Journal of Tropical Agriculture 62(2): 172-192, 2024

Climate resilient agricultural practices: An Indian scenario

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Received on 04 March 2024; received in revised form 26 September 2024, accepted 25 October 2024.

Abstract

Changes in atmospheric temperature, carbon dioxide (CO_2) level, soil and air moisture content affect crop growth and agricultural productivity in both direct or indirect ways. Climate change influences the farming community of entire world. Developing countries like India, however, are more vulnerable to climate change as farmers do not have sufficient resources to cope. A planned approach to farming adaptation is needed to address these issues. Climate-resilient agricultural practice aims to manage the interconnected aspects of both sustainable agriculture and food safety. Conventional farming methods often rely on chemical inputs and are less adaptive to changing climate conditions, whereas modern methodologies, like precision agriculture and regenerative practices, focus on sustainability, resilience, and reducing environmental impacts of climate change. In this review, different climate resilient practices are discussed with emphasis on both conventional and modern methodologies along with the constraints of using these practices on field.

Keywords: Climate-change.

Introduction

Climate has a significant influence on agriculture. Crop growth and agricultural productivity are directly or indirectly affected due to alteration in air temperature, carbon dioxide (CO_2) and both air and soil moisture content (Panneerselvam et al., 2019). High temperature, water stress, and reduced rainy days due to intense rains are negatively impacting wheat and paddy yields in several parts of India. Climate change impacts the farming community around the world. However, developing nations like India are more exposed as majority of the population is dependent on farming and lack of coping mechanisms. India attained a population of 1.38 billion in the year 2020; corresponding to 17.7% of the world's population. Since independence, India's population has increased 3.35 times. Although, India represents only 2.4% of the global land area (FAO, 2021). According to the latest Census of Agricultural Holdings, the average landholding size in each state is 1.08 hectares (Ministry of Agriculture & Farmers Welfare, 2020). Most of Indian farmers have landholdings of less than 1 ha; while the rest have 1-2 hectares. Unfortunately, India ranked 94th out of 107 countries in the Global Hunger Index 2020 (Global Hunger Index, 2021). Moreover, nearly 14 percent of India's population (189.2 million) is still undernourished (State of Food Security and Nutrition in the World, 2020). For ecological, economic, and environmental sustainability, agricultural productivity must be increased in order to meet the food demand. This leads an integrated and multi-dimensional approach to the country's overall food and agricultural systems to ensure food and nutritional safety for everyone specially the poor and small farmers who would be affected the most.

In order to address the changing climate and attain

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sustainable development goals (SDG) in India, it is crucial to address the following:

- Implement the appropriate mitigation technologies to prevent the impacts of climate change, such as developing tolerant breeds.
- Management of water and nutrients for effective productivity and resource utilisation.
- Agricultural conservation practice to increase soil organic carbon, create a favourable environment for plant growth and carbon sequestration which ultimately reduces the use of soil fertilizer and greenhouse gas (GHGs) emission.
- Monitoring of crops with agro-advisories.

Under changing climate conditions, climate-resilient agriculture (CRA) involves maximizing crop and livestock production systems using existing natural resources. In order to cope with changing climate, rice growers use stress-tolerant varieties (abiotic stresses *viz*., floods, salinities, heat, and droughts), as well as irrigation technologies and integrated crop management strategies (Sawicka, 2019). As atmospheric CO_2 levels rise, not only does global warming occur, but also agricultural ecosystems are affected (Panneerselvam et al., 2019). A village-level assessment of susceptibility to climate variations is critical to build local communities' resilience and their livelihoods.

As a result, multidisciplinary collaborative approaches are needed to achieve climate resilience in agriculture. Climate change adaptation practices include maintaining soil organic carbon, conserving moisture in-situ, incorporating residues instead of burning them, harvesting rainwater for additional irrigation, planting temperature and moisture-tolerant varieties, enhancing irrigation efficiency, site-specific farming and nutrient management. Building resilience in soil health is a crucial component of crop production under varying weather conditions. In order to achieve agricultural sustainability, dedicated and targeted efforts from several departments, development agencies, and government policies are necessary. Introduction of new crops or replacing existing crops, or changing the crop sequence, as well as cropping pattern change can also aid climate adaptation. Furthermore, the public-private-civil society partnership (PPCP) approach should be promoted (Roy et al., 2018). While promoting conservation and use of indigenous crop varieties, a balance should be struck with the use of high-yielding and hybrid varieties. It is necessary to develop a national seed program for climate resilient and indigenous varieties. Furthermore, a dedicated fund is needed to develop a 'contingent seed bank' in every state. A climate-resilient agricultural approach aims to manage the interrelated aspects of agriculture and food security that are directly affected by climate change. To combat climate change and make agri-production resilient to climate changes and shocks, a planned approach to adaptation in agriculture and development practices is necessary. In this review, different climate resilient practices are discussed with emphasis on both conventional and modern methodologies along with the constraints of using these practices on field.

Climate change and need of climate resilience:

Climate change encompasses various definitions, often defined statistically as a prolonged shift in the climate conditions, typically spanning decades (Parry et al., 2007). The escalation of greenhouse gases (GHGs) within the atmosphere is a catalyst for the steady elevation of earth's average temperature. This phenomenon is increasingly acknowledged as a significant hazard to both food security and agricultural sustainability. Climate change-resistant agriculture is the need of the hour in many parts of the world. Increased temperatures can reduce crop durations, change photosynthesis, increase crop respiration rates, and affect pest populations. Crop yield, water availability, drought intensity and frequency, microbial population slowdown, decrease in soil organic matter, reduction in yield, and degradation of soil fertility as a result of soil erosion are all directly or indirectly impacted by climate change. Rainfed agriculture dominates over 60% of the Indian landmass, which is extremely susceptible to changing climate. Additionally, more than 80 percent of farmers in India have less than one hectare of land, making them less equipped to deal with climate change impact on agriculture (Tripathi & Bisen, 2019). Climate change will affect India in many ways throughout the country. Approximately 40 million hectares of land are prone to floods in the north and north eastern belt despite widespread droughts in Rajasthan, Andhra Pradesh, Gujarat, Odisha and Uttar Pradesh (Tripathi & Bisen, 2019). Due to its high population, low adaptive capacity, numerous unique and valued eco-systems, and extensive low-altitude agricultural activities, India is considered especially vulnerable to predicted climate changes. To fulfil the growing population's demand, India's ecosystems must be sustainable. Understanding the adverse impacts of climate change on plant growth and development, along with devising strategies to mitigate these effects, is crucial for fostering sustainable agriculture. This approach ensures resilience in farming practices against the fluctuations in climatic conditions. A significant response option to climate change is to adjust, not only to guide the selection of best mitigation policies but also to reduce the vulnerability of farmers to its impacts. In addressing climate change, even dramatic mitigation measures won't be able to stop the expected temperature increases by 2100, according to the IPCC, thus adaptation is just as crucial as mitigation. (Tripathi & Bisen, 2019). The concept of climate-smart agriculture (CSA) refers to actions designed to transform agri-food systems to become green, climate-resilient. SDGs and the Paris Agreement are among the international goals that the CSA is committed to achieve.The program's core goals encompass three key areas: enhancing agricultural productivity and incomes in a sustainable manner, adapting to the challenges posed by climate change, and minimizing greenhouse gas emissions wherever feasible (FAO, 2010).

Climate Resilient Agricultural Practices:

Droughts, floods, heat waves, and other climatic shocks are increasing with climate change, changing agriculture patterns such as crop production quality, quantity, and occurrences of pests that cause loss of crop production. Although agriculture is the contributor of greenhouse gases but it has also an alternative remedy to sustain. To overcome such climatic problems scientist and researchers has introduced many strategic ideas of sustainable means of practices such as Climate Resilient Agricultural (CRA) which includes minimum tillage, improved irrigation management, pest management, alternatives of fertilizers so on.An illustration of climate-resilient agricultural practices is shown in Fig. 1. It is very essential and important for a planned adaptation to increase resilience of the agricultural system. A climate resilient agriculture system incorporates adaptation, mitigation, as well as practices to increase the system's ability to answer the climate-related instabilities by bearing damage and regaining

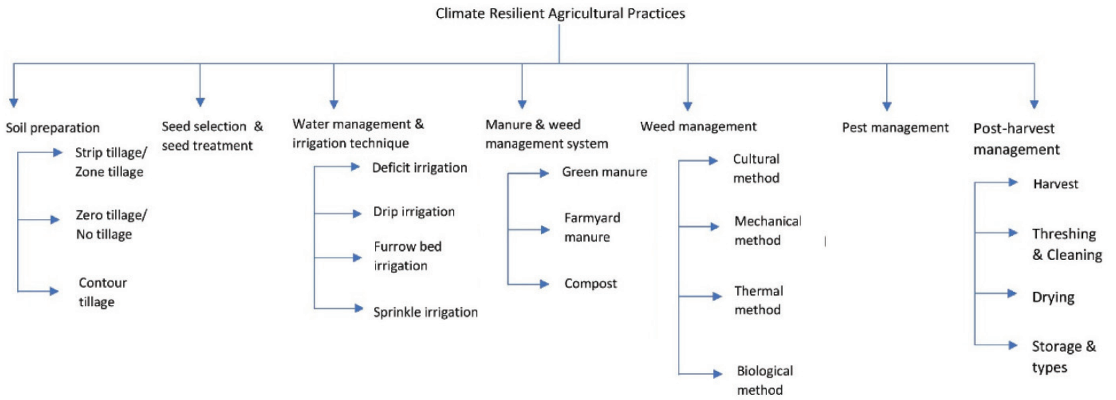

Figure 1: Schematic diagram of the climate resilient agricultural practices

productivity quickly (Rao et al., 2016). Practices that optimize farming output in challenging climates help adaptation by enhancing resilience to unpredictable weather patterns and extreme events (NICRA-ICAR, 2013). A sustainable agricultural framework not only addresses current societal needs but also ensures the capacity for future generations to meet their own requirements. Climate Resilient Sustainable Agriculture (CRSA) prioritizes environmental conservation, food security, and long-term community resilience to counter local food scarcity, contributing to national and global climate strategies for self-sufficiency (Simarmata et al., 2021). The Indian government's commitment to climate change research is evident through the launch of the "National Initiative on Climate Resilient Agriculture (NICRA)" in 2010-2011. This program seeks to bolster the resilience of livestock, fisheries, and crops against climate unpredictability and change, addressing the effects of climate shifts.

Soil preparation:

Soil management stands as a cornerstone in every agricultural system, yet evident signs of erosion, declining organic matter, contamination, compaction, rising salinity, and other adversities pose significant threats to agricultural soils (European Commission, 2002). Unsound soil management practices have detrimentally impacted soil quality, resulting in pollution and heightened erosion. Soil, being the most significant terrestrial carbon reservoir, plays a pivotal role in governing biogeochemical processes that manage the exchange of greenhouse gases with the atmosphere (Scharlemann et al., 2014). Scientists have come up with alternative ways for soil preparation without disturbing the soil, to keep the soil biodiversity in equilibrium. Enhanced comprehension of these characteristics will aid agricultural producers and land users in adapting to climate change, allowing for the mitigation of certain adverse effects.Soil preparation is very essential before planting anything. Some of the resilient practices are discussed :

Strip tillage or zone tillage:

Strip tillage has gain wide popularity in current years in order to overcome the constraints linkedto the no-tillage system (Wang et al., 2017).Strip tillage proves to be very productive in conserving soil moisture as conservation techniques (Licht & Al Kaisi, 2005). In strip-tillage, the presence of varying intensities of tillage is less than or equal to a full-width tillage. In general, this practice disturbs not more than 30% of the surface of the soil, which leaves most of the previous crop's residue intact. The method of strip-tillage enhances seed germination in areas with poorly drained soils, and is an alternative to no-till. The seedbed ploughs create strips that are roughly 20 cm wide and up to 20 cm deep (Hendrix et al., 2004; Trevini et al., 2013; Vynand Raimbault, 1992). These strips effectively retain a significant amount of crop residue on the soil surface, serving to absorb raindrop impact and act as a barrier against runoff. By preserving worm channels and other macropores, strip tillage facilitates better infiltration, collectively minimizing runoff and soil erosion. Studies indicate water saving of 25%-26% through strip tillage in an unpuddled system compared to traditional tillage (Islam et al., 2012). Furthermore, strip tillage has been shown to enhance bacterial activity by 27%, total bacterial counts by 49%, nematodes by 275%, total fungi by 37%, and electrical conductivity by 14% when compared to conventional tillage after six years of practice (Leskovar et al., 2016). On-farm research examining unpuddled rice cultivation during *aman* and *boro* rice seasons suggests that strip tillage caused 9% increase in grain yield during the aman season and a 13% increase during the boro season compared to conventional tillage (Hossain et al., 2015). Strip tillage seeding merges the advantages of conservation agriculture and conventional tillage by restricting tillage to the seeding rows for seedbed preparation. This practice improves soil structure, water retention and also provide ideal environment for seed germination (Zhao et al., 2020). Compared with full-width tillage, strip-tillage also takes less time and involves fewer energy inputs.

Zero tillage or no-tillage:
Without any field preparation, crop seed is sown using drillers in a procedure known as zero tillage, which also ensures that previous crop stubbles will not be disturbed and remain in the soil (ICAR-ATARI, 2020). With zero tillage, the water use efficiency can be enhanced that will reduce irrigation requirements (Laxmi et al., 2008). Zero tillage practices can nearly saves 68% of time and 85% of cost compared to conventional and shows many advantages such as improvement of soil structure, fertility and crop yield and no lodging of crops during maturity in case heavy rain occurs (Prasad et al., 2014). Employing resource conservation practices such as minimum or zero tillage stands as a sustainable and cost-efficient solution to address the challenges posed by climate change, notably enhancing soil moisture retention. To enhance agricultural productivity, the ICAR Research Complex for North East Hill (NEH) Region in Meghalaya implemented zero tillage technology within the Nongthymmai hamlet, integrated into the NICRA (Technology Demonstration Component) project. In this case, the gross return was found to be much higher than conventional ploughing practices (Tripathi et al., 2016). In 2001, zero tillage was initially implemented in the rice-wheat cropping systems of Pratapgarh district, Uttar Pradesh, covering only an acre.

However, by 2009, its application had expanded significantly, encompassing close to 13,000 hectares. According to Singh et al. (1997), zero tillage was found to significantly save time during sowing (83.44%) and reduce fuel consumption (80.93%), thereby enhancing its efficiency. Zero tillage improves productivity as it led to 93% reduction in the risk of obtaining efficiency levels below 40% (El-Shater et al., 2020). Zero tillage improve soil organic content by 21% with the benefit of residue recycling. In the Basmati rice-wheat system, yield increased by 36% and net returns by 43% compared to conventional practices (Jat et al., 2019).

Contour tillage:
Soil erosion in the hilly areas is very common if they are devoid of plants**.** Agricultural practices lik**e** contour tillage, mainly practice in the hilly areas plays an important role in preventing soil erosions.The goal is to collect rainwater and keep it in the furrows between the ridges (Wang et al., 2017). Contour farming decreased annual runoff by 10% in comparison to cultivating perpendicular to the slope (Farahani et al., 2016). Implementing contour ridging encourages rainwater to collect in specific areas, slowing runoff, increasing infiltration, and minimizing soil erosion (Liu et al., 2014). Research indicates that this method reduced sediments by 35.8 per cent compared to a baseline value of 22 t/ha/year (Gathagu et al., 2018). However, the effectiveness of contour tillage can be heightened through integration with additional conservation tillage methods like no-tillage or reduced tillage (Gathagu et al., 2018).

Seed selection and seed treatment:
Stress tolerant varieties can play an important role in coping with climate variability as well as enhancing the productivity. To develop such tolerant varieties, it is crucial to identify traits that support and enhance plant growth and development during stress periods (Maheswari 2017). Selection of healthy seed and use of seed treatment helps in better plant establishment by providing good germination and proper protection in the early stages of crop development (Mathad et al., 2013). Farmers who opted for improved and adapted seeds in climate hotspots obtained high-yield and profit. To resist the ever-changing climate, KVK, Mon in the Mon district of Nagaland demonstrated that use of short duration soybean variety (Birsa soya 1) and Maize (HQPM-1) gives good percentage of yield more than local cultivars (ICAR-ATARI, 2019). Some submergence-tolerant rice varietiesdeveloped by IRRI like Swarna, Ranjit, Bahadur and BINA Dhan 11 demonstrated better performance in flood-prone areas of Assam.

Water management and Irrigation technique:

The temperature surge from climate change has led to the drying up of numerous water bodies, altering rainfall patterns, reducing both its frequency and volume significantly. Addressing water resource management will become crucial to meet the escalating demands in regions affected by erratic and potentially diminished rainfall scenarios (Garg et al., 2012). The concept of water management combines the physical concept of a watershed as a hydrological unit with the societal aspect of communities and their institutions, focused on strengthening agricultural resilience through the sustainable management of water, land, and other resources (Reddy et al., 2007).Introduction of sustainable water management for future strategy can be achieved by (a) Reuse of marginal water (Chartzoulakis & Bertaki, 2015) (b) Rainwater harvesting and recycling (NICRA-ICAR, 2013) (c) Crop contingency plans (NICRA-ICAR, 2013) (d) Adoption of innovative irrigation techniques (Chartzoulakis & Bertaki, 2015) (e) Water pricing policy (Chartzoulakis & Bertaki, 2015) (f) Reduction of water losses in the conveyance, distribution and application networks (Chartzoulakis & Bertaki, 2015) (g) Improvement of small on-farm water storage structures (Reddy et al., 2007). Moreover, agro-hydrological models that aims to check the soil moisture, availability of water for the crops, stress parameters should be followed. Water harvesting is the set of practices that collect and store of rainwater runoff to provide available water for plants, including water dispersion and retention in the soil (James et al., 2018). Numerous water-smart technologies, including rainwater gathering structures, cover crops, greenhouses, laser field levelling, wastewater reuse, deficit irrigation, furrow irrigation, raised beds, and drainage management, can help farmers reduce the impact of climatic changes. Such measures and awareness of management of water will lead to resilient practices.

Irrigation techniques:

The water scarcity became the highlighted problem worldwide which affect the agricultural system. Thus developing sustainable irrigation practices with efficient use of water without any compromise of crop quality and yield production (Adeyemi et al., 2017). According to Postel (1998) irrigation will meet 46 per cent of worldwide crop water requirements by 2025, up from 28 per cent in 1995, resulting in drop in rain-fed agriculture. Some of the irrigation practices are discussed below:

Deficit irrigation:

Deficit irrigation (DI) methods represent an enhanced sustainable approach to water conservation. Within this approach, regulated deficit irrigation (RDI), sustained deficit irrigation (SDI), and partial root zone drying (PRD) emerge as the three primary strategies (Corell et al., 2018). The DI system has been widely adopted in many parts of northwest China as a result of studies conducted in China that showed significantly higher wheat and maize yields and water per unit area when ridge furrow planting combined with the DI system (Zhou et al., 2011). When similar amounts of water are applied, yields in RDI have been reported to be greater than those in SDI and even similar to those in fully water-logged conditions (Tejero et al., 2018). Regions in West Bengal contaminated with arsenic (As) are at risk of surpassing concentration limits due to continuous underground irrigation. To counter water scarcity, deficit irrigation serves as a crucial method to reduce water use below full crop water requirements, aiding in dropping irrigation needs while maintaining agricultural goals (Fereres & Soriano, 2007). This form of irrigation involves supplying water at a level lower than that needed to meet maximum evapotranspiration (ET) (English, 1990). The practice of deficit irrigation offers an added advantage in quinoa cultivation, granting farmers control over flowering and harvest timing, facilitating better agricultural planning. In these affected areas, deficit irrigation is highly recommended as it eases the burden on the soil-root-shoot-leaf-grain continuum of heavy metals (Sarkar et al., 2012). It brings multiple benefits, including reduced irrigation costs, enhanced irrigation efficiency, and minimized water expenses (English et al., 1990), proving especially valuable in regions grappling with insufficient water due to unpredictable climate conditions (Fereres & Soriano, 2007).

Drip irrigation:

In recent years drip irrigation is widely used in agriculture (Kumar & Palanisami, 2010). This method aids in mitigating the environmental issues linked to surface irrigation methods, such as problems with waterlogging and salinity (Narayanamoorthy, 1997). Studies from countries like India, Spain, United states and Israel has revealed that drip irrigation raises crop production by 20%-90% and also reduces water by 30%-70% (Postel et al., 2001). Drip irrigation stands out for its water-saving attributes and elevated production capacities, improving water efficiency by up to 50%. This technology has emerged as a frontrunner in the global endeavour to enhance crop production (Chartzoulakis & Bertaki, 2015). The practices of drip irrigation by the farmers will not just determined the desire to use water but also provides broader objectives of lively-hood security or agricultural productivity (Kooij et al., 2013). Drip irrigation in villages (in Coimbatore district, Tamil Nadu) was studied, and it has been found to be considerably efficient. In the drip-irrigated villages, the net sown area has increased from 4.51 hectares to 5.31 hectares, while the gross cropped area has expanded from 4.77 hectares to 6.36 hectares (Kumar & Palanisami, 2010). According to a survey by Indian Council of Agricultural Research (ICAR), drip irrigation approach has enabled the tribal farmers to earn between 1.5 and 1.7 lakhs income per hectare in a single season of vegetable cultivation.

Furrow Bed (Raised Bed) Irrigation:

This irrigation method is widely used across the globe for surface irrigation. It's often considered a more water-efficient technique compared to traditional systems like flat basins due to its ability to swiftly move water to lower areas within an area (Gillies et al., 2008). The furrow bed irrigation technology increase crop output, decrease irrigation losses, and increase water productivity (Akbar et al., 2020). While regarded as highly efficient among surface irrigation methods, achieving maximum output and water conservation through this technique necessitates meticulous management of land, water, and irrigation practices (Akbar et al., 2020). One of the crucial benefits of using furrow bed systems is the efficient irrigation application. Water savings of up to 29% in rice, 30% in maize, 40% in cotton, and 50% in wheat have been recorded by various researchers (Ahmad et al., 2009; Akbar et al., 2017; Hassan et al., 2005). However, furrow bed irrigation is a traditional irrigation method that uses a lot of water and so has to be improved to increase its water usage efficiency (Jat et al., 2011; Sarker et al., 2016). Furrow irrigation can be quite efficient under favourable soil conditions with proper management and design (Clemmens & Dedrick, 1994). Reviving the old practice with proper management and scientific method will be very beneficial as it is low cost than the other methods of irrigation.

Sprinkle irrigation:

Sprinkler irrigation is widely in practice as it is efficient in uneven land where water is deficit. Sprinkler irrigation is a significant step forward from traditional surface irrigation. It promotes natural rainfall by disseminating water in the form of rain that falls equally throughout the land surface as needed, in the required quantity, and in a consistent way (Patel & Prajapati, 2020). Water losses can be further decreased by using sprinkler method by practicing at night because evaporation losses are smaller. The performance of sprinklers aids in the choosing of a cropping system approach (Hashim et al., 2021). Evaporation losses, uniform distribution, and wind drift stand as primary factors influencing the performance of sprinkler systems within highly efficient irrigation methods (Mikkelsen, 2000). It should be noted that such practice needs proper maintenance and continuous monitoring and also the expenses are higher than other practices.

Manure and weed management system:

Green manure:

Green manuring, an ancient practice, utilizes organic matter to improves soil fertility and crop yields. It enhances water retention, reduces use of artificial fertilizer, reduces climate change effects and boosts soil nutrients and crop quality (Prajapati et al., 2023). After the development of the pesticide industry following the world war II, the use of green manure (GM) in modern agricultural systems was largely replaced by synthetic fertilizers, weeds and pesticides (Dinnes et al., 2002; Smil, 2001). Green manure (GM) that is mainly used as a soil conditioner and as a nutrient source for subsequent crops. A green manure approach to crop production can prove to be economically feasible while reducing the environmental impact of agriculture (Cherr et al., 2006). Implementing green manure within agricultural soil is esteemed as an exceptional management practice due to its ability to stimulate the growth and function of soil microorganisms, leading to the mineralization of phytonutrients (Eriksen, 2005). An experiment was conducted by treating green manure in plots and resulted greater biomass (17.89 tons/ha) and rise in fertile tillers in wheat crops about 7.6% compared to non-green manuring fields. Further more, it also increases the soil moisture capacity, which is an integral component (Sajjad et al., 2018). The positive effect of green manure provides ecological benefits, particularly in tropical environments, as they increase nitrogen fixation and nutrient cycling (Adekiya et al., 2019; Kumar et al., 2020). Besides, it also maintains soil health, preserves the biodiversity and has great potential for sustainable crop production (Joshna et al., 2024).

Farmyard manure:

Farmyard manure, an assorted organic compost comprising a blend of dung, crop residues, and sometimes household waste at different decomposition stages, serves as a widely utilized organic soil amendment in numerous countries (Wang et al., 2017). In many nations, farmyard manure, which is consisting of decomposed organic waste made up of dung, crop leftovers, and/or home sweepings in various stages of decomposition, is a crucial component of sustainable agricultural productivity (Wang et al., 2017). A study examining the impact of combining farmyard manure with varying levels of chemical fertilizers (80:40:30 kg N, 120:60:45 kg P_2O_5, and 160:80:60 kg K_2O per hectare) discovered that the application of farmyard manure at a rate of 10 tons per hectare led to a 25% increase in rice yield (Satyanarayana et al., 2002). The replacement of FYM with fertilizers helps in maintaining ecological equilibrium as it remediates heavy metals and insecticides (Bhatt et al., 2023). Moreover, it positively impacts the physical, chemical, and biological aspects of the soil, leading to a decreased reliance on chemical fertilizers in a targeted, sustainable, and climate-smart manner. This approach not only helps mitigate the negative effects of global warming but also enhances the overall productivity of various crops in the area (Bhatt et al., 2023).

Compost:

In addition to the nitrogen value, using compost has other benefits, including use in increasing soil organic matter, refining soil tilt and aeration, and increase other phytonutrients such as potassium, phosphorus and some micronutrients (Gaskell et al., 2007; Mikkelsen, 2000). In low-input intensive farming, using animal waste composts with minimal inorganic fertiliser as a soil supplement has long been acknowledged as an important agricultural strategy for improving soil fertility and production (Tilman et al., 2002). Besides, compost has a significant carbon sink effect (Favoino & Hogg, 2008). Thus, increase in composting practices on-farm will allow to reduce other activities that shows negative impact on environments and deliver many agronomic, environmental and societal benefits, including carbon sequestration and GHG emission reductions (Jeong et al., 2019)

Weed management:

Weeds compete with crops for almost all the same resources, including water, nutrients, light, and CO_2. Also, they serve as alternate hosts for agricultural pests and pathogens. Many methods for eradication of weeds are developed besides the traditional weed management. However, the use of pesticides and insecticides are found to be harmful for the environment as well the human beings.An alternative and integral approach to weed management would be the most ideal option in this regard. Indirect (preventive) measures should be used with direct (cultural and curative) methods in weed management strategies. The first category includes all techniques used before a crop is sown, whereas the second category includes all techniques used as a crop is growing. Weed management practices includes:

Cultural method:
Cultural weed control involves techniques like crop rotation, cover crops, inter cropping, sanitation, mulching, planting pattern, tillage system, variety selection are some methods that can eradicate weed (Sims et al., 2018). In India, tribes such as the Apatani and Dongria Kondh include traditional weeding techniques as part of broader climate-adaptive practices. These methods support agro-biodiversity, maintain soil fertility, and reduce reliance on chemical inputs that contribute to environmental degradation (Aich et al., 2022). However, cultural method alone cannot control or reduce the weed so various strategies are developed for the weed management.Using cultural methods to control weeds requires constant vigilance and monitoring. Also, several practices are labour-intensive.

Mechanical method:
Mechanical method of weed management is an old practice and still used by the small farms. Hoeing, tilling, harrowing, torsion weeding, finger weeding, and brush weeding represent a selection of mechanical weed management methods typically employed during the initial stages of weed growth (Kewat, 2014). Mechanical weeding has proven to be a fast and efficient method for weed control (Quan et al., 2021; Rao et al., 2020) making it a more commonly adopted approach. In recent decades, excessive reliance on chemical herbicides has raise several new issues, such as rapid development of weed resistance, which ultimately affect sustainable weed management (Wang et al., 2019). However, traditional mechanical weeding methods includes tilling, turning, raking, and other techniques to uproot or cut weeds, are still limited in their ability to break up the soil and weed aggregates (Fang et al., 2022), often leaving some weeds behind (Wang & Chen, 2017). Thus, to overcome such limitations, researchers has introduce combining mechanical and chemical methods, both between and within crop rows, on weed control and crop growth (Fang et al., 2022).

Thermal method:
Thermal methods use temperature to kill the emerged weeds and weed seeds (Bond et al., 2003). Soil solarization stands as an initial thermal weed management method involving the heating of soil through the application of a plastic cover (Horowitz et al., 1983). This passive technique, known as soil solarization (SS) is commonly employed to treat polluted farmland in tropical areas (Samtani et al., 2017). It controls soil pests like bacteria, insects, and weeds while being environmentally benign. Flame weeding, which was recently utilised in thermal weed management uses an powerful wave of heat to burst plant cells (Bond et al., 2003; Hatcher & Melander, 2003). Flame-weeding systems vary, from small-scale handheld flamers used in vegetable cultivation to larger tractor-mounted equipment for burning weeds in extensive row-crop farming (Bond & Grundy, 2001). Thermal weed control employs flaming equipment that directly contacts the plant, triggering a rapid expansion of sap within plant cells, leading to their eventual rupture.This process can sometimes entirely incinerate the weeds as a method of heat control. Within organic farming, flame weeding stands out as a promising approach for managing weeds (Bond & Grundy, 2001; Datta & Knezevic, 2013). Additionally, its relevance in traditional crops

is gaining prominence owing to escalating herbicide expenses, unfavourable environmental consequences, and the rise of herbicide-resistant weeds (Boutin et al., 2004; Seifert & Snipes, 1996). Notably, flaming doesn't disrupt the soil or bring buried weed seeds to the surface, where they might sprout (Stepanovic, 2013). While the thermal approach effectively targets certain weeds, overuse could potentially diminish soil moisture levels.

Biological methods:

This method has gained popularity after recent experiment and studies. This method normally uses living organisms such as insects, snails, competitive weeds etc. There have been numerous successes in biological weed management around the world. Introduced agents such as insects and pathogens have effectively controlled 41 weed species, while three species (*Aeschynomene virginica*, *Morrenia odorata*, *Orobanche ramose*) are managed using native fungi employed as mycoherbicides (Mcfadyen, 2000). The introduction of organisms into an environment with the goal of suppressing one or more undesired species is known as biological control in general (Bailey et al., 2011). The inundative biological control technique is better appropriate for agricultural and lawn care demands since inoculum can be utilised similarly to conventional herbicides by applying it as liquid sprays or solid granules. Thus, the impact of biological control method is slower and doesn't show much effective in weeds of annual crops (McFadyen, 1998).

Pest management:

The number and variety of pest were less in the past. To combat the pest attack in the crops the use of pesticides increases rapidly. Continuous use of pesticides isa major problem in detouring the land and leads the land unfertile. Thus, climate-smart pest management (CSPM) practices are adopted. The CPSPM (Cross-sectoral Precision Sustainable Agriculture) strategy is a multi-faceted approach directed at enhancing ecosystem services, reducing greenhouse gas emissions per unit of food produced, and fortifying agricultural systems against the impacts of climate change. This involves collaborative efforts among crop production, extension services, research, and policy implementation aimed at enhancing the efficiency and resilience of food production systems through the adoption of CSPM principles (Heeb et al., 2019). Moreover, through the examination of historical weather and climate data, coupled with the development of specialized models predicting the probable dispersal of pest species across diverse climatic scenarios, pest risk forecasting emerges as a valuable tool. This tool facilitates proactive measures for pest prevention and control efforts (Heeb et al., 2016).

Post-harvest management:

The post-harvest management process involves handling, storing, and transporting agricultural commodities after harvest. However, the post-harvest management has gained a little importance as the loss of crops has hamper the investment of labour, time and also economy. Post-harvest management plays a primary role in the production, transport, and processing of food and all other products that provide sustenance to the world's population. Post-harvest management is very important in keeping and storing of the harvest products in order to prevent from damage and spoilage.The losses are usually classified into several categories, including weight loss from rotting, diminished quality, reduced nutritional value, loss of seed viability, and commercial losses (Boxall, 2001). Studies indicate that root crops, cereal crops, and fruits along with vegetables contribute to approximately 19%, 20%, and 44% of total agricultural commodity losses, respectively (FAO, 2011). As compared to industrial agriculturists in many parts of the world, post-harvest management can be challenging for smallholder farmers. Many modern techniques have been developed for conservation and handling the crops such as cool storage, chemicals, pesticides but in either way it is costly and directly or indirectly effect the environment. This is mainly because the small-business owners usually have limited resources, such as manpower, finances, inputs, etc. Adaptation practices include postharvest practices such as preventing pests from carrying over to grain storage. It can be done by timely harvesting and sorting and using controlled on-farm drying. Storage management practices such as sanitation, fumigation, and monitoring should be improved. Fig. 2 shows the effect of climate change on post-harvest agriculture. Some post-harvest management processes have been discussed below for:

Harvest:
A crucial operation in determining the overall crop quality is harvesting, the first step in the grain supply chain. In developing countries, crop harvesting is primarily done physically with different tools such as sickles, knives, scythes, and cutters. Combine harvesters are used almost exclusively in developed countries to harvest most of the crops.The date of harvesting and the type of harvesting (automated vs. manual) are key factors in determining harvesting losses. When harvesting operations are not performed at the appropriate maturity and moisture content, a great deal of losses occurs.Crops with high moisture content that are harvested too early incur high drying costs, mould growth, insect infestation, a high percentage of broken grains, and low milling yields. Even nations like India and Bangladesh experience manpower shortages during the height of harvest, which causes harvest to be delayed and leads to crop loss (Grover and Singh, 2013).

Threshing and cleaning:
Threshing is the process to loosen and detach of grains from the panicles. Delay in threshing after harvesting significantly increase the loss of quality and quantity of crops, susceptible increase of rodents and insect attack and increase moisture content due to exposure in atmosphere (Alavi, 2011).

The cleaning process removes cracked grains and other foreign contaminants such as straw, stones, sand, chaff, and weed seeds (Kumar & Kalita, 2017). When it comes to cleaning in underdeveloped countries, winnowing is the most common method. It is reported that a significant quantity of grain is lost during this procedure which can account for up to 4% of total production (Sarkar et al., 2013). Grains that have not been cleaned properly can be infested with insects or mould during storage, and they can add aflatoxins, undesired flavours or colors to the final product as well as damage processing equipment.

Drying:
The grains or cereals right after harvesting and cleaning cannot be stored directly as there is much possibility of fungal infestation and pest development. The drying process can be done either naturally (sun or shade drying) or mechanically (using a dryer). Sun drying, is a cost-effective technique and one that is most preferred by underdeveloped nations (Kumar & Kalita, 2017). The natural drying has some limitation and can be replaced by mechanical drying processes. A mechanical drying system has some advantages, including reduced management losses, more control over hot air temperature, and easier space utilization. However, its drawbacks include expensive initial and ongoing maintenance expenses, lack of available sizes, and inadequate operating skills, particularly for smallholders (Kumar & Kalita, 2017).

Storage:
Storage is the most important for preserving and maintaining cereals or grains. So, a proper way of storage will reduce the burden of farmers. Some grains become difficult to store till the next season due to unfavourable conditions prevail. The most frequent ways to accomplish this are to store them in structures made of different materials or to combine them with natural or chemical substances (Manandhar et al., 2018). Better storage practices are a key tactic for lowering possible crop losses and raising smallholders' income levels during climate shocks, boosting their climate resilience. As a result of better storing facilities, farmers will not

be forced to sell their crops immediately after harvesting, which increases their bargaining power, since they can delay selling and negotiate a higher price. Providing farmers with better and safer storage options, such as hermetic bags and pre-fabricated silos, is one of the main interventions under this component. Some of the various storage type practices are discussed below:

Conventional Storage:
Weevils, beetles, moths, and rats are the primary causes of losses, making proper storage essential to prevent these issues (Kartikeyan et al., 2009). 60–70% of the nation's food grain production is kept domestically in local storage facilities. Smallholder farmers generally build conventional storage structures out of materials that are readily available nearby, including mud, wood, bamboo, cow dung, and bricks. (Naik & Kaushik, 2010; Nukenine, 2010). In the developing countries of Asia, Africa and Latin America, woven granaries made out of bamboo and straws are very commonly practice (Moreno et al., 2006).

Conventional storage has advantages in storing grains, prevent spillage also resistant against pest and rodents and keep protected from the outside environment. Although it has some disadvantages such as air and moisture can pass through the structure and promotes the growth of mould and pest (Manandhar et al., 2018). There were several problems associated with traditional modes of grain storage, so some modifications have been made to provide improved grain storage structures for farmers.

Warehouses Community: Warehouses serve as scientific storage structures built to keep goods in good condition. The Central Warehousing Corporation manages 120 agricultural and industrial commodities in safe, reliable storage facilities. It is a storage facility provided by the government or community in the form of a ware house or cover and plinth (CAP) structure to help smallholders in developing countries to pay fees for a specific period, as well as to record information and keep records (Naik & Kaushik, 2010,). This type of storage solution allows for large-scale grain storage, protects grain from the elements, and is cost-effective; however, it is ineffective against rodents, insects, pests and mould.

Community Storage Structures and On-Farm Storage: These are made near the farm itself, and may either be temporary or permanent. These storage buildings provide farmers with a great deal of flexibility and control over their lands. Such storage practices significantly reduce time, labour costs, and transport costs.On-farm storage structures and collective storage facilities could be beneficial for smallholder farmers in rural areas of developing countries, especially when tailored to the needs of small groups or cooperatives of farmers (Manandhar et al., 2018).

Hermetic metals: In recent years, a storage method known as Punjab Agricultural University (PAU) bins has gained popularity as an alternative to chemical-based storage (Manandhar et al., 2018). These bins serve as a barrier to moisture exchange between the interior and exterior environments of the storage structure, effectively inhibiting mold growth (Bbosa et al., 2017; Chigoverah & Mvumi, 2016; Hell et al., 2014). Besides, it is resistant to rodents, birds and insect as well. An examination of smallholder farmers indicated that utilizing silos enabled them to store grain for an extended period, approximately 1.8 to 2.4 months longer, with an average loss of only 3 kg of grain. In contrast, non-adopters experienced losses ranging from 157 to 198 kg of grain, valued at \$104 to \$132 on average (Manandhar et al., 2018).

Hermetic Bagging Technology: To protect grains, modern technology bags are created by combining high-density polyethylene (HDPE) bags with an extra layer of polypropylene or utilizing conventional bags. Among these, two types of hermetic bags stand out: the Purdue Improved Crop Storage (PICS) bags and the Super Grain Bags (Manandhar et al., 2018).

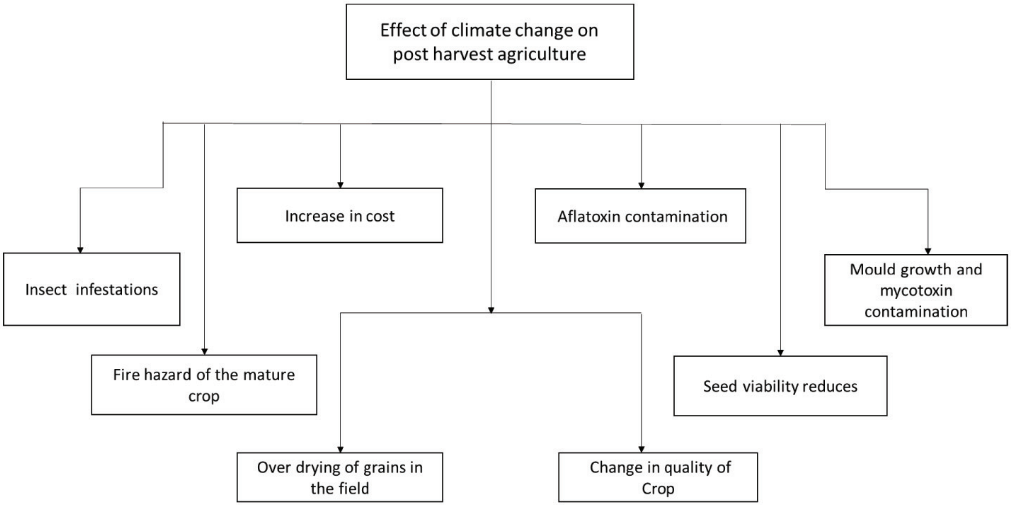

Figure 2. Consequence of Climate Change on Post-Harvest Agriculture

Research indicates that both types of bags are significantly more effective than conventional woven plastic bags in managing pests and minimizing grain losses (Baoua et al., 2013). In a case study, a comparison of hermetic bags, plastic container and jute bags of green gram was kept for 180 days where amount of moisture, insect manifestation, microbial load and weight was calculated. The moisture content decreased a little compared to others while the insect population drastically reduced by 30 days and reached to zero by 60days (Yewle et al., 2020). However, Physical damage and punctures decrease the reusable life of bags, therefore increasing the cost of the system (Manandhar et al., 2018). Fig.2 shows the consequence of Climate Change on Post-Harvest Agriculture. In Table 1, Climate Resilient Agricultural Practices are listed below.

Constrains for adaptation of Climate Resilient Practices:

The increased input of agrochemicals as a result of green revolution excessively affecting the microbial community of soil ecosystem. To deal with the dual difficulties of increased food demand to feed the expanding population and lowering the environmental impact of agriculture, this severely restricts the interactions within soil (Godfray et al., 2010; Srivastava et al., 2016). As a new paradigm for crop production, climate resilient agriculture will provide a sustainable solution to meet the various and context-specific needs of the present. Climate resilience is built on the People-Planet-Profit (P3P) framework of sustainable development goals (Arulbalachandran et al., 2017). However, a multitude of socioeconomic, technological, infrastructural and institutional obstacles prevent the effective implementation of solutions for adaptation or resilience to climate change. For the current climate change situation, it is crucial to recognise and overcome these obstacles in order to locate relevant opportunities (Eisenack et al., 2014). To overcome the uncertainties of climate change on agriculture, the farmers must play an important role by adopting alternate strategies in their farming practices. Few of the major barriers for adoption and adaptation to climate resilient practices by the farmers are discussed as follows (Table 2):

Limited knowledge:

Climate resilient agriculture is a complex system and performance of the system greatly depends on efficient management. The most important constrained for adaptation of climate resilient practices is the partial knowledge especially site-

Table 1: Climate Resilient Agricultural Practices

Methods			Result	References
Soil preparation		Strip Tillage	Saves water by 25%-26% and also increase yields compare to conventional soil preparation.	Licht & Al Kaisi, 2005 Hendrix et al., 2004 Islam et al., 2012 Hossain et al., 2015
		Zero Tillage	Rice-pea cultivation for 3 consecutive years, gross turn to be much higher than conventional ploughing.	ATARI ICAR, 2020 Prasad et al., 2014 Tripathi et al., 2016
		Contour tillage	Reduce sediments by 35.8% when compared to the baseline value also reduce runoff velocity, boosts infiltration.	Wang et al., 2017 Farahani et al., 2016 Gathagu et al., 2018
Seed selection and treatment			Mon district of Nagaland demonstrated a short duration variety of Soybean and results in a good percentage of yield.	Mathad et al., 2013 ATARI ICAR, 2019
Water management and irrigation techniques				
		Drip irrigation	Drip irrigation approach has enabled the tribal farmers to earn between 1.5 and 1.7 lakhs per hectare of vegetation production in a single season.	Narayanamoorthy, 1997
		Furrow bed irrigation	Water savings of up to 50% in wheat, 30% in maize, 40% in cotton, and 29% in rice have been recorded by various researchers.	Akbar et al., 2020 Ahmad et al., 2009 Akbar et al., 2017 Hassan et al., 2005
Manure and weed management				
	Manure	Farmyard	Rice grain output improved by 25% when farmyard manure was applied at a rate of 10 tonnes per hectare in comparison to when it wasn't.	Asai et al., 2021 Satyanarayana et al., 2002
		Compost	Increases other phytonutrients like phosphate, potassium, and several micronutrients, as well as soil tilth and aeration.	Buchanan &Gliessman, 1991, Gaskell et al., 2007
	Weed	Biological method management	*Aeschynomene virginica,Morrenia odorata Orobanche ramose,* are controlled using native fungus used as mycoherbicide.	Mikkelsen, 2000 Bailey et al., 2011 Mcfadyen, 2000
Post-Harvest management				
	Storage	Conventional	Prevents spillage also resistant against pest and rodents and keep protected from the outside environment.	Naik & Kaushik, 2010 Nukenine, 2010
		Hermetic Bagging Technology	Bags shows much effective compared to conventional woven plastic bags in controlling pest and limiting grains.	Manandhar et al., 2018 Baoua et al., 2013

specific knowledge on climate change and importance of adoption measures. The performance of the system also demands the understanding of basic processes and component interactions. Crop residues left on the surface function as a natural mulch, prevent soil water loss owing to evaporation, and sustain a reasonable temperature regime (Gupta & Jat, 2010). In addition to this, crop leftovers can harbour pest populations, change the ecosystem, and act as an easily decomposable substrate of organic matter. No-tillage systems will have an impact on the root system's distribution and depth of penetration, which will then have an impact on the uptake of water, nutrients, and minerals. However, the fact that if the climate resilient practices are not applied in combination might not show the desired results. Thus, there is a need to identify the practices and develop management strategies for the success of adoption of the climate resilient agricultural practices.

Lack of skilled and scientific manpower:

A team of researchers, extension agents, scientists, farmers, and other stakeholders must collaborate to manage climate resilient agricultural systems. The process for prioritising research and resource allocation must be established within a framework that calls for improved scientific capacity to approach problems from a systems viewpoint. Some of the gaps between farmers and the policy makers/ scientific community include the inadequate number of extension functionaries at the grassroots level, insufficient weather-based crop warnings, a lack of knowledge on water-efficient crops, etc. However, establishing connections and looking for partners in comparable sectors is not given much emphasis. Therefore, mechanisms such as strengthening knowledge and sharing of information among different stakeholders are needed.

Technological challenges:
One of the key challenges of climate resilient agriculture is adoption of basic principles of resilient agriculture *i.e.*, no-tillage and surface managed crop residue management practices. The limitations for adoption of such practices arise from the access to the farm machineries and understanding of these practices by small and medium scale farmers. Development of low-cost farm machineries, standardization for site/region specific needs, training and subsidy on the machineries might aid to overcome these constraints.

Socio-economic barriers:
The adoption of climate resilient management strategies is hampered by the high cost of agricultural inputs and the absence or restricted availability of agricultural markets. Resource improvement and benefits out of these practices come only after a considerable time. Indeed, benefits with respect to increased yield may come after many cycles of cultivation rather than early years of implementing. Some of the socio-economic obstacles to the adoption of climate resilient agricultural practices include a lack of awareness of the need to adapt to climate change, an absence of understanding of the social costs and benefits of adaptation, uncertainty regarding the effectiveness of climate resilient strategies and technologies, and financial and farm size restrictions. Enhancing the farmers' capacity for adaptation requires addressing these issues delay their ability to adjust. Some of the possible limitations regarding the use of climate resilient agricultural practices are listed in Table 2.

Conclusion

In conclusion, climate-resilient agricultural practices are crucial for ensuring the sustainability of Indian agriculture and coping with changing climatic conditions. By focusing on improved soil preparation, strategic seed selection and treatment, efficient water management and irrigation techniques, along with effective manure, weed, and pest management, farmers can alleviate climate change impacts. In addition to these practices

Table 2: Limitations regarding the use of climate resilient agricultural practices.

Limitations	Explanation	Reference
CRA is a complex system and limited knowledge is available	Understanding the basic processes and interactions of components is also critical for the performance of the system. For instance, crop residues that are left on the soil's surface serve as a mulch, cut down on water loss due to evaporation, and maintain a stable soil temperature.	Gupta & Jat, 2010
Lack of skilled and scientific manpower and technological barrier	An efficient and core group of scientists, workers, farmers and stakeholder who know the scientific know how and also necessities is lacking in many CRA practices that leads to failure in many cases. Utilizing participatory and empowering methodologies, smallholder farmers can be included in the definition of research priorities as well as the design and execution of research, which is one of the best ways to ensure that research results address the complex social, economic, and ecological settings of smallholders.	Pretty et al., 2011
High cost of farm machinery	The high cost of farm inputs and the lack of access to formal credit and agricultural markets reduce the ability of farmers to adopt climate resilient management practices.	Kumar et al., 2020

improved and efficient post-harvest techniques is vital to reduce losses and improve food security. Together, these practices not only protect crops from climate stress but also promote long-term agricultural productivity and sustainability in India. Proper implementation of the people–planet–profit aspects to achieve a single goal, i.e., climate resilience is an urgent necessity in today's world. However large scale on field execution of advanced farm practices along with indigenous knowledge is required for better result.

Acknowledgement

The authors extend their heartfelt gratitude to the Department of Science and Technology (DST), Ministry of Science and Technology, India, for their invaluable support and contribution.

Reference

Adekiya, A. O., Agbede, T. M., Aboyeji, C. M., Dunsin, O. and Ugbe, J. O. 2019. Green manures and NPK fertilizer effects on soil properties, growth, yield, mineral and vitamin C composition of okra (*Abelmoschus esculentus* (L.) Moench). J. Saudi Soc. Agric. Sci. 18(2):218-223.

Adeyemi, O., Grove, I., Peets, S. and Norton, T. 2017. Advanced monitoring and management systems for improving sustainability in precision irrigation. Sustainability. 9(3): 353.

Ahmad, N., Arshad, M., and Shahid, M. A. 2009. Bed-furrow system to replace conventional flood irrigation in Pakistan. In Proceedings of 59th IEC Meeting and 20th ICID, India.

Aich, A., Dey, D., and Roy, A. 2022. Climate change resilient agricultural practices: A learning experience from indigenous communities over India. PLOS Sustainability and Transformation. 1: 7.

Akbar, G., Asif, M., Islam, Z. and Hameed, S. 2020. Furrow bed irrigation system: Installation and management. Pak. J. Agric. Res. 33(2): 406-413.

Akbar, G., Raine, S., McHugh, A. D., Hamilton, G. and Hussain, Q. 2017. Strategies to Improve the Irrigation Efficiency of Raised Beds on Small Farms. Sarhad J. Agric. 33(4).

Alavi, H. R. 2011. Trusting trade and the private sector for food security in Southeast Asia. World Bank Publications.

Arulbalachandran, D., Mullainathan, L., Latha, S. 2017. Food Security and Sustainable Agriculture. In: Dhanarajan, A. (eds), Sustainable Agriculture towards Food Security, Springer.

Asai, H., Rabenarivo, M., Andriamananjara, A., Tsujimoto, Y., Nishigaki, T., Takai, T. and Razafimbelo, T. 2021. Farmyard manure application increases spikelet fertility and grain yield of lowland rice on phosphorus-deficient and cool-climate conditions in Madagascar highlands. Plant Prod. Sci. 24(4): 481-489.

ICAR-ATARI (ICAR- Agricultural Technology Application Research Institute Umiam, Meghalaya) 2019. Climate Smart Villages of North Eastern Hill States of India [online]. Available:https://www.icarzcu3.gov.in/book_publications/Climate%20Smart%20Village%20Final_compressed.pdf

ICAR-ATARI (ICAR-Agricultural Technology Application Research Institute, Zone-I, Ludhiana, Punjab) 2020. Promoting Climate Resilient Agriculture Journey of 51 Climate Smart Villages [online]. Available:https://atariz1.icar.gov.in/pdf/Promoting%20Climate%20Resilient%20Agriculture.pdf

Bailey, K. L., Pitt, W. M., Falk, S. and Derby, J. 2011. The effects of Phomamacrostoma on nontarget plant and target weed species. Biol. Control. 58(3): 379–386.

Baoua, I. B., Amadou, L., Lowenberg-DeBoer, J. D. and Murdock, L. L. 2013. Side by side comparison of GrainPro and PICS bags for postharvest preservation of cowpea grain in Niger. J. Stored Prod. Res. 54: 13-16.

Bbosa, D., Brumm, T. J., Bern, C. J., Rosentrater, K. A., & Raman, D. R. 2017. Evaluation of Hermetic Maize Storage in 208 Liter (55 Gal) Steel Barrels for Smallholder Farmers. Transactions of the ASABE, 60(3): 981-987.

Bhatt, R., Naresh, R.K., Tiwari, H., Singh, P.K., Das, D., Kumar, M., Banik, R. and Tomar, G., 2023. Farm-yard manure as a resource for integrated nutrient management. The Pharma Innovation Journal. 12(4): 672-681

Bond, W. and Grundy, A. C. 2001. Non chemical weed management in organic farming systems. Weed Res. 41(5): 383–405.

Bond, W., Turner, R. J., and Grundy, A. C. 2003. A review of non-chemical weed management. HDRA, the Organic Organisation, Ryton Organic Gardens, UK.https://agricology.co.uk/sites/default/files/updated_review.pdf

Boutin, C., Elmegaard, N. and Kjaer, C. 2004. Toxicity testing of fifteen non-crop plant species with six herbicides in a greenhouse experiment: implications for risk assessment. Ecotoxicology. 13(4): 349–369.

Boxall, R. A. 2001. Post-harvest losses to insects—a world overview. Int. Biodeterior. Biodegradation. 48(1-4): 137-152.

Buchanan, M. and Gliessman, S. R. 1991. How compost fertilization affects soil nitrogen and crop yield. BioCycle. 32(12): 72–77.

Carter, M. R. and Ivany, J. A. 2006. Weed seed bank composition under three long-term tillage regimes on a fine sandy loam in Atlantic Canada. Soil Tillage Res. 90(1-2): 29-38.

Chartzoulakis, K. and Bertaki, M. 2015. Sustainable water management in agriculture under climate change. Agri. Agricul. Sci. Procedia. 4: 88-98.

Cherr, C. M., Scholberg, J. M. S. and McSorley, R. 2006. Green manure approaches to crop production: A synthesis. J. Agron. 98 (2): 302-319.

Chigoverah, A. A. and Mvumi, B. M. 2016. Efficacy of metal silos and hermetic bags against stored-maize insect pests under simulated smallholder farmer conditions. J. Stored Prod. Res. 69: 179-189.

Clemmens, A. J. and Dedrick, A. R. 1994. Irrigation techniques and evaluations. In: Clemmens, A. J. and Dedrick, A. R.(eds), Management of water use in agriculture. Springer, Berlin, Heidelberg, 64-103.

EC (Commission of the European Communities) 2002. Communication from the commission to the council, the European parliament, the economic and social committee and the committee of the regions[online]. Available:https://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=COM: 2002:0179:FIN:EN:PDF

Corell, M., Centeno, A., Galindo, A., Collado-gonzález, J., Gri, I., Girón, I. F., Rodríguez, P., Cruz, Z. N., Memmi, H. and Pérez-lópez, D. 2018. Deficit irrigation and emerging fruit crops as a strategy to save water in Mediterranean semiarid agrosystems. Agric. Water Manag. 202: 311–324.

Datta, A. and Knezevic, S. Z. 2013. Flaming as an alternative weed control method for conventional and organic agronomic crop production systems: a review. Adv. Agron. 118: 399–428.

Dinnes, D. L., Karlen, D. L., Jaynes, D. B., Kaspar, T. C., Hatfield, J. L., Colvin, T. S. and Cambardella, C. A. 2002. Nitrogen management strategies to reduce nitrate leaching in tile drained Midwestern soils. J. Agron. 94(1): 153-171.

Eisenack, K., Moser, S.C., Hoffmann, E., Klein, R.J., Oberlack, C., Pechan, A., Rotter, M. and Termeer, C.J. 2014. Explaining and overcoming barriers to climate change adaptation. Nat. Clim. Change. 4(10): 867-872.

El-Shater, T.; Mugera, A.; Yigezu, Y.A. 2020. Implications of Adoption of Zero Tillage (ZT) on Productive Efficiency and Production Risk of Wheat Production. Sustainability. 12, 3640.

English, M. 1990. Deficit irrigation. I: Analytical framework. J. Irrig. Drain. 116(3): 399-412.

English, M., James, L. and Chen, C. F. 1990. Deficit irrigation. II: Observations in Columbia basin. J. Irrig. Drain. Eng. 116(3): 413-426.

Eriksen, J. 2005. Gross sulphur mineralisation–immobilisation turnover in soil amended with plant residues. Soil Biol. Biochem. 37(12): 2216–2224.

Fang, H., Niu, M., Wang, X., and Zhang, Q. 2022. Effects of reduced chemical application by mechanical-chemical synergistic weeding on maize growth and yield in East China.Front. Plant Sci. 13.

Farahani, S. S., Fard, F. S. and Asoodar, M. A. 2016. Effects of contour farming on runoff and soil erosion reduction: a review study. Elixir Agriculture, 101(1): 44089-44093.

Favoino, E., and Hogg, D. 2008. The potential role of compost in reducing greenhouse gases.Waste Manag. Res. 26(1), 61–69.

Fereres, E. and Soriano, M. A. 2007. Deficit irrigation for reducing agricultural water use. J. Exp. Bot. 58(2): 147-159.

FAO. 2021. The State of Food and Agriculture 2021. Making agrifood systems more resilient to shocks and stresses. Rome, FAO.

FAO. 2010. Climate-Smart Agriculture Policies, Practices and Financing for Food Security, Adaptation and Mitigation. Rome, FAO.

FAO. 2011. Global food losses and food waste – Extent, causes and prevention. Rome, FAO.

Garg, K. K., Karlberg, L., Barron, J., Wani, S. P. and Rockstrom, J. 2012. Assessing impacts of agricultural water interventions in the Kothapally watershed, Southern India. Hydrol. Process. 26(3): 387-404.

Gaskell, M., Smith, R., Mitchell, J., Koike, S.T., Fouche, C., Hartz, T., Horwath, W. and Jackson, L., 2007. Soil fertility management for organic crops, University of California, Division of Agriculture and Natural Resources.

Gathagu, J. N. A. A., Mourad, K. A., and Sang, J. 2018.

Effectiveness of contour farming and filter strips on ecosystem services. Water, 10(10): 1312.

Gillies, M.H., Smith, R.J. and Raine, S.R., 2008. A review of Basin (Contour) Irrigation Systems II: Research needs for evaluation and design. National Centre for Engineering in Agriculture, University of Southern Queensland.

Godfray, H. C., Beddington, J. R., Crute, I. R., Haddad, L., Lawrence, D., Muir, J. F., Pretty, J., Robinson, S., Thomas, S. M., Toulmin, C. 2010. Food security: the challenge of feeding 9 billion people. Science.

Grover, D., Singh, J. 2013. Post-harvest losses in wheat crop in Punjab: past and present. AERR, 26: 293–297.

Gupta, R. and Jat. M. L. 2010. Conservation agriculture: addressing emerging challenges of resource degradation and food security in South Asia. Behera, U. K., Das, T. K., Sharma, A. R. (Eds), Conservation Agriculture, Division of Agronomy. Indian Agricultural Research Institute, 1-18.

Hamill, T. M., Whitaker, J. S. and Wei, X. 2004. Ensemble reforecasting: Improving medium-range forecast skill using retrospective forecasts. Mon. Weather Rev. 132: 1434–1447.

Hashim, S., Khan, A. A., Ikram, R. M., Mehvish, F., Saifullah, M., Ali, M. and Almalki, M. 2021. Performance evaluation of indigenous floppy sprinkler irrigation system for various crops water management. J. King Saud Univ. Sci. 33(8): 101636.

Hassan, I., Hussain, Z. and Akbar, G., 2005. Effect of permanent raised beds on water productivity for irrigated maize–wheat cropping system. Australian Centre for International Agriculture Research Proceeding, 121.

Hatcher, P. E. and Melander, B. 2003. Combining physical, cultural and biological methods: prospects for integrated non chemical weed management strategies. Weed Res. 43(5): 303-322.

Heeb, L., Jenner, E. and Cock, M. J. W. 2019. Climate smart pest management: building resilience of farms and landscapes to changing pest threats. J Pest Sci. 92(3): 951–969.

Heeb, L., Jenner, W. and Romney, D. 2016. Promising innovative extension approaches for climate-smart agriculture: the plantwise example. Supporting agricultural extension towards climate smart agriculture: an overview of existing tools. GACSA. 50-57.

Hell, K., Ognakossan, K. E. and Lamboni, Y. 2014. PICS hermetic storage bags ineffective in controlling infestations of Prostephanus truncatus and Dinoderus spp. in traditional cassava chips. J. Stored Prod. Res. 58: 53-58.

Hendrix, B. J., Young, B. G. and Chong, S. 2004. Weed management in strip tillage corn. J. Agron. 96(1): 229–235.

Horowitz, M., Regev, Y. and Herzlinger, G. 1983. Solarization for weed control. Weed Sci. 31(2): 170-179.

Hossain, M. M., Begum, M., Rahman, M. M. and Hashem, A. 2015. Response of T. Aman and Boro rice to residue retention under strip tillage. Bangladesh agron. J. 18(2): 39-44.

Islam, A. K. M. S., Hossain, M. M., Saleque, M. A., Rahman, M. A., Karmakar, B. and Haque, M. E. 2012. Effect of minimum tillage on soil properties, crop growth and yield of aman rice in drought prone northwest Bangladesh. Bangladesh agron. J. 15(1): 43-51.

James, A. J., Bahadur, A. V., Verma, S., Reid, P. and Biswas, S. 2018. Climate-resilient water management: An operational framework from South Asia. International Water Management Institiute, Oxford Policy Management.

Jat, H. S., Datta, A., Choudhary, M., Sharma, P.C., Yadav, A.K., Choudhary, V., Gathala, M. K., Jat, M.L. and McDonald, A., 2019. Climate Smart Agriculture practices improve soil organic carbon pools, biological properties and crop productivity in cereal-based systems of North-West India. Catena. 181, 104059.

Jat, M. L., Gupta, R., Saharawat, Y. S. and Khosla, R. 2011. Layering precision land levelling and furrow irrigated raised bed planting: Productivity and input use efficiency of irrigated bread wheat in Indo-Gangetic Plains. Am. J. Plant Sci. 2(04): 578.

Jeong, S. T., Cho, S. R., Lee, J. G., Kim, P. J., and Kim, G. W. 2019. Composting and compost application: Trade-off between greenhouse gas emission and soil carbon sequestration in whole rice cropping system. J. Clean. Prod. 212: 1132–1142.

Joshna, A., and Bokado, K. 2024. Green Manure for Sustainable Crop Production: A Review.Int. J. Environ. Clim. 14(5): 147-156.

Karthikeyen, C., Veeraragavathatham, D., Karpagam, D. and Firdouse, A. S. 2009. Indigenous storage structures. IJTK, 8(2), 225-229.

Kewat, M. L. 2014. Improved weed management in Rabi crops. Improved weed management in rabi crops. National Training on Advances in Weed

Management. 22-25.

Kooij, S. Van Der, Zwarteveen, M., Boesveld, H. and Kuper, M. 2013. The efficiency of drip irrigation unpacked. Agric. Water Manag. 123: 103–110.

Kumar D. and Kalita P. 2017. Reducing postharvest losses during storage of grain crops to strengthen food security in developing countries. Foods.

Kumar S, Samiksha and Sukul P 2020. Green manuring and its role in soil health management. Soil Biol. 59:219-241.

Kumar, D. S. and Palanisami, K. 2010. Impact of drip irrigation on farming system: evidence from southern India. Agric. Econ. Res. Rev. 23(2): 265-272.

Laxmi, V., Erenstein, O. and Gupta, R. K. 2008. Impact of Zero Tillage in India' s Rice-Wheat Systems. Soil Till Res. 100: 1-14

Leskovar, D., Othman, Y. and Dong, X. 2016. Soil Tillage Research Strip tillage improves soil biological activity, fruit yield and sugar content of triploid watermelon. Soil Tillage Res. 163: 266–273.

Licht, M. A. and Al Kaisi, M. 2005. Corn response, nitrogen uptake, and water use in strip tillage compared with no tillage and chisel plow. J. Agron. 97(3): 705–710.

Maheswari, M. 2017. Enhancing tolerance to climatic stresses in rainfed crops: The road ahead. In: Belavadi, V.V., Nataraja K.N. and Gangadharappa, N.R. (Eds), Agriculture under Climate Change: Threats, Strategies and Policies. Allied Publishers, 105-111.

Manandhar, A., Milindi, P. and Shah, A. 2018. An overview of the post-harvest grain storage practices of smallholder farmers in developing countries. Agriculture. 8(4): 57.

Mathad, R. C., Vasudevan, S. N., Mathad, N. C. and Patil, S. B. 2013. Traditional seed treatment and storage methods of northeastern region of Karnataka. Asian Agri-History. 17(3): 233-239.

McFadyen, R. C. 2000. Successes in biological control of weeds. In: Spencer , N. R., (Eds) Proceedings of the X international symposium on biological control of weeds. Montana State University Bozeman, USA, 3-14.

McFadyen, R. E. C. 1998. Biological control of weeds. Annu. Rev. Entomol. 43(1): 369-393.

Mikkelsen, R. L. (2000). Nutrient management for organic farming: A case study. J. Nat. Sci. Res., *29*(1), 88-92.

Moreno, L. L., Tuxill, J., Moo, Y., Reyes, L. A., Alejo, J. C. and Jarvis, D. I. 2006. Traditional Maize Storage Methods of Mayan Farmers in Yucatan, Mexico: Implications for Seed Selection and Crop Diversity. BiodiversConserv. 15: 1771–1795.

Naik, P. S. N. and Kaushik, G. 2010. Grain Storage in India: An Overview. J. Post Harvest. Technol. 1–6.

Narayanamoorthy, A. 1997. Economic viability of drip irrigation: An empirical analysis from Maharashtra. Indian J. Agric. Econ. 52(4): 728-739.

NICRA-ICAR. 2013. Climate resilient agriculture. http://www.nicra-icar.in/nicrarevised/images/Books/NICRA Climate Resilient Agriculture Brochure.pdf

Nukenine, E. N. 2010. Stored product protection in Africa: Past, present and future. Julius-Kühn-Archiv, (425): 26.

Panneerselvam, P., Kumar, U., Senapati, A., Parameswaran, C., Anandan, A., Kumar, A., and Nayak, A. K. (2019). Influence of elevated CO2 on arbuscular mycorrhizal fungal community elucidated using Illumina MiSeq platform in sub-humid tropical paddy soil. Appl. Soil Ecol. 145: 103344.

Parry, M. L., Canziani, O., Palutikof, J., Van der Linden, P. and Hanson, C. 2007. Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC (Vol. 4). Cambridge University Press, UK.

Patel, N. H. and Prajapati, C. R. 2020. Agricultural Sprinkler for Irrigation System. Int. J. Eng. Res. Technol. 9, 162-166.

Postel, S. L. 1998. Water for food production: will there be enough in 2025?. BioScience, 48(8), 629-637.

Postel, S., Polak, P., Gonzales, F. and Keller, J. 2001. Drip irrigation for small farmers: A new initiative to alleviate hunger and poverty. Water Int. 26(1): 3-13.

Prajapati, S. K., Dayal, P., Kumar, V., and Gairola, A. 2023. Green Manuring: A Sustainable Path to Improve Soil Health and Fertility. International Journal, 1(2), 24–33.

Prasad, Y. G., Maheswari, M., Dixit, S., Srinivasarao, C., Sikka, A. K., Venkateswarlu, B., Sudhakar, N., Prabhu Kumar, S., Singh, A. K., Gogoi, A.K. and Singh, A. K. 2014. Smart practices and technologies for climate resilient agriculture. Central Research Institute for Dryland Agriculture (ICAR), Hyderabad, 76(3).

Press Information Bureau Government of India, Ministry of Agriculture & Farmers, https://pib.gov.in/newsite/PrintRelease.aspx?relid=199780

Pretty, J., Toulmin, C., and Williams, S. 2011. Sustainable intensification in African agriculture.IJAS. 9(1): 5-24.

Quan, L., Jingyu, Z., Wei, J., Hengda, L. I., Chunjie, Y., and Xilin, Z. 2021. Development and Experiment of Intra-row Weeding Robot System Based on Protection of Maize Root System. NongyeJixieXuebao/Transactions of the Chinese Society of Agricultural Machinery. 52(12).

Rao, A. N., Singh, R. G., Mahajan, G., and Wani, S. P. 2020. Weed research issues, challenges, and opportunities in India. Crop Prot. 134: 104451.

Rao, C. S., Gopinath, K. A., Prasad, J. V. N. S. and Singh, A. K. 2016. Climate resilient villages for sustainable food security in tropical India: concept, process, technologies, institutions, and impacts. Adv. Agron. 140: 101-214.

Reddy, V. R., Shiferaw, B., Bantilan, M. C. S., Wani, S. P. and Sreedevi, T. K. 2007. Collective Action for Integrated Watershed Management in Semi-Arid India: Strategic Policy and Institutional Options. Strategic Assessments and Development Pathways for Agriculture in the Semi-Arid Tropics.

Roy, S. S., Ansari, M. A., Sharma, S. K., Sailo, B., Devi, C. B., Singh, I. M. and Ngachan, S. V. 2018. Climate resilient agriculture in Manipur. Curr. Sci. 115(7): 1342-1350.

Sajjad M R, Subhani A, Rafique R, Hussain T, Naseem W, Bibi R and Malik S N 2018. Greenmanuring for moisture conservation and wheat yield improvement in rainfed agriculture. J. Nat. Sci. 8(9):33-41.

Samtani, J. B., Derr, J., Conway, M. A. and Flanaganiii, R. D. 2017. Evaluating soil solarization for weed control andstrawberry (Fragariaxananassa) yield in annual plasticultureproduction. Weed Technol. 31: 455-463.

Sarkar, D., Datta, V. and Chattopadhyay, K. S. 2013. Assessment of pre- and post-harvest losses in rice and wheat in West Bengal. Agro-Economic Research Centre, Visva-Bharati, Santiniketan: Santiniketan, India.

Sarkar, S., Basu, B., Kundu, C. K. and Patra, P. K. 2012. Deficit irrigation: An option to mitigate arsenic load of rice grain in West Bengal, India. Agric. Ecosyst. Environ. 146(1): 147-152.

Sarker, K. K., Akanda, M. A. R., Biswas, S. K., Roy, D. K., Khatun, A. and Goffar, M. A. 2016. Field performance of alternate wetting and drying furrow irrigation on tomato crop growth, yield, water use efficiency, quality and profitability. J. Integr. Agric. 15(10): 2380-2392.

Satyanarayana, V., Vara Prasad, P. V., Murthy, V. R. K. and Boote, K. J. 2002. Influence of integrated use of farmyard manure and inorganic fertilizers on yield and yield components of irrigated lowland rice. J. Plant Nutr. 25(10): 2081-2090.

Sawicka, B. 2019. Resilient agricultural practices.W. Leal Filho et al. (eds.), Zero Hunger. Springer, Nature Switzerland, 42-51.

Scharlemann, J. P., Tanner, E. V., Hiederer, R. and Kapos, V. 2014. Global soil carbon: understanding and managing the largest terrestrial carbon pool. Carbon Manage. 5(1): 81-91.

Seifert, S. and Snipes, C. E. 1996. Influence of flame cultivation on mortality of cotton (*Gossypium hirsutum*) pests and beneficial insects. Weed technol. 10(3): 544-549.

Simarmata, T., Proyoga, M. K., Herdiyantoro, D., Setiawati, M. R., Adinata, K. and Stöber, S. 2021. Climate Resilient Sustainable Agriculture for Restoring the Soil Health and Increasing Rice Productivity as Adaptation Strategy to Climate Change in Indonesia. In IOP Conference Series: Earth and Environmental Science. IOP Publishing.

Sims, B., Corsi, S., Gbehounou, G., Kienzle, J., Taguchi, M. and Friedrich, T., 2018. Sustainable weed management for conservation agriculture: Options for smallholder farmers. Agriculture. 8(8): 118.

Singh, R. K., Singh, D. K. and R. P. Singh. 1997. Weed crop competition in wheat as affected by different weed species. Indian j. weed sci.29: 69 -71.

Smil, V., 2004. Enriching the earth: Fritz Haber, Carl Bosch, and the transformation of world food production. MIT press.

Srivastava, P., Singh, R., Tripathi, S. and Raghubanshi, A. S. 2016. An urgent need for sustainable thinking in agriculture–An Indian scenario. Ecol. Indic. 67: 611-622.

State of Food Security and Nutrition in the World,https://www.fao.org/3/ca9692en/online/ca9692en.html, 2020.

Stepanovic, S. V. 2013. Positioning an Innovative Flame-weeding Technology into Crop Production. Thesis. The University of Nebraska-Lincoln, Lincoln, NE, USA

Tejero, I. F. G., Gordillo, S.G, Souza, L., Cuadros-Tavira, S. and Zuazo, V. H. D. 2017. Fostering sustainable water use in almond (*Prunus dulcis* Mill.) orchards in a semiarid Mediterranean environment, Arch. Agron. Soil Sci. 164-181.

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R. and Polasky, S. 2002. Agricultural sustainability and intensive production practices. Nature. 671-677.

Training Manual, Model Training Course on Climate Resilient Agricultural Technologies for Future, ICAR-National Rice Research Institute, Cuttack. 1-102.

Trevini, M., Benincasa, P. and Guiducci, M. 2013. Strip tillage effect on seedbed tilth and maize production in Northern Italy as case-study for the Southern Europe environment. Eur J Agron. 48: 50-56.

Tripathi, R., and Bisen, J. P. 2019. Climate Resilient Agricultural Technologies for Future.

Tripathi, A. K., Mohanty, A. K., Rajkhowa, D. J., Roy, A., Ngachan, S. V. and Umiam, U. R. 2016. A success story on Zero tillage pea cultivation creates impact under climate stress condition ICAR Research Complex for NEH Region. 1–13.

UN. Sustainable Development Goals Report, 2017.

Vyn, T. J. and Raimbault, B. A. 1992. Evaluation of strip tillage systems for corn production in Ontario. Soil Tillage Res. 23(1-2): 163-176.

Wang, A., Zhang, W., and Wei, X. 2019. A review on weed detection using ground-based machine vision and image processing techniques. Comput. Electron. Agric. 158, 226–240.

Wang, L., Dalabay, N., Lu, P. and Wu, F. 2017. Effects of tillage practices and slope on runoff and erosion of soil from the Loess Plateau, China, subjected to simulated rainfall. Soil Tillage Res. 166: 147-156.

Wang, Y., and Chen, Y. 2017. Research progress in water uptake models by plant roots. Acta Prataculturae Sinica. 26(3): 214.

Yewle, N., Charpe, A. M., Gupta, S., Patil, B. and Mann, S. T. S. 2020. Impact of hermetic packaging on green gram (*Vigna radiata*) insect and microbial damage under environmental storage condition. J. Entom. Zoology Stud. 8: 1883-1887.

Zhao, H., Li, H., Ma, S., He, J., Wang, Q., Lu, C. and Zheng, Z. 2020. The effect of various edge-curve types of plain-straight blades for strip tillage seeding on torque and soil disturbance using DEM. Soil Tillage Res. 202: 104674.

Zhou, J., Wang, C. Y. and Zhang, H. 2011. Effect of water saving management practices and nitrogen fertilizer rate on crop yield and water use efficiency in a winter wheat–summer maize cropping system. Field Crops Res. 122: 157–163.