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REVIEW ARTICLE

Enhancing resilience to climate change through prospective strategies for climate-resilient agriculture to improve crop yield and food security

Vasavirama Karri[1]* & Nirmala Nalluri[2]

[1]Department of Biotechnology, GITAM School of Technology, GITAM (Deemed to be University), Visakhapatnam 530 045, Andhra Pradesh, India
[2]Department of Biotechnology, GITAM School of Science, GITAM (Deemed to be University), Visakhapatnam-530045, Andhra Pradesh, India

*Email: vasavi8@gmail.com

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Abstract

It is important to highlight that agriculture is one of the sectors that will be directly affected by climate change scenarios in recent years. There are a number of processes such as drought, floods, temperature, salinity etc along with other forms of biotic factors posing significant impacts on crop yields of various crops due to their fluctuating scenario in the environment. Espousal of smart technologies and practices like smart crop and variety selection, efficient climate-based cropping system, agricultural water management (AWM), balanced fertilization, contingency planning, recarbonization of soils, no-till system, integrated farming system, site specific nutrient management etc are being advised to exercise in many regions for climate-resistant agriculture. These approaches minimize soil disruption and energy usages, enhance soil health and alleviate greenhouse gas discharges, minimize unproductive losses and improve efficiency of land and water use result in greater crop production with reduced fertilizer usage. As a part of this strategy, weather stations and mini-weather lookouts are set up at the village stage to register relevant weather observations like temperature, rainfall, wind speed and relative humidity etc to furnish customized agro-advisories to farmers, which reduce detrimental consequences attributed to the climate. A climate smart approach integrates farmer's practices with related technologies, plans, institutes, policies and financial packages. So, initiating the choice of site-specific crops, development of customized technologies and tools, diversification of crops, improvement of climate-resistant crop varieties, syndication of forecasting tools and proper management of resources at the community level can effectively enhance climate resilience in agriculture.

Keywords

agriculture, climate, resilience, crops, yield

Introduction

Plant Material

Global population growth will continue to increase exponentially which require an additional effort to obtain agricultural produces (1) to ensure a healthier global food supply with reduced food losses that assures nutritious food material to people experiencing problems of malnutrition and starvation (2). At current, world countenances the twin demanding situations, first one is augmenting agricultural output to feed its expanding populace and the next is safeguarding agriculture from the unfavourable consequences of climatic change. Due to climatic change and the dominance of traditional agricultural practices, land resources are being overused and depleted at an increasing rate (3). As a result, food security is the greatest challenge confronted by agricultural sector under the looming scenario of climate change (4). India is agriculture based country with nearly 55 % populace immediately and indirectly engaged in agriculture (5). It is estimated that India's agriculture is highly sensitive and susceptible to climate change due to prevalence of rainfed agriculture which reported for 51 % of net sown area and 46 % of total production of food grains during 2014-15 (6). Climate variability is long-term alteration (i.e., over the many years) within the statistical distribution of climate which impersonate an extremely good trouble in the matter of ecology and remain for lengthy periods of time with its noxious degree. Several parts of the globe are experiencing considerable changes within precipitation and temperature due to climate change (7) and this is causing the susceptibility of plants to both biotic and abiotic stress conditions to increase (8). Consequently, these changes affect symbionts, pathogens and the microbiome that covers the plant's ecosystem (9). Unfavourable effects of global warming encompass dropped crop size and grade owing to the lowered crop season following elevated degrees of temperature upswing, decreased sugar quantity and shortened storage longevity within fruits, increased in number of weeds, blights and dangerous bugs in agricultural plants that ultimately limits the productiveness (10). Such circumstances may jeopardize livelihoods of smallholders and farmers (11).

An agricultural productivity measure involves measuring TFP (total factor productivity), that measures yield per unit of calculated intake such as capital, labor, material and land (12, 13). After the Green Revolution, TFP gradually declined, followed by an increase in 1990s and 2000s as croplands expanded, increasing greenhouse gas emissions (14).

Relation amongst TFP and economic upgrowth

$$Y = AF(L, K, N)$$

where Y = Gross domestic product (GDP), A = Total factor productivity, L = The quantity of labour input, K = The size of capital stock, N = The quantity of natural resources. While studying, natural resources were treated as constant and human capital is included as individual factor in calculating gross domestic product, Now

$$Y = AF(L, K, H)$$

Where, H depicts the amount of human capital. The entire productivity of the economy is assessed by total factor productivity index. This index represents the output produced in relation to the amount of all inputs used. Consequently, the growth of GDP relies on variations in total factor productivity (TFP) as well as alterations in factors like labor and capital. For instance, assuming that the total factor productivity is growing by 2 % annually, then the GDP will rise at the same rate of 2% annually, even if the labor force and capital stock remain constant (15). There had been considerable terrible outcomes identified in mid-time (2010-2039) weather change including yield diminution of around 5 % - 9 % as consequence of temperature variance, fluctuation in rain fall and rise in pest impedance etc (16). The agriculture sector experiences an annual impact of approximately 4-9 % due to variations in climate. Since this sector contributes 15 % to India's GDP (Gross Domestic Product) which can be inferred such that climate change leads to a loss of around 1.5 % in the GDP (17).

Enhancement of TFP expansion can be achieved through advancements in technology or agricultural breakthroughs, thereby diminishing the reliance on additional land for increased productivity. However, augmented productivity can pose a challenge as it enables farmers to generate a greater output with fewer resources, resulting in reduced unit costs and agricultural prices (18). Consequently, it is crucial to sustain TFP growth by stabilizing input and output proportions through technological improvements (19) to ensure a sustainable food system. Hence, it's crucial to evolve suitable plans in order to alleviate adverse effects attributed to climatic changes, enhance TFP and simultaneously bolster agricultural sustainability. To surmount these obstacles, cultivators must gradually adapt to climate-resistant farming (CRF).

Resilience is the capability of a system and it’s constituent to predict, engross, adapt or restore from the impact of risky event in a timely and efficacious way (20). Climate resilient agriculture is the technique of espousing agricultural exercises which lessen the destitution and hunger in the conditions of climatic fluctuations with concurrent preservation of natural sources for succeeding generations (21). As per the findings, the resiliency of an agricultural system is dependent on its capacity to foresee and prepare for climate variations and extreme weather circumstances (22). Therefore, agriculture that is resilient to climate change sustains productivity in a sustainable manner by improving adaptability measures and mitigating measures to decrease or eliminate greenhouse gas emissions (23). Further, it strengthens the potential of the structure to recuperate and it switches in such a manner that it doesn’t revert back to the preceding scenario. According to one report, the effective handling of "land and water resources, agricultural practices and means of living" through strategic management is crucial in guaranteeing food security worldwide (24). After conducting a cost-benefit analysis, numerous researchers across the globe have demonstrated through their research that CRA is financially feasible (25-27).

Weather resilient agriculture is a new phrase however this acclimatization and alleviation process previously exists in the environment since eternal, nevertheless the hassle is celerity of the climate alteration, it modifies too rapid so nature can’t harmonize with such transitions. Climate alteration can be innate (i.e., ascribable to displacement of continents, inclination of earth, volcano, marine currents) or anthropomorphic (i.e., because of civilization, development of industries, fossil fuel blazing, disforestation, non-scientific farming exercises); spontaneous weather change could be syncing along with nature but anthropicly generated weather alterations reign the native environmental regulation strength, however by adopting certain alleviation and flexible environmentally sound technologies, nature will be able to resist climatic variations occur in consequence of anthropical or human-derived activities (10).

Impact of climatic changeability on Agriculture

The correlation among climate, water, soil and crop yield is intricate and resembles a never-ending cycle, where each component impacts the others (28). The effects of climatic change have had a substantial influence on agriculture and security of food in nations, whether developed or developing (29). The future food security issues are expected to worsen due to the rising climatic variability, which will put more strain on agriculture (30). Agriculture is specifically at risk of weather change. There may be exclusive sort of threats governed by the climatic change, amongst them CO_2, temperature, rainfall have an immediate effect on plant progress (31, 32) whereas watering, availability of land, weed expansion, pesterer and infections etc have a circuitous action on plant development. So, the climatically possible output which relies on weather circumstances gets lessened as a result of the fluctuations of the menaces. From 1970, worldwide standard temperature has proven to be increasing at a speed of 1.7 °C per century (33). Excessive temperature will have a tendency to mitigate grade and capitulate of vegetation (34, 35); furthermore it urges the unwanted plants and badgerer multiplication. On the whole, the temperate areas look to be much less prone to weather change compared to the tropical areas because of the reality that elevated temperatures in temperate zones change vital activities levels closer to optima, and advantageous repercussions are expected to establish (36). Amplifications of temperature will further increase the no-frost period in temperate areas, admitting to cultivate longer duration variety of crops and providing the chance of cultivating sequential crops. In tropical places wherein raised temperatures may shift outside optima, undesirable effects might predominate over gains. Every increase of 1 °C in the mean temperature of the planet results in a decrease of 7 % in the global yield of maize, 6 % in the yield of wheat, 3 % in soybean and 3 % in the yield of rice, as well as a reduction of 7-8 % in overall milled rice, a decrease of 9 -14 % in head rice, and a decline in overall milling profit ranging from 8 -11 % (37, 38). In groundnut, potato and mustard yield was substantially decreased by 3 to 7 % whenever the temperature rises by 1 °C (39). The yield of wheat in north-western India was decreased by 4 Mt with every 1 °C rise in temperature (40). However, C3 plants are profited better in high levels of CO_2 in comparison with C4 plants owing to the evidence that stomata of C4 plants were closed preliminary to C3 plants because of their lower compensation point (0-10 ppm) for CO_2 and higher activity of the enzyme PEP carboxylase that diminish transpiration rate and produce temperature emphasis in leaves. With raise in concentration of CO_2 to 550 ppm, produce was enhanced to 10-20 % in C3 plants such as oil seeds, rice, legumes and wheat (41). The compiled impact of CO_2 and temperature is intricate but the adverse consequences of temperature are more eminent over beneficial effect of CO_2, because higher temperatures in tropical climate stimulate mineralization, respiration, decrease nutriment utilization capacity and net acculturation in crop plants (Fig. 1).

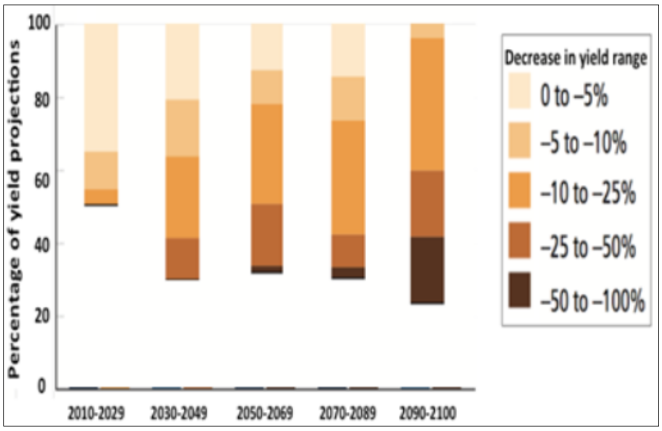

Fig. 1. Studies disclose that global climate change has an impact on decrease in crop yields (Source; Climate change and Food Security IPCC 2014; 5th assessment)

When plants are stressed by severe heat they mature faster and resulting in low yield of crops. CO_2 level is positively correlated with vegetative growth in general, however in most cases an optimal temperature is more closely linked to the reproductive stage of the crop, as a result economic output will be declined with raising temperature as it doesn't acquire required temperature during crucial stages followed by intensified vegetational growth because increased CO_2 utilize the entire moisture content of soil swiftly so fertile stages experience two kinds of stresses namely water and temperature as well (10). Changing precipitation patterns increase the likelihood of crop failure and production losses in the short and long-run crops. Further, waterlogging occurs when there are large amounts of unpredictable rainfall with high CV% (10). In the northwest, Andhra Pradesh and north-western India, monsoon seasons have increased by 10 to 12 % over the past century; in eastern India, the north-eastern states, as well as in Gujrat and Kerala, the monsoon seasons have decreased by 6 to 7 % (40). Alterations in pattern of precipitation and rainfall amend the communication among insect pests and corresponding host plants would prompt variation in water availability that eventually result in weed transformation, for this reason excessive utilization of agricultural chemicals results in an increase in environmental pollution. Further, droughts and floods are also likely to increase variability in production, but farmers always prefer a system that has fewer variations in yield throughout the year. Due to droughts, livestock are unable to graze on high-quality forages. Similarly, fish breeding and migration may be affected by increased temperatures in the sea and rivers. In addition, other factors like acidification also reported to effect organisms, for instance it is possible that acidification of the ocean, leading to a enervating of shellfish composed of Ca, could cause serious harm to shellfish (10). The rise in climatic unpredictability and anomalies has been identified as a primary factor behind the recent surge in worldwide undernourishment and a primary contributor to acute food emergencies (42), negatively impacting both animal husbandry and agricultural production.

Climate resilient agriculture: what it is and how it works

CRA pertains to all sustainable practices for managing land and water that boost climate change resilience, enhance the efficiency of resource utilization, promote sustainable yield growth and lower greenhouse gas emissions (43). According to reports, the CRA system is advantageous from an economic, financial and ecological standpoint and also benefits the less privileged (42, 43). Agriculture that is able to withstand the effects of climate change helps to reduce its harmful consequences and has advantageous and noteworthy outcomes on the effectiveness of resource utilization and the yield of crops (43, 44). The concept of climate-resilient agriculture (CRA) varies from climate smart agriculture (CSA) that it is too sophisticated and astute that it does not permit any negative circumstances of climatic changes over environment including productiveness; nevertheless climate resilient agriculture (CRA) was an inherent system to identify the process that required to be empathizing with productiveness (45, 46). In order to minimize the consequences of climate alteration, climate smart planning is pivotal to address vagaries of the change in advance, which might entail preventing strain or condoning stress through any sort of processes. In contrast, the idea of climate resilience is that it can withstand stress caused by a given set of circumstances.

Climate-resilient agriculture (CRA) incorporate three stages (Fig. 2).

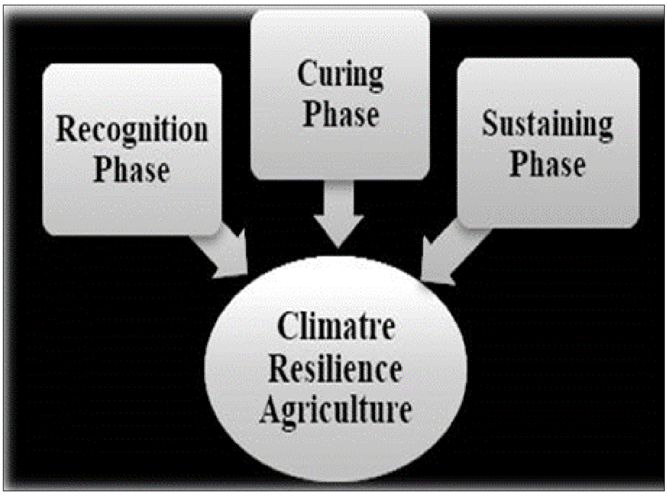

Fig. 2. Recognition Phase, Curing Phase, Sustaining Phase work collectively to fetch CRA or climate resilient agricultural practice (Source: Agricultural magazine Volume-1, Issue-4, March, 2022 issue)

Recognition stage:

"In the event of an adverse threat, the system quickly recognizes it". That kind of menaces involve unpredictable rainstorm, cyclone, overflows, drought, cool or hot waves, lengthy dry weather, hoarfrost, pest and insect outbursts and disparate hazards generated because of climatic variations. This was also referred to as starting stage of CRA.

Curing stage

A system cures itself by adapting to and mitigating environmental stresses. These mechanisms include cover crops, carbon sequestration, conservation agriculture, precision farming, direct seeded rice, site specific nutrient management and integrated farming system etc.

This is intermediary stage of CRA.

Sustaining stage

"It is important for systems to maintain their adjustable processes through a prolonged period of time". As a result, CRA will be able to overcome any hurdle it encounters with these mechanisms. This is the last stage of CRA.

Identification of menaces in farming

A system (i.e., agricultural system) identifies its risk during the recognition stage, but now climatic variation is occurring more rapidly, so human intercession is needed in identification of menaces. Menaces will be in 2 kind's i.e temporary and lasting risks. Lasting risks include exhaustion of ground water, burning of crops, variation in rain fall pattern, degeneration of carbon in organic form, contamination of ground water and atmosphere, sub-urbanization and industrial enterprise etc. Temporary risks involve deluge, drought (earlier-time, median time and end time drought), hoarfrost, warm/cool waving, whirlwind, hailrain and pest assault etc). Scientists continue to conduct extensive research on long-duration menaces, which is crucial for the detection of these threats, so detecting long -duration menaces, is now possible (10). The first regional report on ground water exhaustion was published through long-term research (1996–2014, utilizing in excess of 19000 identification places) in situ and decadal (2003–2014) satellite-supported ground water repository proportions in southern and western regions of India (47). Expansion employees provide consciousness about these risks to farmers. In the long run, short-term threats create problems that are more damaging and erratic than long-term threats. Our vulnerability to transitory threats will not exist if we are aware of these long-lasting threats and act accordingly. It's always better to impede than heal, so recognition of long-term menaces is the first step towards preventing them. Further, weather forecasting performs a prominent function in the case of short-term menaces. Weather forecasts for the medium terms are for 3 to 4 days to 2 weeks, which are more important for agricultural purposes. So identification of both long and short term threats is imperative to succeed with CRA (Fig. 3).

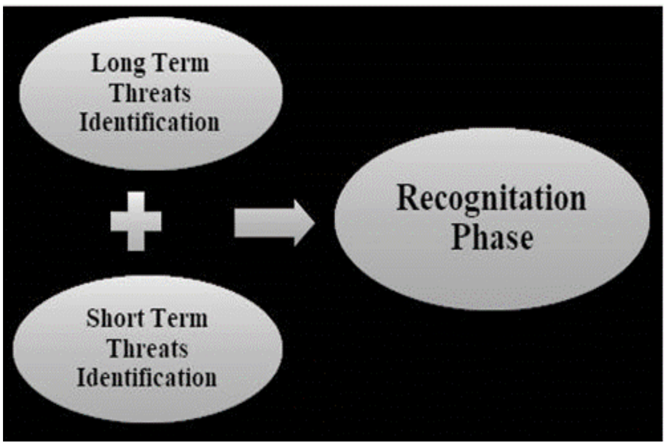

Fig.3. Both long- and short-term threats identification help to succeed in CRA

Hardening of the menaces to lower the impact of Climatic alteration

With a view to overcome effects of climate variations, adaptation and mitigation are important strategies. Adaptation alludes to modification of environmental, sociable or economical approach in relation to real or anticipated impulses and their consequences or influences. The concept of mitigation refers to manufacturing old-fashioned tools which are more capable for the use of new technologies and renewable energies, or altering management or consumer behaviour to diminish the influence of climatic fluctuations (48). There exist practical and efficient adjustment alternatives that can diminish hazards to both humans and the environment. Viable and efficient measures for adaptation exist, which can lower the threats to human beings and the environment. A thorough, efficient, and inventive approach can exploit synergies and minimize conflicts between adaptation and mitigation, thus promoting sustainable development by safeguarding biodiversity and ecosystems that represent the cornerstone of climate-resilient development through adaptation and mitigation (49).

Development of improved methods for adapting to changes in climate

With the purpose of minimizing adverse effects related to changes in climate, programs such as climate-based agro-cautions, crop and variety choice, productive cropping methods, harvesting of water for preserving water resources, custom leasing of farm equipment, contingency preparation, etc. can be implemented.

Climate based agro-cautions

There are a number of weather stations and mini-weather lookouts set up at the village stage that register relevant weather observations like temperature, rainfall, wind speed and relative humidity etc. Using these methods, farmers can receive better weather information and get customized agro-advisories. As a result of this, agro advisory materials are produced in respective languages and posted in public places such as Panchayat Buildings, Schools or any other places where farmers can obtain information. It has become increasingly popular among rural users to use mobile phones to give weather updates to farmers. Farmers were capable to reduce detrimental consequences attributed to the climate in the upcoming season by acting according to weather-based agro advisory.

Smart Crop & Variety selection

The best adaptation strategy is to select crop varieties that are climate-smart; broad sowing dates are good for crops with more sowing windows. A particular zone's potential climatic yield is reduced by different weather calamities such as heat waves, tornadoes, cyclones, frosts and hailstorms. As a result, we must select a crop appropriate for this region based on weather forecasting and long-term research. A crop reallocation to alternative areas can also be an effective climate change mitigation strategy, for instance tea, basmati rice and coffee are sensible to temperatures as they increase, reducing their quality, so alternative areas that are better suited to them from a quality point of view required to be assigned (10). Further introduction of a break crop or catch crop like moong beans in rice-wheat systems retain quality of soil and supplement organic matter and lessen nitrogen discharges from soil because of residual nitrogen utilization by the moong bean plants (10).

Further, employment of climate-resistant harvests and plant types has been suggested as a strategy for farmers to manage or conform to climate change (50). These crops and varieties are better equipped to withstand biotic and abiotic pressures (51). Millet – the crop of valor Medak, where maximum numbers of farmers take their lives due to financial troubles in Telangana, is a tale of opposites. Although farmers who have adhered to high-input crops such as sugarcane, cotton and paddy are suffering, a specific area has weathered the drought. This region cultivates millets. As temperatures raise, the cultivation of wheat and rice, which require large amounts of water, will become increasingly difficult. In countries like India, where ensuring food and nutrient security is a major concern, millets are the ideal solution for the future (52).

Currently, MINI is a nationwide coalition comprising of more than 65 establishments that endorse diverse types of millets such as foxtail, kodo, pearl millet and finger millet-age-old cereals that were overshadowed by cotton and maize. The Foundation of Professor M S Swaminathan has also been engaged in the conservation of germplasm of millets for almost twenty years. He expresses his regret over the fact that India's food diversity has been reduced with the increasing importance of wheat, rice, corn, soybean and potato, leading to the near extinction of many of our traditional cereals, also known as coarse cereals. Additional agricultural trials are underway. As an example, researchers at the IRRI are endeavouring to produce rice strains that are adaptable to various weather conditions. In Odisha and Jharkhand, Sahbhagi Dhan, a type of rice, is currently undergoing testing. Additionally, strains of maize that can withstand drought are also being introduced to fields (52, 53).

Efficient climate-based cropping system

An efficient cropping system fulfils the market's demands, the soil's health, consumer choices, as well as weed control and minimize outbreaks because of pests. In the event of adverse weather conditions, farmers are able to get at least one crop by practicing intercropping, mixed cropping and relay cropping. Sorghum, cotton, pearl millet-based cropping systems performed best with pigeonpea as either the base crop or intercrop (54). Intercropping techniques augment the total output of crops and enhance the quality of soil (55). Adopting mixed cropping practices can sustain equivalent yields to monoculture farming while utilizing fewer lands and reduced fertilizer inputs (56, 57). The implementation of relay cropping has the potential to tackle food insecurity and promote environmental sustainability through spatial and temporal diversification of cropping methods (58).

Rather than exclusively cultivating pigeonpea, combining pigeon pea with sorghum in a row ratio of either (1:1) or (1:2), or alternatively with foxtail millet (1:1), could be advantageous pigeon pea dependent cropping methods that lead to greater economic profitability (59). An integrated cropping system with legumes adds soil cover and biological nitrogen to the system and increases sustainability. It is a well-known rainfed farming strategy to cultivate a legume after the principal cereals crop. Regardless of the region, the cropping systems that are efficient always meet the required climatic conditions (Table 1).

Table 1. The prospective cropping methods in India based on the rainfall & soil type.

Rain fall (in milli meter)	Soil nature	Season of effective growth (week)	Crop systems recommended
350 to 650	Shallow vertisols & alfisols	Twenty	Cultivation of only one crop per rainy season
350 to 600	Entisols & Deep aridisols	Twenty	Kharif or Rabi single cropping
350 to 600	Deep Entisols	Twenty	Cropping during the post-rainy season
600 to 750	Entisols, Vertisols & Alfisols	Twenty to Thirty	Cropping by intercropping
750 to 900	Deep Alfisols & Vertisols, Inceptisols & Entisols	Thirty	Monitored double cropping
> 900	Deep Vertisols, Deep Alfisols, Entisols & inceptisols	More than thirty	Double cropping assured.

Water harvesting

The World Bank estimates that India has > 18 % of global population nevertheless only 4 % of freshwater available to it (60). There will be implications for agriculture and water resources because of climate change. Crops and natural vegetation will require more water evapotranspiration if the temperature rises and soil moisture will be depleted more rapidly. One projection predicts a 2 % increase in crop water demands due to a temperature increase of 1 °C. In coastal areas, sea level is significantly affected by climate change, which may have implications for groundwater and surface water salinity. As CO_2 concentrations rise, the atmosphere becomes warmer and precipitation becomes more intense, the hydrological and regional water supply may be affected significantly. Oceanic temperatures rising above 27 °C now cause more frequently cyclones, which cause devastating coastal losses. Water harvesting will be of benefit for any resource-saving adaptation programme in water management since increased precipitation induces runoff, whereas increasing temperatures may increase evapotranspiration demand. It is common to use a rain harvesting system to collect rainwater during the rainy season (water tanks, dug wells, percolation tanks, farm ponds) in dry farming areas. By harvesting rainwater, lift irrigation requires less electricity than would otherwise be required. People can then consume and use this water during dry seasons when clean water is a scarce resource. In this manner small farm reservoirs (1000 to 500000 cu.m), micro-catchments (around 1000 sq. m), inter row harvesting, rooftop systems, runoff farming, water spreaders, trapezoidal bunds, run-off strips, semi-circular bunds, small runoff basins, flood water system and small pits can minimize crop 's water stress. Water harvesting structures occasionally provide growers with reasonable yields with a few supplemental irrigations.

Water recovery technologies

Agricultural water management methods to enhance the ability of irrigated farming to withstand climate variability.

The fact that the climate change is undeniable and the adverse effects it has on the water balance in certain regions and the existing water management systems can pose a considerable threat as per (61). A rise in consumption of water source due to growing population, economic progress, evolving lifestyles and changing consumption habits, coupled with unpredictable and unstable water availability, will exacerbate condition in presently water-deprived areas and create water scarcity in areas wherein water reserves were currently plentiful (62). Thus, the sustainable administration of previously strained water supplies and farming presents a hurdle. Agricultural water management (AWM) may serve as a crucial factor in practicing climate-resilient agriculture since AWM pertains to the regulation of water utilized in farming to boost agricultural output while utilizing water efficiently. Effective implementation of intelligent AWM strategies can lead to improved availability of surface water, groundwater and soil moisture, better balance of water in soil, decreased vaporization/leakage and unprofitable losses and ultimately increase crop yield/produce, aqua usage ability and water productive capacity. There are 2 different and complementary methods to give priority to AWM practices: the first one employs stakeholder analysis to construct a portfolio of climatic-conscious AWM exercises in a prioritized manner, while the second one uses a basic water balance strategy to emphasize interventions (63). Thus, AWM measures aid in advancing 3 pivotal components of climate-resilient farming (CRF) by enhancing harvests/output, adjusting and fortifying against climate fluctuations and conceivably diminishing greenhouse gas (GHG) discharges (64, 65). Several studies based on field observations have shown that the implementation of practices and technologies for water demand and supply management, such as LLL, DSR, drip irrigation, AWD, CA, BBF system, optimized irrigation scheduling, subsurface drip, aquifer recharge and water harvesting have considerably boosted resilience by minimizing unproductive losses and improving the efficiency of land and water use. This has resulted in the conservation of extra water, increased/sustained yield and reduced energy and fertilizer consumption, ultimately leading to a reduction in GHG emissions (63). Therefore, the encouragement of pioneering AWM strategies may enhance the capability to adapt to climatic changes (66-69).

Balanced fertilization

In order to achieve optimum growth, yield, and quality, balanced fertilization should be provided which ensures all nutrients (macros and micros) throughout the growth phase of the crop. Balanced fertilization refers to the use of fertilizer in the optimum ratio and in the appropriate amount. Plant needs nitrogen for protein synthesis; further plants also require potassium and phosphorus for enzymatic activity and energy liberation. Therefore, the loss of nutrients from the system can be reduced when the nutrients are applied in a balanced amount. Plant growth is maximized with balanced fertilization, leading to highly efficient nutrient use and less detrimental environmental impact. So, by using nitrogen fertilizer in a balanced manner, N_2O-N emissions can be reduced (70) (Fig. 4). Consequently, the simplest approach to attain notable reductions in N_2O emissions while maintaining crop yields is by manipulating N supply factors such as fertilizer type, amount, timing and application techniques (71).

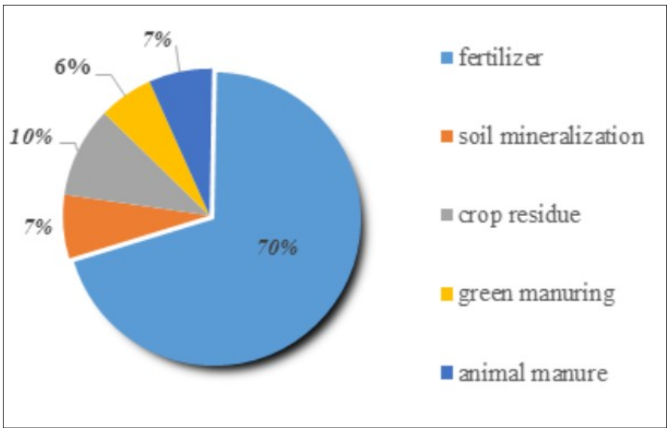

Fig. 4. Emission of N_20-N from different sources of agriculture soil (Pathak et al. 2010)

Custom hiring of farm machineries

At a village level, fragmentation of land is a significant issue; consequently community nurseries and farm machinery hire reduce environmental pressure by reducing cultivation practices. To ensure timely sowing and planting, community directed custom hiring hubs are set up in each village. That is crucial interceding to agreement with changeable weather like postpone in monsoon, insufficient rains desiring replantation of vegetation.

Contingency planning

Contingency planning of crops for venerative rainfall alludes to selecting alternative variety or cultivator of plants that sustain according to soil and rainfall in that particular location (40). It is immensely site-specified owing to differences within the quantity and dissemination of precipitation. Crops must be chosen with a suitable duration that matches the duration of cropping season. As a general rule, early crop showing at the start of monsoon is the best strategy for maximizing output in rain-fed environments. Normally, reseeding, narrowing the crop, withdrawing of substitute crops, application of KNO_3 or DAP or 2% urea, cultivating storm tolerant crops (e.g., pineapple, ginger etc) are some of the encouraging contingency farming activities to fight against climatic changes (10).

Typically, short-term legumes such as moong beans, urad beans and black-eyed peas may be appropriate. Depending on the onset of the rainy season, long-duration crops with yield flexibility or elasticity could be chosen. For instance, sorghum and pearl millet can be regrown as long as the rainy season persists. Sunflowers could be initiated for the sake of greater earnings with undeniable level of venture. Crops similar to sorghum and pearl millet conceivably cultivated for obtaining grain as long as the monsoon persists and if it does not, forage could be received (72).

Improved techniques to mitigate climate change

The primary goal of the mitigation procedure is to minimize or eliminate the emission of greenhouse gases. The hostile effect of climatic variation could be alleviated by diminution of food loss and waste, bettered crop handling exercises, integrated agricultural farming, No-Till farming, soil recarbonization, location specified management of nutrients etc.

Reduction of food losses &wastage

FAO estimated that over one-third of the food generated globally was vanished or wasted annually (73). Irrespective of the level of earnings, the report on food waste index by UNEP demonstrates that food wastage was notable in nearly all countries that underwent evaluation (74). We frequently worry about how to enhance food production, but if we can cut down food waste, it will improve resource utilization since there would be less strain on farmers and the food industry. One of the greatest methods to decrease food waste at home is to prepare meals in advance, rotate perishable goods in the refrigerator and cabinets and freeze extra garden produce. Similarly, remove water by dehydration process from food materials as well as from damaged fruits, other forms of produce and meat for better preservation.

Improved crop management practices

Crop production can be sustained through careful management of cropland, which offers a variety of opportunities. In India, rice is typically cultivated as a transplant, which not only has an adverse effect on groundwater resources but also has certain emotional issues. Intermittent irrigation decreases the synthesis of CH_4 by 40 %, but increases the emission of N_20-N by 6 % as a result of increased water-filled pore space. Around 90 % of the CH_4 produced during this stage of tillering to reproduction in rice travels through the aerenchyma tissue (10). Our system must be resilient in order to lessen the CH_4 production from rice fields, by adopting strategies such as direct seeded rice (DSR), alternate watering and drying (AWD). According to one report, AWD and DSR each cut CH_4 emissions by around 30-40 % and 80-90% respectively (75). Additionally coupled with DSR, water is reduced by 30 to 40% with the benefit of early sowing. Despite the fact that AWD (alternate wetting and drying) of paddy has demonstrated as a means to decrease both water consumption and methane (CH_4) emissions, its impact upon grain produce varies (76). Furthermore, alternate wetting and drying irrigation has been found to enhance water utilization proficiency and water fecundity of rice (77).

Recarbonization of soils

The secret to increase soil resilience to climate change is managing the soil's organic carbon content. Infiltration, fertility and nutrient circulation can all be improved by enhancing soil's carbon repository. It can also reduce wind and water erosion, minimise concretion, improve water grade and overall improve the quality of environment. Carbon sequestration can be increased by modifying best management practices (BMPs) such as excluding fallow periods through use of enduring plant covers, leftovers handling, diversified alternation of crops with legumes and agroforestry. When crop residue is retained without burning, some amount of carbon is added to the soil. Burning rice residue of around 1 ton produces 0.4 kg SO_2, 92 kg of CO, 1515 kg of CO_2, 3.83 kg NOX, 2.5 kg of CH_4 and non-methane volatile organic compounds, contributing to climate change in adverse ways (78). Additionally, the combustion of biomass results in the release of aerosols and trace gases, which contributes to unfavourable climatic conditions (79). The 'N' source from legumes has a significant impact on controlling C-sequestration through controlling the C:N ratio in the soil. The potential of legumes to sequester soil carbon is enormous, owing to their capacity to capture atmospheric nitrogen and reduce CO_2 emissions. Therefore, it is appropriate to harness the dual benefits of legumes as a source of food and a means of soil carbon sequestration to enhance climate resilience (80). Agroforestry is a fantastic choice for worldwide carbon sequestration, which generally entails the long-term storage of atmospheric carbon dioxide and carbon capture (Fig. 5). Carbon storage in the soil in an agroforestry system ranges from 30 to 300 Mg C/ha up to 1m (81).

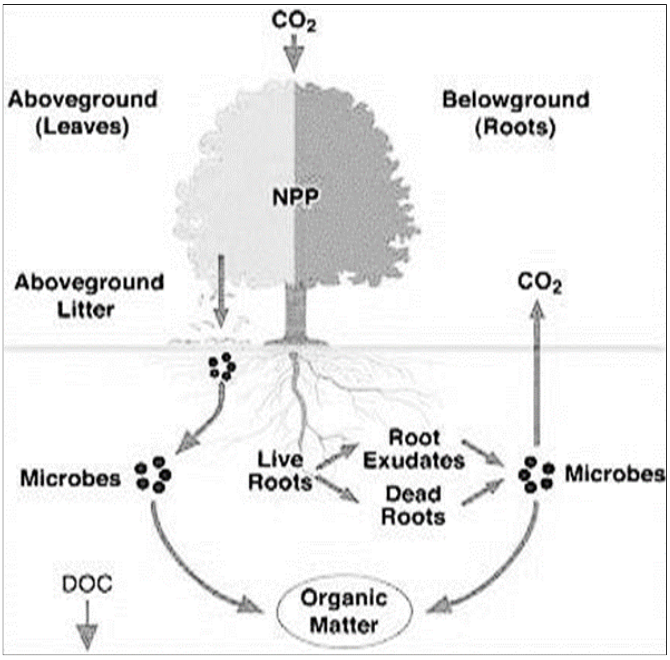

Fig. 5 Forest carbon sequestration

No-Till system

Physical properties of soil and greenhouse gas balance are profoundly affected by soil tillage practices. The reduction of soil erosion and preservation of precious nutrients can be achieved by not tilling their fields, which saves farmers labor and fuel costs. In addition to sequestering atmospheric carbon dioxide, no-till also increases soil organic carbon accumulation. The practice of No Till minimizes soil disruption and energy usage, enhances soil health, amplifies soil carbon storage and alleviates greenhouse gas discharges (82-85). Therefore, No Till can be encouraged as a management strategy to stabilize the global climate system against further alterations caused by human-induced greenhouse gas emissions. According to Mangalassery and his colleagues (86), traditional tillage methods have a net global warming potency which is 6–31% greater than zero tillage systems. The E P A (Environmental protection agency), 2009 (87) reports that it is possible to save 35 liters of water for land preparation by using no-till systems. Because one liter of diesel contains 0.74 kg of carbon dioxide and emits 2.67 kg, this no-till system reduces the warming possibility of a system.

Site specific nutrient management

CGIAR.org reports that N fertilizer is primarily responsible for 70-90% of nitrous oxide emissions (N_2O) in agriculture. With Site Specific Nutrient Management (SSNM), plants are provided with nutrients based on their intrinsic spatial and temporal needs, by matching their needs with appropriate amounts, sources, rates of application, methods and times of application. By using it, we can optimize production through a dynamic system. It is important that SSNM be of the corrective type as well as the prescriptive type. We add nutrients according to soil test, crop and climatic conditions in a prescriptive type. Whereas Curative type includes field management, such as chlorophyll meters (SPAD meters), leaf colour charts (LCCs) and nutrient experts. Even though SSNM process do not notably aspire to diminish or raise application of fertilizer but targets at administration of nutrients at ideal quantity and time period to accomplish exalted nutriment utilization proficiency, productivity under safe environment at economic cost. When N is managed effectively that aids in mitigation and adaptation further reduces other environmental associated threats like, acidification, eutrophication, air pollution and human health hazards. In addition to reducing N_2O emissions, SSNM reduces Nitrogen loss from, leaching, volatilization and runoff through lowering whole Nitrogen administration and /or scheduled application according to crops requirement. Site specific nutrient management (SSNM) diminishes N_2O discharges by lowering total Nitrogen utilization and proper time intervals of fertilization application according to crop demands in consequence preventing N losings because of leaching, runoff and volatilization (Fig. 6). It was found that utilizing SSNM (Nutrient Expert suggested fertilizer) methods resulted in greater crop production with reduced fertilizer usage compared to conventional N application and alternative nutrient strategies (88). This approach is both cost-effective and eco-friendly.

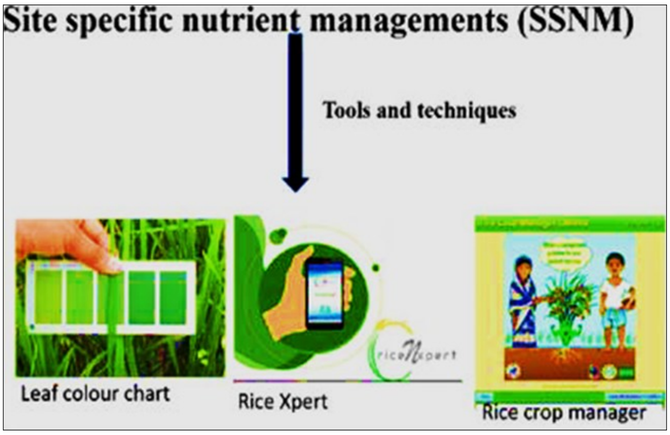

Fig. 6. Site specific nutrient management system

Integrated farming system (IFS)

In an integrated farming system, different crops are grown on the same land and resources are used sustainably, enhancing farmers' resilience to climate change. In addition to managing the farm more efficiently, IFS also reduces output dependence, which makes it less risky. In addition to being environmentally friendly, IFS benefits from synergies among enterprises. By intermittently using farm products and recycling their by-products, crop residues, weeds and other farm wastes, we were able to reduce load of inorganic chemical fertilizer by 36 % (89). The IFS presents an opportunity to incorporate additional types of crops, trees, livestock, honeybees and so on, resulting in a carbon sink that is increasingly robust against the unpredictability of climate conditions. This has the potential to serve as an effective strategy for lessening the impact of climatic change. It is crucial to raise awareness among farmers about the advantages of region-specific IFS models, as well as government policies and subsidies, in order to encourage widespread adoption. By doing so, IFS can contribute to improving profitability, employment opportunities and climate resilience, while also promoting food and nutritional security (90).

National programs to mitigate climatic changes

NAPCC-National Climate Change Action Plan under eight legations; National Mission of Agricultural Sustainability was implemented in 2010 to promote productive exploitation of existing assets. To address issues attributed to water resources, PMKSY (91) (Pradhan Mantri Krishi Sinchayee Yojana) was initiated in 2015 to promote small scale/drip sprinkling to conserve maximum water. As part of the NAPCC, the government of India launched the Green India Mission in 2014 with the goal of safeguarding, renewing and enhancing India's reducing forest cover with a view to reduce detrimental consequences pertaining to climate change. Furthermore, Neem-Coated Urea was introduced in order to reduce excess urea fertilizer application, thereby preserving soil health and providing plant nutrition.

Sustaining or Maintaining the Measures to Curtail Effect in relation to Climatic Changes

Climate change is a very frequent occurrence, so all CRAs should always have best adaptability and mitigation mechanisms on hand to combat it. In order to maintain or sustain climate resilient agriculture over the long-term, a variety of village level awareness programs must be implemented. Through entrenching various schemes and subsides government plays a crucial part in establishing sustainable agriculture. As part of the National Initiative on Climate Resilient Agriculture, technology demonstration projects are currently operating in 100 districts that have been identified as being exposed to repeated climatic vulnerabilities. With National Mission on Sustainable Agriculture -NMSA, the Technology Demonstration component under NICRA aims to mainstream some of the best practices and technologies that promote resilience to climate risks. In addition to national missions, government schemes and projects like MGNREGP (Mahatma Gandhi National Rural Employment Guarantee Programme), RKVY (Rashtriya Krishi Vikas Yojana) and the NFSM (National Food Security Mission) also contribute to country wise development by encouraging resiliency to variations in climate. To make Indian agriculture more resilient to climate variability, the XII 5-year plan aims to scale up proven practices in all vulnerable districts.

Smart agriculture will be taught to farmers in the following ways

In India, many farmers still use traditional farming methods due to lack of knowledge or economic conditions. They are unaware of the advantages of modern farming methods. According to known phrase "knowledge is Power," farmers can make better decisions and eliminate constrains reducing yield by careful monitoring of the crops, climate and market. So, peasants need to become smarter to gain vigour in the agricultural sector.

Farmers can be smart in agriculture by conducting training programmes like the following.

Training on smart agriculture organized by ICAR-CTCRI for farmers in Thiruvananthapuram

The ICAR-CTCRI (Central Tuber Crops Research Institute) organized a one-day training programme for farmers in Thiruvananthapuram on smart farming using the e-crop system. Using artificial intelligence, the e-crop can be connected to the internet of things (IoT). This facility helps farmers to become smarter in agricultural practice by providing smart services. KSHM (Kerala State Horticulture Mission) provided financial support for the installation of such facilities in their fields and launched e-crop SMS services. Under this programme, 100 farmers from 5 Panchayats have been trained in smart farming (92).

Training on climate-smart farming to help Bihar Agriculture University (BAU) officials and scientists to cope with climate crisis impacts

To aid farmers and alleviate impact of weather condition on their sustenance, IRRI (International Rice Research Institute) Education located at IRRI SARC (South Asia regional Centre) in Varanasi conducted training underneath climate Resilient Agriculture software from 02 to 05 March in 2022. A 3 day education on climate-smart farming was implemented for scientists, researchers and officers corresponding to Bihar Agriculture College (BAU); Sabour, India to acquire knowledge and capabilities for farmers to reduce climate-disaster challenges (93).

Training offered by digital green to empower farmers in smart agriculture

Digital green is a worldwide improvement association that entitles small scale farmers to raise themselves from poverty via exploiting joint potency attributed to generation and grassroots- degree corporations (94, 95). Through this organization Farmers could be educated through strategy of virtual education curriculum inclusive of practical instructional videos and a mobile supported courseware in mobile educating app that evaluates the mastery stage of farmers and builds the ability of farmers to practice smart agriculture. The mobile measurement app registers activity corresponding to frontline employees and forwards it to educating analytics dashboard. Then, dashboard permits educators to watch throughout their masters and front-line people they've educated, to recognize wherever consistent interruptions exist during their functionalities. The dashboard also allows digital green association to focus on educating front-line employees based upon aspects wherein they were less competent. Presently digital green is operating to make farmers to watch proper videos at correct time to maximize the earnings on their investiture.

Conclusion

Climate change is having a great impact on agriculture globally via its direct and indirect effect on soil, crops, pests and livestock. Unusual precipitation, a rise in the occurrence of dry spells and unexpected disasters are making farmers increasingly susceptible. This pattern of the alteration in climate conditions not only affects the production of food, but also affecting both its quality and quantity. In this scenario, espousing of climate-adaptive farming and Climate resilient agronomic techniques can offer a solution to these unexpected climatic changes and result in better agricultural produce to fulfil the demands of a continuously growing population. Employment of strategies like selection of smart crop and variety selection, effectual climate-based cropping system, improved agricultural water management methods and balanced fertilization, contingency planning, recarbonization of soils, no-till system, site specified nutrient administration and Integrated farming methods that are adaptable to climate change have the potential to improve the current state of affairs and maintain agricultural productivity at a worldwide, regional and local level, particularly in a sustainable manner through practicing climate-resilient agriculture**.** Further, farmers are regularly updated with weather related information on temperature, rainfall, wind speed and relative humidity etc. by establishing weather stations and mini-weather lookouts at village level to reduce detrimental consequences attributed to the climate. To support farmers and mitigate the impact of climatic variations on their sustenance training programmes were conducted to promote climate resilient agriculture towards sustainable development.

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Authors contributions

VK prepared manuscript according to guidelines by acquiring data on this specific topic. The manuscript was checked and corrected by VK for submission in favour of publication. NN helped VK in writing and analysing the data in this study. All authors have read and approved the manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical issues: None.

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