directly from agricultural production activities (i.e. N₂O and CH₄) and indirectly from land cover change driven by agriculture (CO₂) [21]. The idea that agriculture should mitigate climate change is controversial because of the sector's importance for food security. Agriculture is projected to be a major source of emissions growth, which threatens future food security [22]. CSA therefore prioritizes food security but also considers the potential and costs of capturing mitigation benefits. Mitigation is leveraged to support food security and adaptation, rather than hampering or harnessing them. However, the SI approach, with its focus on improving efficiency of production, is crucial to achieve the mitigation objective of CSA that is to lower N₂O and CH₄ emissions per unit of output. SI on existing agricultural land is also a major potential source of mitigation by reducing land cover change, particularly of carbon-rich forest and wetlands

[23]. Increased efficiencies due to intensification can increase incentives for expansion [24,25]. Intensification therefore needs to be combined with policies and price incentives to strengthen its impacts on land sparing [26]. This discussion illustrates that for achieving the mitigation objective of CSA, we need to go far beyond the simple goal of intensifying agriculture. Both the SI and CSA concepts recognize this reality [6].

4. CLIMATE SMART AGRICULTURE IN INDIA

Climate change and its variability are emerging as the major challenges influencing the performance of agriculture and its sustainability. Long term changes in shifting weather patterns result in changing climate, which threaten agricultural productivity through high and low temperature regimes, increased rainfall variability and rising sea levels that potentially deteriorate coastal freshwater reserves and increase the risk of flooding. The challenge becomes pronounced in the case of unusual or extreme changes in climate, typified by droughts, floods, heat waves, and so on, the frequencies of which are predicted to increase in the future. Developing countries, like India, are more vulnerable to such shocks because of their heavy dependence on agriculture and lack of technical and financial resources to cope up with them [27]. Climate change (and global warming) impacts all sectors of human life. In this context, Indian Council of Agricultural Research (ICAR) started National Innovations on Climate Resilient Agriculture (NICRA) project to overcome the climate change vulnerability.

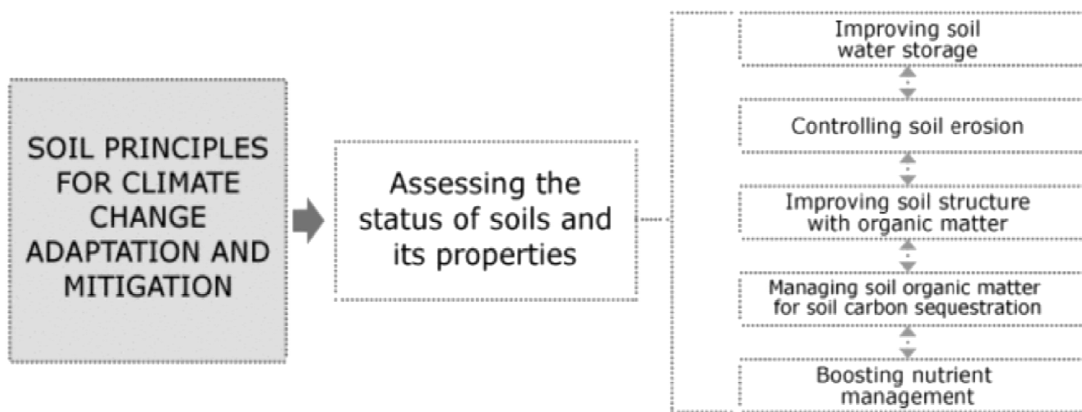


Fig. 2. Soil management principles to enhance climate change adaptation, mitigation and resilience

India is particularly vulnerable to climate change due to widespread poverty, dependence of about 50 per cent of its population on agriculture for livelihood, heavy dependence of agriculture on natural resources and limited coping strategies. Even though the adoption of improved technologies, incorporating high-yielding varieties, fertilizers and irrigation in the mid-1960s was instrumental in achieving unprecedented growth in food grain production and ushering in an era of Green Revolution in Indian agriculture, there are growing concerns on the sustainability of such growth to feed the increasing population in the country [28]. In spite of the success of the Green Revolution technologies in transforming Indian agriculture and making it self-sufficient in food grains, food insecurity, malnutrition, poverty and hunger have been persisting unchecked. Moreover, continued intensive use of the same technologies and the consequent environmental problems, such as groundwater depletion with falling quality of water due to its overexploitation and deteriorating soil health, have been adversely affecting the agricultural sector. Moreover, under climate change, the country will have to import twice the amount of food grains to meet per capita calorie demand when compared to a situation without climate change. Adapting to such climatic changes is critical for ensuring sustainability and stability in crop production in the country and food and livelihood security to farming communities [29]. Thus, Food and Agriculture Organization (FAO) has recognized that agriculture must be 'climate-smart' to achieve these goals. The most challenging task for attaining sustainable agricultural development is to adopt appropriate strategies that enhance CSA. The Consultative Group on International Agricultural Research (CGIAR), in its Research Program on Climate Change, Agriculture and Food Security (CCAFS), has been working with rural communities in collaboration with national programs to develop climate-smart villages (CSV) as models of local actions that ensure food security, promote adaptation and build resilience to climatic stresses [30]. The CSV approach was initiated first in Haryana and Bihar in 2011. In order to minimize the negative effects of climate change and variability and to maximize economic benefits, small landholders have been implementing a range of CSA practices and technologies such as cropping system improvement (e.g. improved crop varieties, diversification, crop rotation and integration of legumes), integrated nutrient management (e.g. green manure, compost and site specific nutrient

management), resource conservation (e.g. minimum/zero tillage), precision water management (e.g. planting crops in bed, laser land levelling, mulching with crop residues) and agro-forestry as measures of adaptation to climate change and variability [31]. CSA practices/technologies have helped small farmers in the Indo-Gangetic Plains of India achieve higher productivity and income than the levels they would have without these practices. This suggests that scaling out of such practices and technologies in other regions would provide economic benefits to farmers and help them reduce the adverse impacts of climate change and variability. CSA technologies and practices used in various regions of India under the CGIAR's CCAFS program have helped farmers achieve higher crop yields, farm incomes and input-use efficiency with lower GHG emissions. A successful switch to smart farming will largely depend on adoption of the smart technologies and the availability of institutional credit [32]. Increasing the targeting of financing to smart farming practices/technologies by linking climate finance to traditional agricultural finance could be an important step towards making agriculture more sustainable and a viable source of livelihood and food security for millions of farmers in the country.

5. EVOLUTIONARY CONCEPTS LINKED WITH CLIMATE SMART AGRICULTURE AND SUSTAINABLE INTENSIFICATION

In agriculture, as elsewhere, popular discourse has a limited shelf-life, as a combination of critique and theoretical evolution drive us to adopt new terminology to describe our ambitions and visions for agricultural development. Perhaps reflecting the growing prominence of climate change within environmental agendas, as well as need for attention to be paid to the adaptive capacities within agricultural production to environmental change, the paradigm of CSA has a great importance. Climate smart agriculture is defined as an approach that simultaneously focuses on, or achieves, increases in agricultural yields, improved resilience or adaptation to climatic changes and variability, and reductions in agricultural greenhouse gas emissions [27,33]. In application, climate smart agriculture tends to place emphasis on new technologies and techniques, such as improved seed varieties, conservation agriculture, alternate wetting and drying rice production, precision fertilizer, etc., all

of which have histories that long precede the adoption of the CSA label. CSA builds on existing experience and knowledge of sustainable agricultural development. Sustainable intensification (SI) is a cornerstone, as more efficient resource use contributes to adaptation and mitigation via effects on farm productivity and incomes as well as reduced emissions per unit of product. Sustainable intensification on existing agricultural land has considerable mitigation potential by reducing the conversion of forest and wetlands, although additional protection measures may be required [3]. The CSA approach builds upon the concepts, technologies and experience of sustainable agriculture, but explicitly focuses on integrating the impacts of unprecedented climate change. CSA involves building recommendations and possible options for reorienting existing sustainable agricultural strategies to respond to changing conditions, as well as to provide innovative policy and financing tools to implement them.

An important foundation of CSA is the sustainable agriculture concept which is in itself part of the larger concept of sustainable development; a development strategy that aims to ensure that future generations would not be worse off compared to the present generation. Sustainable development in itself contains three key elements; economic, social, and environmental. [8] emphasize that CSA as a concept integrates the specificities of climate change adaptation and mitigation into sustainable agricultural development policies, programs and investments. Hence CSA strategies and practices have conceptual links and adhere to the general principles that underpins sustainable agriculture processes and food systems such as; improvements in the efficiency of resource use, conservation, protection and enhancement of natural resources, protection and improvement of rural livelihoods, and responsible and effective governance mechanisms. Additionally, CSA also embeds the objectives of agricultural development of increasing food security through increases in productivity and incomes. [8], however argue that as a concept, CSA is not intended to provide a new set of sustainability principles, but rather a means of incorporating the specificities of adaptation and mitigation into sustainable agricultural development policies, programs and investments. CSA strategies and practices should therefore be in adherence to the principles that underpin sustainable agriculture

and food systems such as (1) improving the efficiency of resource use, (2) conserving, protecting and enhancing natural resources, (3) protecting and improving rural livelihoods, (4) enhancing resilience of people, ecosystems and communities and (5) responsible and effective governance mechanisms. Additionally, CSA underpins some concepts in resource economics such as conservation technologies that enhance input use efficiency and reduce pollution, introduction of strategies that include resilience and ability to withstand environmental risk, adoption of recycling technologies and transition from non-renewable to renewable technologies [34].

CSA shares many objectives and guiding principles with green economy and sustainable development approaches, including a prioritization of food security and a desire to preserve natural resources [14]. CSA is also closely linked to the concept of sustainable intensification [35,36]. In many cases, [30] argues that sustainable intensification constitutes a subset of practices that are potentially climate smart under certain current and future climatic conditions. However, CSA extends the sustainable intensification concepts through a more progressive dimension, more concern about future potential changes and the need to be prepared for them. Thus, CSA is not a set of new agricultural practices or a new agricultural system [35]. Instead, it is understood as a new approach to guide necessary changes to agricultural systems in order to jointly address challenges of food security and climate change [13,29].

6. IMPLEMENTATION OF CLIMATE SMART AGRICULTURE

The development and application of problem-oriented approaches to adaptation planning have considerable potential in identifying robust actions in the face of uncertainty [21]. Synergies among global, regional and local studies can also be exploited [37]. Tools are needed for evaluating the adaptation and mitigation potential of different policies and technologies from local to global scales, covering the impacts of both extreme events and slow-onset changes on agriculture and food security, assessing means of increasing resilience in agriculture and food systems, and identifying options for, and costs of reducing emission growth. CSA strengthens national and local institutions to support adaptive capacity through enhancing people's access to

assets, including information. CSA practices may require that farmers have access to specific inputs, such as tree seedlings, seeds or fertilizers. Lack of such inputs constrains widespread adoption. Timely access to fertilizer is a key determinant of productivity and efficient resource use, but is often lacking [38]. Fertilizer helps to achieve all of CSA's "triple wins"-increasing agricultural productivity; adapting and mitigating agriculture to climate change realities; and achieving global food security. National public, private and civil society stakeholders have key roles in reducing information costs and barriers. In addition to strengthening the capacities of extension systems to disseminate site-specific information, tools such as radio programs and information and communications technologies (ICTs) can be used [33].

CSA adds additional importance to efforts and innovation aimed at uptake of new technologies and practices by smallholders, in particular behavioral change communication so that sustainable and feasible solutions can reach scale. In this context, as in others, CSA needs to be integrated into best practices around farmer and community engagement as emphasized across feed the future. CSA confirms best practices around integration, sustainability, program learning and management, and especially around managing risks. Risk reduction could be its strongest selling point to farmers [39]. Climate change strategies envision increases in emissions associated with economic development while still looking for opportunities for reducing their growth, and agriculture and food security are no exception. Although there may be some instances where absolute reductions are possible, in many instances achieving our hunger, poverty and nutrition goals will require pathways that lead to emissions increases [7]. Feed the future programs should thus consider opportunities to promote efficiencies or enhance carbon sinks in ways that reduce emissions growth as part of an overall approach that is acceptable and likely to be adopted by smallholder farmers. Developing and deploying climate smart elements of agricultural systems will, like other innovation strategies, reflect a range of factors that reflect context and the priorities of farming households, communities and actors across the agri-food system. Feed the future programs should endeavour to provide them with the best, most relevant information about considerations, pre- and post-harvest, that foster climate resilient, resource-efficient and sustainable production systems [40].

7. CONCLUSION

The concept of CSA is becoming a booming topic in agricultural development and climate change communities. It emerges as a promising package to secure food for the growing world population exposed to climate uncertainty and increasing food demand. Many of the CSA interventions continue to focus on the development and diffusion of technological packages to increase the productivity of smallholder farmers. A growing body of literature suggested that technology-oriented interventions alone may not be enough to achieve sustainable agricultural transformation. The 'Sustainable Intensification' (SI) approach and 'Climate Smart Agriculture' (CSA) are highly complementary. The main difference is the focus in CSA on outcomes related to climate change adaptation and mitigation. SI is crucial to both adaptation and mitigation. All cases of CSA invariably turn out to be the cases of SI. A climate justice perspective necessitates action to assist resource-poor farmers who are most affected by climate change but have contributed least to it, so that developing countries can enhance their food security and speed their economic growth. Identifying appropriate ways to incentivize the uptake of climate smart alternatives is a key priority. An integrated, evidence-based and transformative approach to addressing food and climate security at all levels requires coordinated actions from global to local levels, from research to policies and investments, and across private, public and civil society sectors to achieve the scale and rate of change required. With the right practices, policies and investments, the agriculture sector can move onto CSA pathways, resulting in decreased food insecurity and poverty in the short term while contributing to reducing climate change as a threat to food security over the longer term.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Whitfield S, Challinor AJ, Rees RM. Frontiers in climate smart food systems:

- Outlining the research space. *Frontiers in Sustainable Food Systems*. 2018;2:1-5.
2. IPCC. Summary for policymakers. Climate change impacts, adaptation and vulnerability. Part A: Global and Sectoral Aspects. In: Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press. 2014;1-32.
 3. Garnett T, Appleby MC, Balmford A, Bateman IJ, Benton TG, Bloomer, P, Burlingame B, Dawkins M, Dolan L, Fraser D. Sustainable intensification in agriculture: Premises and policies. *Science*. 2013;341: 33-34.
 4. Bennett EM, Carpenter SR, Gordon L, Ramankutty N, Balvanera P, Campbell BM, Cramer W, Foley J, Folke C, Karlberg L. Resilient thinking for a more sustainable agriculture. *Solutions in Press*; 2014.
 5. Newell P, Taylor OG. Contested landscapes: The global political economy of climate smart agriculture. *Journal of Peasant Studies*. 2018;45(1):108-129.
 6. Campbell BM, Thornton P, Zougmore R, Van Asten P, Lipper L. Sustainable intensification: What is its role in climate smart agriculture? *Current Opinion in Environmental Sustainability*. 2014;8:39-43.
 7. Lipper L, McCarthy N, Zilberman D, Asfaw S, Branca G. Climate smart agriculture: Building resilience to climate change. Springer International Publishing; 2018.
 8. Lipper L, Zilberman D. A short history of the evolution of the climate smart agriculture approach and its links to climate change and sustainable agriculture debates. In Lipper, L., McCarthy N., Zilberman, D., Asfaw, S., and Branca, G., Editors, *Climate Smart Agriculture: Building Resilience to Climate Change*. Springer International Publishing, Cham. 2018;13-30.
 9. Verhagen J, Vellinga T, Neijenhuis F, Jarvis T, Jackson L, Caron P, Torquebiau E, Lipper L, Fernandes E, Mensa RE, Vermeulen S. Climate-smart agriculture - Scientists' perspectives; 2014.
 10. Brown ME, Antle JM, Backlund P, Carr ER, Easterling WE, Walsh MK, Ammann C, Attavanich W, Barrett CB, Bellemare MF, Dancheck V, Funk C, Grace K, Ingram JSI, Jiang H, Maletta H, Mata T, Murray A, Ngugi M, Ojima D. Climate change, global food security and the U.S. food system. *USDA*. 2015;146.
 11. Tilman D, Clark M. Global diets link environmental sustainability and human health. *Nature*. 2014;515:518–522.
 12. Mullins J, Zivin JG, Cattaneo A, Paolantonio A, Cavatassi R. The adoption of climate smart agriculture: The role of information and insurance under climate change. In Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S., and Branca, G., Editors, *Climate Smart Agriculture: Building Resilience to Climate Change*. Springer International Publishing, Cham. 2018;353-383.
 13. Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M, Caron P, Cattaneo A, Garrity D, Henry K, Hottle R, Jackson L, Jarvis A, Kossam F, Mann W, McCarthy N, Meybeck A, Neufeldt H, Remington T, Sen PT, Sessa R, Shula R, Tibu A, Torquebiau EF. Climate-smart agriculture for food security. *Nature Climate Change*. 2014;4(12):1068–1072.
 14. Jayne TS, Sitko NJ, Mason NM, Skole D. Input subsidy programs and climate smart agriculture: Current realities and future potential. In Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S. and Branca, G., Editors, *Climate Smart Agriculture Building Resilience to Climate Change*. 2018;251–273.
 15. Sapkota TB, Jat ML, Aryal JP, Jat RK. Climate change adaptation, greenhouse gas mitigation and economic profitability of conservation agriculture: Some examples from cereal systems of Indo-Gangetic Plains. *Journal of Integrative Agriculture*. 2015;14(8):1524-1533.
 16. Parfitt J, Barthel M, Macnaughton S. Food waste within food supply chains: Quantification and potential for change to 2050. *Phil. Trans. R. Soc. B*. 2010;365: 30165-3081.
 17. Vermeulen SJ. Climate change, food security and small-scale producers. *CCAFS Info Brief*. CGIAR Research Program on Climate Change, Agriculture and Food Security; 2014.
 18. FAO & Intergovernmental Technical Panel on Soils (ITPS). Status of the World's Soil Resources (SWSR) - Main Report. Rome; 2015a.
 19. FAO & ITPS. Status of the World's Soil Resources (SWSR) - Technical Summary. Rome; 2015b.

20. Lal R. Soil carbon management and climate change (book); 2013.
21. Vermeulen SJ, Campbell BM, Ingram JSI. Climate change and food systems. *Annu. Rev. Env. Resour.* 2012;37:195–222.
22. Dercon S, Christiaensen L. Consumption risk, technology adoption and poverty traps: Evidence from Ethiopia. *J. Dev. Econ.* 2011;96:159–173.
23. Wollenberg E, Campbell BM, Holmgren P, Seymour F, Sibanda L. Actions needed to halt deforestation and promote climate smart agriculture. CGIAR Research Program on Climate Change, Agriculture and Food Security; 2011.
24. Ewers RM, Scharlemann JPW, Balmford A, Green RE. Do increases in agricultural yield spare land for nature? *Global Change Biol.* 2009;15:1716-1726.
25. Rudel TK, Schneider L, Uriarte M, Turner II, DeFries BL, Lawrence R, Geoghagen D, Hecht J, Ickowitz S, Lambin AEF. Agricultural intensification and changes in cultivated areas. *PNAS.* 2009;106:20675-20680.
26. Angelsen A, Kaimowitz D. Agricultural technologies and tropical deforestation. CABI Publishing; 2000.
27. Lal R, Delgado J, Groffman P, Millar N, Dell C, Rotz A. Management to mitigate and adapt to climate change. *J. Soil Water Conserv.* 2011;66:276–285.
28. Ghosh M. Climate-smart agriculture, productivity and food security in India. *Journal of Development Policy and Practice.* 2019;1-22.
29. FAO. The state of food security and nutrition in the World 2017: Building resilience for peace and food security. Rome: Food and Agriculture Organisation of the United Nations; 2017.
30. Aggarwal P, Zougmore R, Kinyangi J. Climate-smart villages: A community approach to sustainable agricultural development. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), Copenhagen, Denmark; 2013.
31. Khatri-Chhetri A, Aggarwal PK, Joshi PK, Vyas S. Farmers' prioritization of climate-smart agriculture (CSA) technologies. *Agricultural Systems.* 2017;151:184–191.
32. Dadhich CL. Problems and perspectives of financing of smart agriculture in India. In K. R. Gupta and V. B. Angadi (Eds.): *Smart Farming – Problems and Prospects.* 2017;11–25.
33. Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M. Climate-smart agriculture for food security. *Nat. Clim. Chang.* 2014;4:1068–1072.
34. Zilberman D. Conclusion and policy implications to “Climate Smart Agriculture: Building Resilience to Climate Change”. In Lipper, L., McCarthy, N., Zilberman, D., Asfaw, S., and Branca, G., Editors, *Climate Smart Agriculture: Building Resilience to Climate Change.* 2018;621–626.
35. FAO. Climate-smart agriculture sourcebook. Food and Agriculture Organization of the United Nations; 2013.
36. Campbell BM, Thornton P, Zougmore R, Van Asten P, Lipper L. Sustainable intensification: What is its role in climate smart agriculture? *Current Opinion in Environmental Sustainability.* 2014;8:39–43.
37. Challinor A, Martre P, Asseng S, Thornton P, Ewert F. Making the most of climate impact ensembles. *Nature Clim. Change.* 2014;4:77–80.
38. Duflo E, Kremer M, Robinson J. Nudging farmers to use fertilizer: Theory and experimental evidence from Kenya. *Am. Econ. Rev.* 2011;101(6):2350–2390.
39. Campbell BM, Vermeulen SJ, Aggarwal PK, Corner-Dolloff C, Girvetz E, Loboguerrero AM, Ramirez-Villegas J, Rosenstock T, Sebastian L, Thornton P. Reducing risks to food security from climate change. *Glob. Food Security.* 2016;11:34–43.
40. Engel S, Muller A. Payments for environmental services to promote “climate-smart agriculture”? Potential and challenges. *Agric. Econ. (UK).* 2016;47: 173–184.

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