Available online at www.climatechangejournal.org

DOI: http://dx.doi.org/10.18782/2583-4770.121

ISSN (E): 2583 – 4770

Emrg. Trnd. Clim. Chng. (2023) *2*(1), 11-26

Review Article

Emerging Trends in Climate Change

Peer-Reviewed, Refereed, Open Access Journal

Addressing Challenges of Indian Agriculture with Climate-Smart Agriculture Practices

Badal Verma[1*], Muskan Porwal[2], K.K. Agrawal[3], Karishma Behera[4], Vyshnavi RG[5] and Ashish Kumar Nagar[6]

[1,2,3]Department of Agronomy, [4]Department of Genetics and Plant Breeding,
[5]Department of Plant Physiology, [6]Department of Extension Education,
College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (MP) 482004
*Corresponding Author E-mail: badalv82282@gmail.com

Received: 27.12.2022 | Revised: 21.02.2023 | Accepted: 9.03.2023

ABSTRACT

Agriculture in developing nations needs significant transformation to solve the interconnected concerns of guaranteeing food security and mitigating climate change. In order to keep up with consumer demand, agricultural production needs to rise by at least 70% by 2050, according to forecasts based on growing populations and food consumption patterns. The majority of estimates also show that in some regions with already high levels of food insecurity, climate change is likely to diminish agricultural productivity, production stability, and incomes. Thus, creating climate-smart agriculture is vital to accomplishing long-term objectives for both food security and combating climate change. This paper outlines a strategy to address the various agricultural challenges that originated due to climate change and how Climate Smart Agriculture (CSA) and its pillars are necessary to overcome these challenges. The paper attempts to present a variety of methods, ideas, and technologies targeted at increasing the resilience and productivity of agricultural production systems while also reducing and removing greenhouse gas emissions. CSA methods are viewed as environmentally beneficial and contribute to sustainably increasing productivity with minimal impact on resources and ecosystems. Some of these practices include no-till, reduced-till, intercropping, integrated pest management, rainwater harvesting, use of information and communication technology, etc. Also, women play a crucial role in the agriculture sector and are particularly at risk from climate change than males, so it is important to implement a gender-responsive strategy which contributes to reducing the disparity between men and women in the agricultural sector.

Keywords: *Agricultural production, Climate change, Climate smart practices, Food Security, Global warming.*

Cite this article: Verma, B., Porwal, M., Agrawal, K. K., Behera, K., Vyshnavi, R. G., & Nagar, A. K. (2023). Addressing Challenges of Indian Agriculture with Climate Smart Agriculture Practices, *Emrg. Trnd. Clim. Chng. 2*(1), 11-26. doi: http://dx.doi.org/10.18782/2583-4770.121

INTRODUCTION

Global hunger and food insecurity have risen in the past few years following a lengthy period of decline. Undernourishment is particularly prevalent in India, where it is estimated that most of the population is malnourished. The total amount of undernourished persons in India has grown more in six years, owing in part to fast-growing populations (FAO et al., 2018). Current Indian population trends forecast an additional doubling of the population by 2050, creating an urgent need to produce more food and enhance food security and nutrition, particularly for small farmers. Most rural households grow their own food but are typically more vulnerable to food insecurity than their urban counterparts.

The effects of climate change and rising food demand present threats to global food security (IPCC, 2014). Smallholder farmers in poor nations, who are the most sensitive to climate change but also provide 70% of the world's food needs, are already struggling due to these impacts (Campbell & Thornton, 2014; & FAO, 2013). Agriculture productivity has been poor and stagnant during the past few decades, especially in smallholder production systems (FAO, 2015). Due to shifting rainfall patterns and an increase in the frequency of extreme events like droughts and floods, productivity has, in some cases, already begun to decline. In comparison to a counterfactual without climatic trends, yields for important food crops like rice (Verma et al., 2022; & Shukla et al., 2022), maize (Sairam et al., 2023), and wheat (Sahu et al., 2022; & Tanisha et al., 2022) have already fallen by an estimated 3.8% and 5.5%, respectively (Lipper et al., 2014). Agriculture's ability to help millions of poor rural families escape poverty is in danger. Smallholder farmers are the group most at risk from climate change because they lack the financial, technical, and political resources to support adaptation initiatives. Smallholder farmers are helpless to address the issues brought on by a changing environment without access to information, technology, markets, financing, institutional support, and possibilities for decision-making. Thus, farmers need an integrative approach to mitigate ongoing climate change and adapt to its consequences without compromising food security (Wiederkehr et al., 2018).

The climate-smart agriculture approach advocates incorporating climate change into the preparation and execution of sustainable agricultural strategies, thereby recognizing synergies and trade-offs inside the three pillars of CSA (food security, adaptation, and mitigation) in favour of climate change-related decisions and policies (Nagothu et al., 2016). According to its definition, CSA strives to assist activities that increase food and nutrition security, therefore absorbing critical adaptation and mitigation strategies (Chandra et al., 2018). It offers enabled methods for evaluating the consequences of various technologies and practices, particularly national development and food safety goals under changing climate conditions. Furthermore, CSA incorporates environmentally friendly agricultural expertise and participatory community-driven approaches (Ongoma et al., 2017), with effective intensification as the fundamental foundation of on-farm income and productivity, in addition to existing agricultural land protection strategies. CSA also emphasizes the adoption of low-income farming methods such as conservation agriculture, agroecology, ecosystem services, small-scale irrigation, aquaculture and agroforestry systems, soil/water conservation and nutrient management, integrated crops, livestock, landscape approaches, grassland and forestry management, best practices for reducing tillage and breeds, all in order to improve food productivity, adaptation, and mitigation measures.

Climate Change and Its Impacts on Agriculture

General weather patterns over a large area and for an extended period of time are referred to as "climate". Temperature, precipitation, and humidity are factors that are taken into account by both weather and climate. Climate change is defined as a change in the climate that can be directly or indirectly linked to human activities and that goes beyond the natural climate variability that has been documented across comparable time periods (UNFCC, 2011). Although the weather has always been unpredictable, agriculture is now significantly more vulnerable due to the fast-changing climate. Due to the changing climate, there is a larger impact on Indian agriculture (**Table 1**). Significant rising trends in surface air temperatures, including nighttime temperatures and extreme precipitation occurrences, were found by analyzing historical climate records from the nation. Rainfall across all of India does not exhibit any notable trends. However, there are notable regional trends and sub-seasonal rainfall. The surface air temperatures, particularly nighttime temperatures, are anticipated to continue rising, according to the climate model forecasts based on IPCC ARSCMIP5 models (Vuren et al., 2009).

In the future, planning for adaptation to climate change should incorporate the revised climatic projections. One of the most important climate systems in the atmosphere's general circulation is the Indian monsoon. During the southwest monsoon season, the nation receives more than 80% of its annual rainfall during a period of about four months (June to September). The agricultural industry is significantly impacted by the yearly fluctuations in the season's start, end, total amount of rainfall, and distribution. The Earth's surface has warmed over the past 100 years, and there is now indisputable proof that this warming is primarily due to human activities. Changes in a variety of precipitation-related factors, including snow cover, sea ice, extreme weather occurrences, etc., have also been noted. These changes, however, revealed notable regional disparities. Each plant variety has an ideal temperature for vegetative growth, with growth declining as temperatures rise or fall. The Indian summer monsoon may be one of the localized effects of global warming. Similarly, a plant will not reproduce in a range of temperatures.

Table1. Consequences of climate change in Indian agriculture

Parameters	Impact	References
Production and Quality	Reduced crop yields due to increased concentration of CO_2 and temperature. C/N ratio increases which decreases grain density	Damatta et al., 2010; Nardone et al., 2010; Bisbis et al., 2018
Soil	Soil becomes drier due to increased temperature and increased ET losses, which reduces productivity, results in more soil erosion and release more carbon from the soil	Porcal et al., 2009; Jones et al, 2009
Irrigation	Increased demand for water and reduced supply of water which is creating a scarcity of water resources	Seckler, 1996; Doll, 2002; Zhou et al, 2010
Pests	Increased ranges and populations of pests and diseases due to adverse climatic conditions	Das et al., 2011; Skendžić, et al., 2021; Rosenzweig et al., 2001; Pareek et al., 2017
Livestock	Abiotic stresses such as heat stress increases the incidence of diseases like Foot and Mouth Diseases in cattle	Baumgard et al., 2012; Kaffenberger et al., 2017;
Fishery	Climate change adversely affects the abundance and spawning of fishes	Graham & Harrod, 2009; Munday et al., 2008; Moyle et al., 2013; Stenevik & Sundby, 2007.
Economic Impact	Reduced agricultural output due to increased pest and disease outbreak	Ju et al., 2013; Aydinalp & Cresser, 2008; Mahato, 2014.

Climate Smart Agriculture

The idea of climate-smart agriculture (CSA) is pertinent in this situation. Agricultural strategies that sustainably boost agricultural production and system resilience while lowering greenhouse gas emissions are known as climate-smart agriculture (Venkatramanan & Shah, 2019). There is evidence that top-down command and control systems for the diffusion of technology do not result in long-lasting change. CSA is strongly promoted as the next generation of Indian agriculture and an adaptable answer to climate change. Because agriculture is still vital to growth, CSA offers the potential to boost productivity and resilience while reducing the vulnerability of India's hundreds of millions of small-scale farmers (Azadi et al., 2021). By improving the productivity of precious inputs like manpower, seeds, and fertilizers, CSA may directly help smallholder farmers while also boosting food security and creating new options for revenue generation (Aryal et al., 2020). CSA contributes to the preservation of natural resources for future generations by preserving ecosystems and landscapes.

The original meaning of CSA, adopted by FAO, defines three goals in the framework of landscapes and food systems: (1) increasing agricultural productivity sustainably to support suitable growth in farm incomes, food security, and development; (2) adapting and developing resilience to climate change at different scales (from farm to national); and (3) reducing or eliminating greenhouse gas emissions from agricultural operations, which spans environments, animals, and people (Thakur & Uphoff, 2017). A strategy called CSA seeks to accomplish various arrangements of these goals that are pertinent to the local situation. It integrates policies, institutions, investments, behaviours, technology, and practices at many levels (Makate, 2019). Several tools and strategies have been developed in recent years to assess a given intervention's "CSA-ness." However, recent analyses have revealed the shortcomings of present studies, particularly when evaluating the adaptation and mitigation pillars in the context of smallholder farming in low- and middle-income countries (LMICs).

This study investigates whether CSA, as it is currently administered, addresses the problems that farmers are experiencing due to climate change and efficiently reaches its stated goals. we evaluate the current climate scenario tools for evaluating smart agriculture, emphasizing smallholder household levels in countries with low and middle incomes. We also make an effort to pinpoint any extra side effects that CSA interventions may have, as well as how they address social and gender inequality. Key success factors and obstacles to CSA intervention uptake are also looked at.

Why Climate Smart Agriculture

Climate-smart agriculture (CSA) contributes to the resolution of several major issues:

1. CSA addresses food security, inequity and malnutrition

Despite the focus placed on the development of agriculture and food security in recent years, there are still more than 800 million people globally who are undernourished and a billion more who are malnourished. At exactly the same time, one-third of all generated food goes to waste, and over 1.4 billion persons are overweight. By 2050, it is expected that there will be 9.7 billion people on Earth. (2015) (United Nations). World patterns of food intake are drastically changing at the same time; for instance, the desire for diets high in meat is being driven by increased income. By 2050, it is predicted that we will need 60% more agricultural output if current consumption trends and food waste habits continue. CSA lessens global food waste while improving food security for underprivileged and marginalized communities.

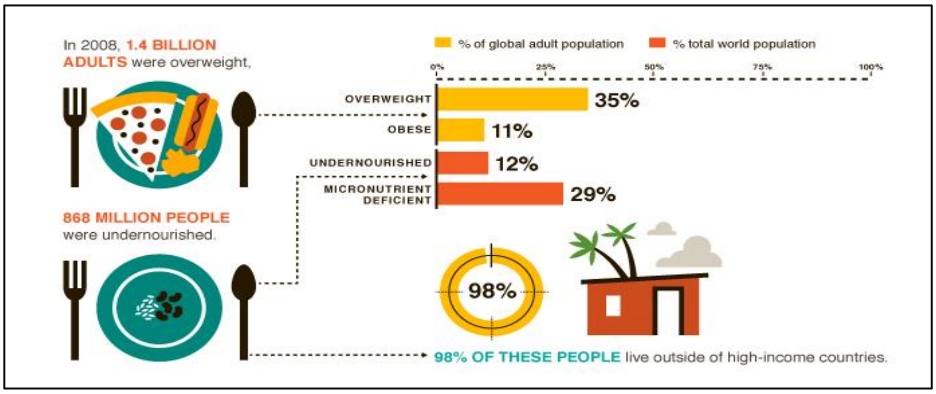

Figure1. Food security, inequity and malnutrition

2. CSA addresses the relationship between agriculture and poverty

For many individuals in developing nations, agriculture is their main source of nutrition, employment, and income. In fact, according to Lipper et al. (2014), approximately 75 per cent of the world's poor reside in rural areas and depend heavily on agriculture for their livelihood. Agriculture is thus uniquely positioned to help people escape poverty. Agricultural growth is frequently the most efficient and fair method of both decreasing poverty and boosting food security.

3. CSA addresses the relation between climate change and agriculture

Worldwide mean temperatures are increasing due to climate change, and the coming years are predicted to be hotter and more unpredictable. This subsequently, in turn, will have an impact on the amount, location, and timing of precipitation. The severity and frequency of extreme weather events like hurricanes, floods, heat waves, snowstorms, and droughts will rise as a result of these shifts combined. They might upset whole ecosystems and cause salinization and sea level rise. These alterations will have significant effects for agriculture, forestry, and fisheries.

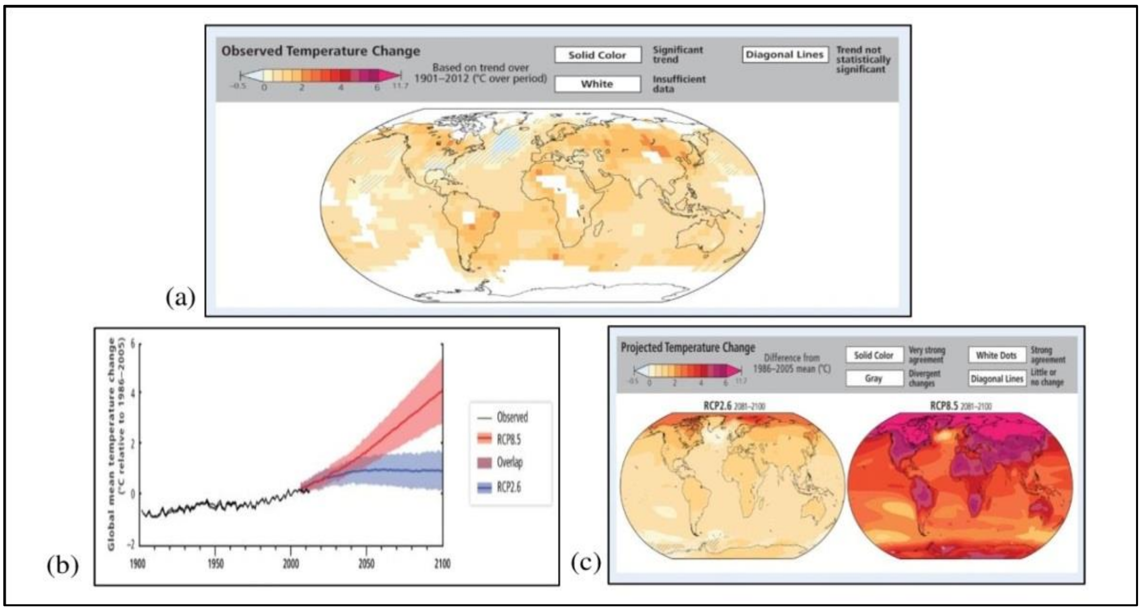

Figure2. Observed and projected changes in annual average surface temperature

Because different crops and animals flourish in different conditions, the agriculture sector is especially vulnerable to climate change. Agriculture is so heavily reliant on constant temperature ranges and water availability, both of which are threatened by climate change. Furthermore, plant pests and diseases are projected to grow in frequency and spread into new areas posing additional difficulties to agricultural productivity (Mishra et al., 2022).

Climate change and the way it affects agriculture have a tremendous impact on the agricultural sector, making the relationship among the two mutual. Forestry, land use change, and agriculture account for 19 to 29% of global GHG emissions. This number increases to 74% when referring to the least developed nations (Vermeulen et al., 2012). Agriculture will be responsible for 70% of all GHG emissions that can be released if temperature increases are kept to 2°C if agricultural emissions are not curtailed (fig. 3). The cost-effectiveness of the mitigation alternatives established in the energy, transportation, and forestry sectors are comparable to those offered in the agricultural sector.

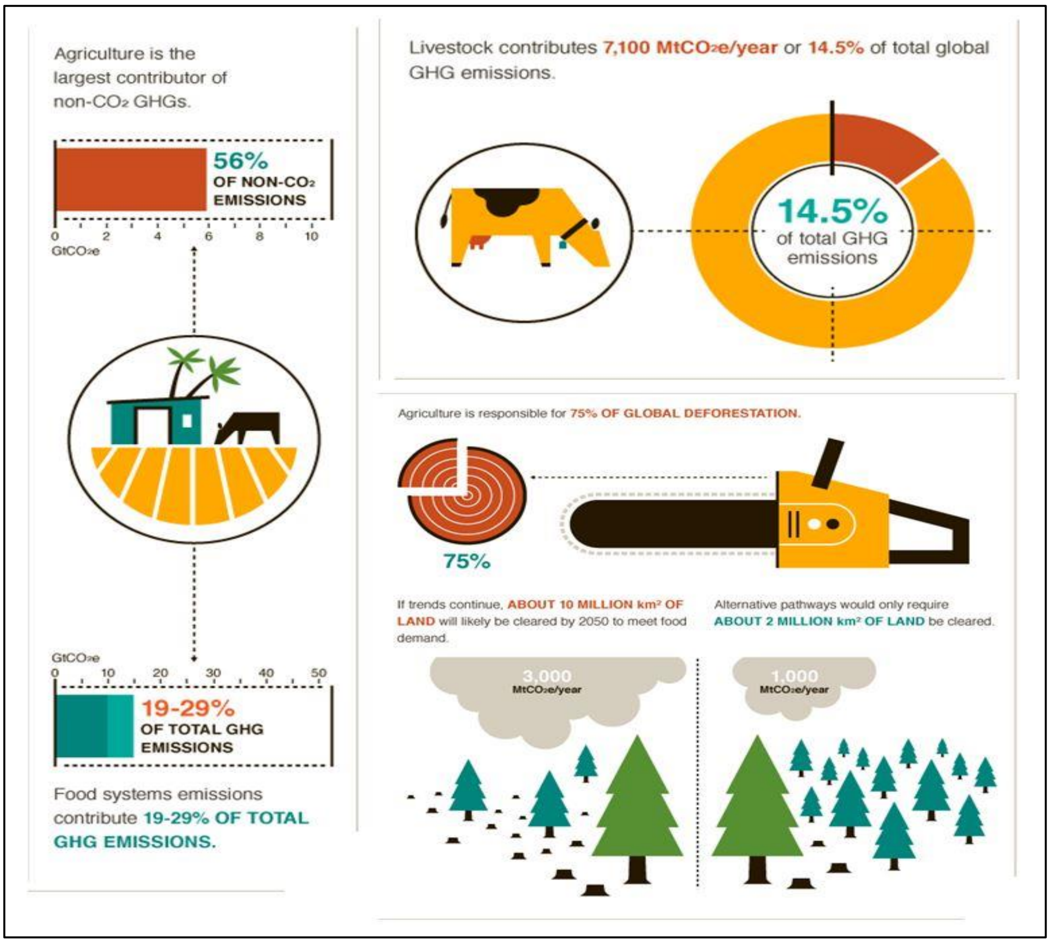

Figure3. Agricultural greenhouse gas emissions

THREE PILLARS OF CSA

Our evaluation technique for present CSA assessment methodologies is based on each of the three CSA pillars: food productivity, adaptation, and mitigation. This part discusses our strategy and the decisions adopted to conduct an appropriate and comparative evaluation of the individual tools. We examine the individual pillars independently in the system, even if we understand this structure can be somewhat artificial sometimes. The concept of "sustainability," for example, has substantial ramifications and difficulties for both the productivity and adaptation pillars, while the environmental element of sustainability may be further examined under the mitigation pillar.

Pillar 1: Food Productivity

This pillar is typically converted into productivity quantification (as defined by FAO). However, relying entirely on manufacturing ignores two crucial pillar components: (1) It is unduly simplistic to equate food security and productivity (as well as one of its key indicators, nutrition) to output. Many instances in the literature imply that increased crop output reduces food security and even famine (such as the fact that introducing a more profitable crop may result in a decline in crop diversity) (Fraval et al., 2019). According to Campbell et al. (2016), CSA should look beyond production to other issues of food security. The productivity pillar concept expressly indicates that increases in food security and productivity increase the need for sustainability, but it fails to clarify how this should be quantified. Pretty et al. (2011) discovered over 100 distinct concepts of sustainability, but in general universal characteristics of sustainable agriculture (which we concentrate on in this study) involve the production of food and nourishment for current as well as future requirements, the capacity to produce the desired results over a longer duration of time, i.e., decades, resilience (ability to absorb or recover from climate shocks and stresses), and environmental sustainability. Agricultural sustainability concepts have traditionally lacked specificity, yet there has recently been an increase in the effort to create indicators and measurements to make generic concepts actionable in a given setting. One example of such research is the sustainable intensification (SI) evaluation framework, which looks at five different aspects (i.e., productivity, social, human, economics, and environment), as well as other multidimensional strategies like the Five Capitals (Karanja et al., 2016). As an outcome, we will move beyond the basic approach of associating food security with output amount and study how production translates into food and nutrition security. Thus, sustainability includes numerous aspects that exist in the remaining pillars, emphasizing the difficulty of simply splitting the CSA "cake" into three discrete pillars. Key traits such as "resilience" will, of course, be properly defined in the "adaptation" pillar and are unlikely to be discussed in the "productivity" pillar. On the other hand, ecological footprints and ecosystem services are classified as productivity instead of mitigation. However, it is clear that opinions on how to differentiate the three pillars could vary.

Pillar 2: Adaptation

The researchers discovered that the concept of adaptation is inadequately defined in many investigations, with the terms "coping" and "adaptation" being used interchangeably. To determine whether the frameworks can handle both, we will look at "short-term adaptation," which reflects coping mechanisms for dealing with single-year weather anomalies, price volatility, and associated dangers. We will also investigate "long-term adaptation" in response to the steadily changing climate, such as modifying cropping systems, management, or crop variety utilization. Wiederkehr et al. (2018) make an important proposal that the comparability of many local case study results be improved in order to derive relevant and generalizable conclusions about climate change adaptation and possible technology adoption. "Basic socioeconomic characteristics of the study population (age mean/range and sex ratio of interviewees, ethnic background, economic status of households, e.g., farm size or the number of livestock, and the number of household members) are known to be important factors influencing the coping and adaptation behaviour of households" and not only relevant for the adaptation pillar. As a result, but it is also critical to collect such data across all studies and create a reliable "adoption indicator." In this section of the evaluation, we will see if the assessment frameworks discriminate technologies, farms, and households in a way that informs their ability to adopt specific coping and adaptation measures ("adoptability").

Pillar 3: Mitigation

Mitigation is a key pillar of CSA, and it aims to reduce the environmental (climate) footprint of food production because

a) Agriculture is the most important driver of environmental degradation globally,
b) Agriculture is a major source of anthropogenic GHGs, particularly in LMICs, and
c) Agriculture can benefit a variety of ecosystem services (e.g., biodiversity, carbon sequestration).

Mitigation is usually translated into or evaluated through GHG emissions, but we wish to emphasize in this study that the boundary may be drawn more extensively to encompass other environmental indicators such as nutrient use and leakage, water use and quality, and biodiversity. Following the convention, we will explore these other environmental mitigation indicators under the sustainability component of food security, with this pillar focusing solely on GHG emissions reduction. It should be noted that nutrient use efficiency (for example, a fundamental aspect of mineral fertilizer application) has an effect on GHG emissions in both the short and long run. Emission factors are a suitable starting point for quantifying greenhouse gas (GHG) emissions from agricultural sources. The mitigation impacts of various management measures for the primary GHGs related to agricultural production, namely CO_2, CH_4, and

N_2O, as well as short-lived climatic pollutants, are easily quantifiable. These are transformed into CO_2-equivalents for comparison with natural emissions and other industries. This is usually done for a single year and marks a point in time. Simultaneously, continuous observations will enable for the detection of variations in emissions and other changes over time (extremes, etc.), such as those caused by changes in local land use in conjunction with a changing climate. These observations are critical bookkeeping operations in the context of measuring, reporting, and verifying (MRV) at the national, regional, and global levels.

CLIMATE SMART AGRICULTURAL PRACTICES

Climate change poses significant problems to the agricultural industry and, thus, to national food security and development objectives. These difficulties can be managed successfully with the appropriate climate-smart agricultural (CSA) techniques:

Crop Smart

Intercropping systems improve the sustainability of the environment, output stability, productivity, and resilience to disturbance (Sisodiya et al., 2022 & Vandermeer, 1989). Growing peas and grain crops together reduce the growth of weeds because they are more competitive and utilize resources more efficiently than a single pea crop (Shiv et al., 2023; & Hauggaard-Nielsen et al., 2001, 2006). Green manuring and climate-smart farming techniques restrict the use of external inputs and resources, making them ideal for smallholders (Gurung et al., 2017). Mulching conserves both water and labour (Subedi & Basnet, 2016; & Sahu et al., 2022). Biofertilizers application boosts crop yields due to a more rapid supply of nutrients, which aids plant growth by resolving transitory nutritional deficits (Gajjela, 2018). In order to promote crop development, growth-promoting bacteria stimulate soil nitrogen fixation, trigger the synthesis of growth hormones, and suppress pathogens (Rakesh et al., 2017). Organic farming preserves soil fertility by using natural methods of managing insects and controlling weeds, recycling agricultural waste, vermicomposting, avoiding or reducing external inputs, and bio-intensive nutrient management (Goldsmith & Hildeyard, 1996; & Hansen et al., 2006). Alternate wetting and drying may sustain yields comparable to flooded rice while reducing irrigation requirements by around 30% (Bouman et al., 2007 & Verma et al., 2022). In a stressful climate, drought-tolerant rice, wheat, maize, and legumes cultivars can still produce (Paudel, 2012).

Soil Smart

A growing population can get their food and fibre from the soil. The worldwide shortage of food is a result of how climate change components like moisture, temperature, and carbon dioxide influence soil characteristics like soil formation, development, and fertility. No-tillage (NT) maintains the level of soil organic carbon, particularly on topsoil, and reduces the detrimental effects on soil quality (Kern & Johnson, 1993; & West & Post, 2002). It retains soil moisture, reduces erosion losses, and lowers the cost of fuel, labour, and machinery (Lal et al., 2007). According to Su et al. (2007), ZT had a much greater water consumption efficiency. Many macrospores and inter-pedal spaces lead to enhanced infiltration, and zero tillage boosted the population of surface-feeding earthworms (Kemper et al., 1987). According to studies by Ismail et al. (1994), exchangeable Ca, Mg, and K were considerably greater in the surface soil under NT than in the ploughed soil. Sloping Agriculture Land Technology (SALT), a strategy for preserving soil and producing food in sloping lands, nourishes the soil, stabilizes slopes, allows cultivation on slopes, and gradually builds bio-terraces (Pratap, 1998; & Grogan et al., 2012). It also helps to save soil and water. Agroforestry, agri-horticultural, and agri-pastoral systems boost soil physical characteristics, decrease runoff and erosion, retain soil organic matter, boost nitrogen fixation, and encourage effective nutrient cycling (Nair, 1984).

Water Smart

Water is the principal channel through which people, ecosystems, and economies are experiencing the effects of climate change (Stuart-Hill et al., 2012). The need for clean water to consume is growing as a result of a growing population, industries, intensive farming, climate change, and higher water use (Bakkenes et al., 2002). As a substitute method of reducing water scarcity, rainwater collection systems are now being used (Patil & Mali, 2013). Rainwater collection is being used to increase food availability globally, encourage farmers to diversify their businesses, establish new water sources, and assist traditional water delivery systems (Maume, 2014). Drip irrigation significantly lowers water losses due to evaporation, transport, and distribution (Dhawan, 2002; INCID, 1994; & NCPA, 1990), which increases water use efficiency. Fertigation offers a greater and better yield while saving time and labour (Singh, 2002). It also helps to apply nutrients to the root zone uniformly. Water and nutrients are used inefficiently due to fertilisation, making it easier for plants to utilize both at once. Using soluble fertilizers conveniently, controlling the supply and surveillance of water and nutrients, and conserving energy and labour are other benefits of fertigation (Imas, 1999).

Livestock Smart

Livestock contributes up to 18% of the world's greenhouse gas emissions (Thornton & Herrero, 2010). The production of livestock is responsible for one-third of the change in land use, one-third of the nitrous oxide emissions through manure and slurry management, and around 25% of the methane released into the atmosphere from ruminant digestion (Jha et al., 2023). The issues that the cattle industry faces as a result of climate change include changing feed prices, habitat changes, an increase in vector-borne diseases in warm areas, decreased reproductive, poor pasture quality and availability, and physiological heat stress (Opio et al., 2013; & Thornton et al., 2009). It is possible to produce more with fewer animals while using less feed by upgrading feeding methods. This reduces greenhouse gas emissions (Blummel et al., 2010). Planting high-productivity, drought-tolerant, and deeply rooted forage grasses or legumes can increase the vegetation on pasture land (Branca et al., 2011). Where preventative measures are unsuccessful, weather-indexed livestock insurance can be incredibly useful (Skees & Enkh-Amgala, 2002). Agroforestry protects farming systems from risks and improves feed, which in turn reduces enteric methane and helps with carbon sequestration. Animals are less stressed by the heat thanks to shade trees, which also increase the quantity and quality of food. This can help prevent overgrazing and stop soil degradation (Thornton & Herrero, 2010).

ICT Smart

Telephone, television, printed media, radio, and internet networks contribute significantly to boosting crop production when used pluralistically (Singh, 2014). Telecommunications initiatives (farmer call centre), media initiatives (Krishi Samachar, Krishi Karyakram on television and FM radios providing knowledge related to modern problems and technologies in agriculture), printed publications (Krishi diary, bimonthly magazines, booklets and pamphlets, Krishak Pana in national magazines like Kantipur), and internet-based initiatives (Smart Krishi, IBA Krishi, mobile applications and other agriculture online portals) are ICTs initiatives in agriculture-advisory services that from preliminary planning to post-harvest procedures, as well as information about agro-entrepreneurship, Smart Krishi offers reliable information without charge (Das, 2016; & Regmi, 2016). ICT increases a framer's creativity and competence, which helps farmers manage risk and uncertainty (Abraham, 2007). In relation to cost-effectiveness and resolving farmer-specific field-based challenges, mobile applications are helpful in the transfer of technology (Wankhade et al., 2011).

Gender Smart

According to Quisumbing et al. (2017), climate change affects women more than men. Women perform a key role in field planning, sowing to harvesting, managing livestock, and post-harvest operations. In light of climate change, gender inequalities in resource access, agricultural production, and vulnerability must be addressed (Nyasimi & Huyer, 2017; & ChananaNag & Aggarwal, 2018). Building resilient households on farms, farming communities, and food chains is crucial to improving the capacity of women farmers. In the development and implementation of CSA, specific needs, targets, and experiences of men and women must be acknowledged and taken into account (World Bank, FAO, & IFAD, 2015). In multiple villages in India, encourages women farmers to adopt CSA practices like solar water supply, plastic tunnel farming, greywater collection ponds, home gardens, drip irrigation, and livestock shed improvement. These practices help to raise farmers' productivity and resilience, reduce greenhouse gas emissions, and achieve food safety and development goals (Sherpa et al., 2017).

CONCLUSION

Climate change cannot be avoided. Unusual rainfall patterns, drought, storms, erosion, and landslides are the main difficulties Indian farmers face. Climate-smart agricultural techniques, which primarily make use of materials and knowledge already accessible locally, can assist to reduce these issues. The government has created a number of plans and strategies to combat climate change, but they are not properly carried out. In the long run, appropriate strategies and regulations for climate change should be created and properly executed because climate change significantly impacts agriculture production. Therefore, it is imperative that sustainable practices be considered and put into action for the benefit of farmers, the environment, and food security.

Acknowledgement:

I would like to sincerely thank my co-authors for their support and kind gesture to complete this manuscript in time.

Funding: NIL.

Conflict of Interest:

There is no such evidence of conflict of interest.

Author Contribution

All authors have participated in critically revising the entire manuscript and approving the final manuscript.

REFERENCES

Abraham, R. (2007). Mobile Phones and Economic Development: Evidence from the Fishing Industry in India. *Information Technology and International Development, MIT Press, 4*(1), Pp. 5–17.

Aryal, J. P., Sapkota, T. B., Rahut, D. B., & Jat, M. L. (2020). Agricultural sustainability under emerging climatic variability: the role of climate-smart agriculture and relevant policies in India. *International Journal of Innovation and Sustainable Development, 14*(2), 219-245.

Aydinalp, C., & Cresser, M. S. (2008). The effects of global climate change on agriculture. *American-Eurasian Journal of Agricultural & Environmental Sciences, 3*(5), 672-676.

Azadi, H., Moghaddam, S. M., Burkart, S., Mahmoudi, H., Van Passel, S., Kurban, A., & Lopez-Carr, D. (2021). Rethinking resilient agriculture: From climate-smart agriculture to vulnerable-smart agriculture. *Journal of Cleaner Production, 319*, 128602.

Bakkenes, M., Alkemade, J., Ihle, F., Leemans, R., & Latour, J.B. (2002). Assessing effects of forecasted climate change on the diversity and distribution of European higher plants. *Global Change Biology, 8*(4), Pp. 390-407.

Baumgard, L. H., Rhoads, R. P., Rhoads, M. L., Gabler, N. K., Ross, J. W., Keating, A. F., & Sejian, V. (2012). Impact of climate change on livestock production. Environmental stress and amelioration in livestock production, 413-468.

Bisbis, M. B., Gruda, N., & Blanke, M. (2018). Potential impacts of climate change on vegetable production and product quality–A review. *Journal of Cleaner Production, 170*, 1602-1620.

Blümmel, M., Wright, I. A., & Hegde, N. G. (2010). Climate change impact on livestock production and adaptation strategies: a global scenario, Pp. 136-145. In: Lead Papers 2010 National Symposium on Climate Change and Rainfed Agriculture, February 18-20.Indian Society of Dryland Agriculture, *Central Research Institute for Dryland Agriculture*, Hyderabad, India. pp 192.

Bouman, B. A. M., Lampayan, R. M., & Tuong, T. P. (2007). Water management in rice: coping with water scarcity. *International Rice Research Institute*, Los Baños, Philippines, Pp. 54.

Branca, G., McCarthy, N., Lipper, L., & Jolejole, M. C. (2011). Climate-Smart Agriculture: A Synthesis of Empirical Evidence of Food Security and Mitigation Benefits from Improved Cropland Management. Working paper. Food and Agriculture Organization of the United Nations.

Campbell, B. M., Vermeulen, S. J., Aggarwal, P. K., Corner-Dolloff, C., Girvetz, E., & Loboguerrero, A. M. (2016). Reducing risks to food security from climate change. Glob. *Food Security 11*, 34–43. doi: 10.1016/j.gfs.2016.06.002

Chanana-Nag, N., & Aggarwal, P. K. (2018). Woman in agriculture, and climate risks: hotspots for development. Clim. Change., Pp. 1–15. doi: 10.1007/s10584-018-2233-z.

Chandra, A., McNamara, K. E., & Dargusch, P. (2018). Climate-smart agriculture: Perspectives and framings. *Clim. Policy 18*, 526 541.

DaMatta, F. M., Grandis, A., Arenque, B. C., & Buckeridge, M. S. (2010). Impacts of climate changes on crop physiology and food quality. *Food Research International, 43*(7), 1814-1823.

Das, D. K., Singh, J., & Vennila, S. (2011). Emerging crop pest scenario under the impact of climate change–a brief review. *Journal of Agricultural Physics, 11*, 13-20.

Das, S. (2016). Enhancing the Role of ICT in Disseminating Agricultural Information to Farmers in Bangladesh (Ph.D. thesis). University of Dhaka, Bangladesh.

Dhawan, B. D. (2002). Technological change in Indian irrigated agriculture: A study of water saving methods. New Delhi: Commonwealth Publishers.

Döll, P. (2002). Impact of climate change and variability on irrigation requirements: a global perspective. *Climatic change, 54*(3), 269-293.

FAO (2018). Upscaling Climate Smart Agriculture. Lessons for Extension and Advisory Services. Occasional Papers on Innovation in Family Farming. Rome: *Food and Agriculture Organization of the United Nations*.

FAO (2013). Coping with the food and agriculture challenges: smallholders' agenda. Rome, FAO.

FAO (2015). Smallholder productivity under climatic variability: adoption and impact of widely promoted agricultural practices in Tanzania. *EPIC, Policy Brief no. 2,* Rome: FAO.

Fraval, S., Hammond, J., Bogard, J. R., Ng'endo, M., van Etten, J., & Herrero, M. (2019). Food access deficiencies in Sub-saharan Africa: prevalence and implications for agricultural interventions. Front. Sustain. *Food Syst. 3*, 104. doi: 10.3389/fsufs.2019.00104

Gajjela, S., Chatterjee, R., Subba, S., & Sen, A. (2018). The prospect of liquid organic manure on organic bitter gourd cultivation. *Journal of*

Pharmacognosy and Phytochemistry, 7(6), Pp. 189–193.

Goldsmith, E., & Hildeyard, E. (1996). (eds) The Earth report 2. *Mitchell Beazley*, London.

Graham, C. T., & Harrod, C. (2009). Implications of climate change for the fishes of the British Isles. *Journal of Fish Biology, 74*(6), 1143-1205.

Grogan, P., Lalnunmawia, F., & Tripathi, S. K. (2012). Shifting cultivation in steeply sloped regions: a review of management options and research priorities for Mizoram state, Northeast India. *Agroforestry System, 84*, Pp. 163–177.

Gurung, A., Basnet, B. B., Paudel, B., Chaudhary, P., & Bhatta, K. (2017). Scaling up pathways for championing climate-smart agriculture technologies and practices in Nepal.

Hansen, L., Noe, E., & Højring, K. (2006). Nature and nature values in organic agriculture. An analysis of contested concepts and value among different actors in organic farming. *J. Agric. Environ. Ethics., 19,* Pp. 147–168. doi:10.1007/s10806-005-1804-y

Hauggaard-Nielsen, H., Ambus, P., & Jensen, E. S. (2001). Interspecific competition, N use and interference with weeds in pea–barley intercropping. *Field Crops Res 70,* 101–109. doi:10.1016/S0378-4290(01)00126-5

Hauggaard-Nielsen, H., Andersen, M. K., Jornsgaard, B., & Jensen, E. S. (2006). Density and relative frequency effects on competitive interactions and resource use in pea–barley intercrops. *Field Crops Res., 95*, Pp. 256– 267. doi:10.1016/j.fcr.2005.03.003

Imas, P. (1999). Recent Techniques in Fertigation of Horticultural Crops in Israel. Presented at the IPIPRII-KKV Workshop on Recent Trends in *Nutrition Management in Horticultural crops*. Dapoli, Maharashtra, India.

INCID (1994). Drip irrigation in India. New Delhi: Author.

IPCC (2014). Climate Change 2014: Synthesis report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, Pachauri, R. K., & Meyer, L. A. (eds.)]. IPCC, Geneva, Switzerland.

Ismail, L., Blevins, R. L., & Frye, W. W. (1994). Long-term no-tillage effects on soil properties and continuous corn yields. *Soil Science Society of America Journal, 58*, Pp. 193–198.

Jha, A. K., Yadav, P. S., Shrivastava, A., Upadhyay, A. K., Sekhawat, L. S., Verma, B., & Sahu, M. P. (2023). Effect of nutrient management practices on the productivity of perennial grasses under high moisture conditions. AMA, Agricultural Mechanization in Asia, *Africa and Latin America. 54*(3), 12283-12288.

Jones, A., Stolbovoy, V., Rusco, E., Gentile, A. R., Gardi, C., Marechal, B., & Montanarella, L. (2009). Climate change in Europe. 2. Impact on soil. A review. *Agronomy for sustainable development, 29*, 423-432.

Ju, H., van der Velde, M., Lin, E., Xiong, W., & Li, Y. (2013). The impacts of climate change on agricultural production systems in China. *Climatic Change, 120*, 313-324.

Kaffenberger, B. H., Shetlar, D., Norton, S. A., & Rosenbach, M. (2017). The effect of climate change on skin disease in North America. *Journal of the American Academy of Dermatology, 76*(1), 140-147.

Karanja, S. N., van Wijk, M. T., Rufino, M. C., & Giller, K. E. (2016). Adaptation of agriculture to climate change in semi-arid Borena, Ethiopia. *Reg. Environ. Change 16*, 2317–2330. doi: 10.1007/s10113-016-0940-4

Kemper, W. D., Trout, T. J., Segeren, A., & Bullock, M. (1987). Worms and water.

Journal of Soil and Water Conservation, 42, Pp. 401–404.

Kern, J., & Johnson, M. (1993). Conservation tillage impacts on national soil and atmospheric carbon levels. *Soil Sci Soc Am J., 57*(1), Pp. 200–210.

Lal, R., Reicosky, D. C., & Hanson, J. D. (2007). Evolution of the plough over 10,000 years and the rationale for no-till farming. *Soil and Tillage Research, 93*, Pp. 1–12.

Lipper, L., Thornton, P., Campbell, B. M., 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, P. T., Sessa, R., Shula, R., Tibu, A., & Torquebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature Climate Change 4*, 1068-1072.

Lipper, L., Thornton, P., Campbell, B. M., 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, P. T., Sessa, R., Shula, R., Tibu, A., & Torquebiau, E. F. (2014). Climate-smart agriculture for food security. *Nature Climate Change 4*, 1068-1072.

Mahato, A. (2014). Climate change and its impact on agriculture. *International Journal of Scientific and Research Publications, 4*(4), 1-6.

Makate, C. (2019). Effective scaling of climate-smart agriculture innovations in African smallholder agriculture: A review of approaches, policy and institutional strategy needs. *Environmental Science & Policy, 96*, 37-51.

Maume, J. (2014). Impacts of rainwater harvesting and socioeconomic factors on household food security and income in moisture stress areas of eastern Haraghe, Ethiopia. *Novelty Journal, 1*(1), Pp. 10-23.

Kumar, M. Y., Kumar, S. A., Shobha, S., Yogita, G., Raju, P., Anand, P., Pratap, S. M., Amit, J., Sundal, P., & Badal, V. (2023). To assess the climate-resilient management strategy for pod borer Helicoverpa armiger (Hubner) in chickpeas under field conditions in Madhya Pradesh. *Scientist. 2*(1), 370-375.

Munday, P. L., Jones, G. P., Pratchett, M. S., & Williams, A. J. (2008). Climate change and the future for coral reef fishes. *Fish and Fisheries, 9*(3), 261-285.

Nagothu, S. N., Kolberg, S., & Stirling, C. M. (2016). Climate-smart agriculture. Is this the new paradigm of agricultural development? In Climate Change and Agricultural Development: Improving Resilience through Climate Smart Agriculture, Agroecology and Conservation; Nagothu, S. N., Ed.; Routledge: Oxford, UK, pp. 1–20.

Nair, P. K. R. (1984). Role of trees in soil productivity and conservation. Soil productivity aspects of agroforestry. *The International Council for Research in Agroforestry*. Nairobi, Pp. 85.

Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M. S., & Bernabucci, U. (2010). Effects of climate changes on animal production and sustainability of livestock systems. *Livestock Science, 130*(1-3), 57-69.

NCPA (1990). Status, potential and approach for adoption of drip and sprinkler irrigation systems. Pune: Author.

Nyasimi, M., & Huyer, S. (2017). Closing the gender gap in agriculture under climate change. *Agr. Dev., 30*, Pp. 37–40.

Ongoma, V., Chen, H., & Gao, C. (2017). Projected changes in mean rainfall and temperature over East Africa based on CMIP5 models. *Int. J. Climatol. 38*, 1375–1392. doi: 10.1002/joc.5252

Opio, C., Gerber, P., Mottet, A., Falcucci, A., Tempio, G., MacLeod, M., Vellinga, T., Henderson, B., & Steinfeld, H. (2013). Greenhouse Gas Emissions From Ruminant Supply Chains: A Global Life Cycle Assessment. Rome: Food and Agriculture Organization of the United Nations (FAO). [http://www.fao.org/ docrep/018/i3461e/i3461e.pdf] (accessed 26 July 2014).

Pareek, A., Meena, B. M., Sharma, S., Tetarwal, M. L., Kalyan, R. K., & Meena, B. L. (2017). Impact of climate change on insect pests and their management strategies. *Climate change and sustainable agriculture*, 253-286.

Patil, V. P., & Mali, S. P. (2013). Potential Roof Rain Water Harvesting In Pirwadi Village of Kolhapur District, Maharashtra (India). *Journal of Research in Humanities and Social Science, 1*(4), Pp. 19-24.

Paudel, M. N. (2011). Rice cultivation is at the highest elevation in the world. *Agronomy Journal of Nepal, 2*, Pp. 31-41.

Porcal, P., Koprivnjak, J. F., Molot, L. A., & Dillon, P. J. (2009). Humic substances—part 7: the biogeochemistry of dissolved organic carbon and its interactions with climate change. *Environmental Science and Pollution Research, 16*, 714-726.

Pratap, T. (1998). Sustainable land management in marginal mountain areas of the Himalayan region. *Mountain Research and Development, 19*(3), Pp. 251−260.

Pretty, J., Toulmin, C., & Williams, S. (2011). Sustainable intensification in African agriculture. *Int. J. Agric. Sustain. 9*, 5–24. doi: 10.3763/ijas.2010.0583

Quisumbing, A. R., Kumar, N., & Behrman, J. A. (2017). Do shocks affect men's and women's assets differently? Evidence from Bangladesh and Uganda. *Dev. Policy Rev., 36*, Pp. 3–34. doi: 10.1111/dpr.12235.

Rakesh, S., Poonguzhali, S., Saranya, B., Suguna, S., & Jothibasu, K. (2017). Effect of Panchagavya on growth and yield of Abelmoschus esculentus cv. Arka Anamika. *International Journal of Current Microbiology and Applied Sciences*, *6*, 3090–3097. doi:10.20546/ijcmas.2017.609.380

Regmi, A. (2016). Application of ICT tools in the Agriculture Sector in Nepal. resilient innovations? CCAFS Info Note. CGIAR Research Program on Climate Change, *Agriculture and Food Security* (CCAFS), Copenhagen.

Rosenzweig, C., Iglesius, A., Yang, X. B., Epstein, P. R., & Chivian, E. (2001). Climate change and extreme weather events-Implications for food production, *plant diseases*, and pests.

Sahu, V., Kewat, M. L., Verma, B., Singh, R., Jha, A. K., Sahu, M. P., & Porwal, M. (2023). Effect of sulfentrazone-ethyl on weed flora, growth and productivity in wheat. *The Pharma Innovation Journal 12*(3), 3621-3624.

Sahu, M. P., Kewat, M. L., Jha, A. K., Sondhia, S., Choudhary, V. K., Jain, N., & Verma, B. (2022). Weed prevalence, root nodulation and chickpea productivity are influenced by weed management and crop residue mulch. AMA, Agricultural Mechanization in Asia, *Africa and Latin America. 53*(6), 8511-8521.

Gaini, S., Jha, A. K., Badal, V., Muskan, P., Sahu, M. P., & Meshram, R. K. (2023). Impact of pre and post-emergence herbicides on weed flora of maize. *International Journal of Plant & Soil Science*.

Seckler, D. W. (1996). The new era of water resources management: from" dry" to" wet" water savings (Vol. 1). Iwmi.

Sherpa, Khatri-chhetri, & chanana (2017). *Mainstreaming Gender and Climate-Smart Agriculture in the National*

Adaptation Plan (NAP) of Nepal, 15(5).

Swati, S., Agrawal, S. B., Badal, V., Singh, Y. P., Richa, S., Muskan, P., Jirtendra, S., & Raghav, P. (2023). Weed dynamics and productivity of chickpea as affected by weed management practices. *Pollution Research. 42*(2), 21-24.

Shukla, S., Agrawal, S. B., Verma, B., Anjna, M., & Ansari, T. (2022). Evaluation of different doses and modes of application of ferrous ammonium sulfate for maximizing rice production. *International Journal of Plant & Soil Science. 34*(23), 1012-1018.

Singh, H. P. (2002). Precision Farming in Horticulture. In: Proceedings of the National Seminar cum Workshop on Hi-Tech Horticulture and Precision Farming.26- 28 July 2012, Lucknow. Pp. 1-20.

Singh, M. (2014). Critical Analysis of Mobile-based Agro-advisory Services: A case of mKRISHI. (Master's thesis). IARI, New Delhi.

Jitendra, S., Sharma, P. B., Badal, V., Muskan, P., Mahendra, A., & Rahul, Y. (2022). Influence of irrigation scheduling on the productivity of wheat + mustard intercropping system. *Biological Forum – An International Journal. 14*(4), 244-247.

Skees, J. R., & Enkh-Amgala, A. (2002). Examining the feasibility of livestock insurance in Mongolia. *Policy Research Working Paper 2886*, Washington D.C., World Bank.

Skendžić, S., Zovko, M., Živković, I. P., Lešić, V., & Lemić, D. (2021). The impact of climate change on agricultural insect pests. *Insects, 12*(5), 440.

Stuart-Hill, S., Schulze, R., & Colvin, J. (2012). Handbook on adaptive management strategies and options for the water sector in South Africa under climate change. *Water Research Commission* (WRC) Report No. 1843/2/12

Su, Z., Zhang, J., Wu, W., Cai, D., Lv J., Jiang, G., Huang, J., Gao, J., Hartmann, R., & Gabriels, D. (2007). Effects of conservation tillage practices on winter wheat water-use efficiency and crop yield on the Loess Plateau, China. *Agricultural Water Management, 87*, Pp. 307–314.

Subedi, R., & Basnet, S. (2016). Straw Mulches aid farmers battling drought. *International Centre for integrated mountain development*. Retrieved from http://www. icimod. org/?q=24032

Nirala, T., Jha, A. K., Verma, B., Yadav, P. S., Anjna, M., & Bhalse, S. (2022). Bio efficacy of Pinoxaden on Weed Flora and Yield of Wheat (Triticum aestivum L.). *Biological Forum – An International Journal. 14*(4), 558-561.

Thakur, A. K., & Uphoff, N. T. (2017). How the system of rice intensification can contribute to climate-smart agriculture. *Agronomy Journal, 109*(4), 1163-1182.

Thornton, P., & Herrero, M. (2010). Potential for reduced methane and carbon dioxide emissions from livestock and pasture management in the tropics. *PNAS, 107,* Pp. 19667–19672.

Thornton, P. K., van de Steeg, J., Notenbaert, A., & Herrero, M. (2009). The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. *Agric Syst.*, *101*, Pp. 113–127.

UNFCCC (2011). NAPA Priorities Database. United Nations Framework Convention on Climate Change, Bonn, Germany, unfccc.int/cooperation_support/least_developed_countries_portal/napa_priorities_database/item /4583.php.

Vandermeer, J. (1989). The ecology of intercropping. Cambridge University Press, New York.

Venkatramanan, V., & Shah, S. (2019). Climate-smart agriculture technologies for environmental management: the intersection of sustainability, resilience, wellbeing and development. *Sustainable green technologies for environmental management*, 29-51.

Vermeulen, S. J., Campbell, B. M., & Ingram, J. S. I. (2012). Climate change and food systems. *Annu. Rev. Environ. Resour. 37*, 195–222. doi: 10.1146/annurev-environ-020411-130608

Verma, B., Bhan, M., Jha, A. K., Singh, V., Patel, R., Sahu, M. P., & Kumar, V. (2022). Weed management in direct-seeded rice through herbicidal mixtures under diverse agroecosystems. AMA, Agricultural Mechanization in Asia, *Africa and Latin America. 53*(4), 7299- 7306.

Verma, B., Bhan, M., Jha, A. K., Khatoon, S., Raghuwanshi, M., Bhayal, L., Sahu, M. P., Rajendra, P., & Vikash, S. (2022). Weeds of direct-seeded rice are influenced by herbicide mixture. *Pharma Innovation. 11*(2), 1080-1082.

Vuren, D. P. V, Ochola, W. O., Riha, S., Gampietro, M., & Ginze, H. (2009). Outlook on agricultural change and its drivers. In: McIntyre BD, Herren HR, Wakhungu J, Watson RT (ed.). Agriculture at a Crossroads, Island Press, Washington, DC.

Wankhade, A., Khare, N., & Dhruv, S. (2011). ICT Based Kissan Mobile Sandesh-An innovative approach in Information Communication Technology for Agricultural and Rural Development Edited Book By Saravanan, C., & Indira Devi, T. New India Publishing Agency, New Delhi, Pp. 143-150.

West, T. O., & Post, W. M. (2002). Soil organic carbon sequestration rates by tillage and crop rotation. *Soil Sci Soc Am J., 66*(6), Pp. 1930–1946.

Wiederkehr, C., Beckmann, M., & Hermans, K. (2018). Environmental change, adaptation strategies and the relevance of migration in Sub-Saharan drylands. *Environ. Res. Lett. 13*, 113003. doi: 10.1088/1748-9326/aae6de

World Bank, F. A. O., & IFAD (2015). Gender in climate-smart agriculture: module 18 for gender in agriculture sourcebook. *Agriculture global practice*. Washington, D.C.: World Bank Group.

Zhou, Y., Zwahlen, F., Wang, Y., & Li, Y. (2010). Impact of climate change on irrigation requirements in terms of groundwater resources. *Hydrogeology Journal*, *18*(7), 1571-1582.