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REVIEW ARTICLE

Impact of weather parameters on maize agroecosystem and adaptation strategies under changing climatic conditions: A review: Sustainable and climate-resilient adaptation strategies in maize agroecosystem

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Abstract

Change in precipitation patterns and increase in the frequency and intensity of extreme weather events (high temperatures and heat waves) harm crop productivity. As per the future prediction, the temperature may increase by 2.5 ^{0}C by 2050 and by 2-3^{0} C by the end of the century. The present review evaluates the impact of a rise and fall in temperature, solar radiation, and CO_2 on the productivity of maize and other crops. Agronomic management practices during the crop growth period of selecting crop cultivars, date of sowing, plant population, dosage, timing, and methods of application of inputs are influenced by temperature, rainfall, solar radiation, and CO_2 concentration in the atmosphere. Overall crop productivity will reduce by 50.9 % in wheat in the USA, 46% in maize in China,17% in cotton in India, and 30% in sugarcane in India. Changing the sowing date and adopting improved early and short-duration varieties of corn and other crops are becoming significant under low-cost adoption technologies to mitigate climate change. Info Crop-SORGHUM simulation model predicts that change in the sowing date of a variety in sorghum reduces the impact of climate change and vulnerability to 1- 2 % by 2020, 3-8 % by 2050, and 4-9% by 2080. The review highlights the impact of heat stress and drought on soil processes, and overall soil health. The authors conclude to implement climate adoption technologies based on Agriculture 4.0 to sustain crop production globally.

Keywords

Agriculture 4.0; Crop adaptation technology; Date of sowing; Heat stress and drought; Rainfall variation; Weather parameters

Introduction

Over the years, the increasing population is pressurizing the agricultural sector to enhance food production with changing food consumption behavior (1). Crop production should increase by 60-120 % to meet the required global food, energy, and fiber demand, yet the growth rate is not to the expectation (2). Climate change poses a challenge to the scientific community and policymakers in tackling the problems to meet global food security during the 21st century. An increase in the land area under agriculture with intensive agriculture could fulfil the global demand, but the environmental impacts and further expansion of agricultural trackways are unclear. Fertilizer, land cleaning, and crop production are contributing to 1/4th of Greenhouse gas (GHG) emissions along with the destruction of the habitat affecting on natural cycle in the ecosystem. Further, fertilizers adversely affect habitats of terrestrial, freshwater, and marine ecosystems (3).

The performance of rainfed crops in India is influenced by rainfall onset, intensity, and distribution. Agricultural practices (weeding; application of farmyard manures, chemical fertilizers, plant protection chemicals; harvest, and storage) depend upon the weather. Weather parameters at each level play a critical role in the better development of source-to-sink relationships (4). The weather parameters prevailing during the growth period influence day-to-day and total assimilation in plants. Several global studies edge the different onset of the monsoon and report the maximum benefits during the growth period.

Extreme weather conditions (increase in the frequency of drought and extreme precipitations) are frequently increasing over recent years. The increase in GHG is continuously compounding our concerns about climate change and global warming (5, 6). Global warming is characterized by losses in the production of staple cereal crops (7). Among cereals, maize is the third most cultivated food in the world, and the significance of maize in semi-arid and arid zones is higher than rice and wheat crops; therefore, the impact of climate change and the development of adaptation strategies for maize are vital for agricultural productivity (8). To mitigate climate change, the world is looking for sustainable adaptation strategies to achieve sustainable crop production. The optimization of the planting window (changing planting dates, selection of cultivars) for utilizing solar radiation is an eco-friendly and low-cost adaption strategy (9, 10). Similarly, stress-resilient new germplasm of maize is discovered to achieve yield potential with a reduction in the risk concerning climate change (11).

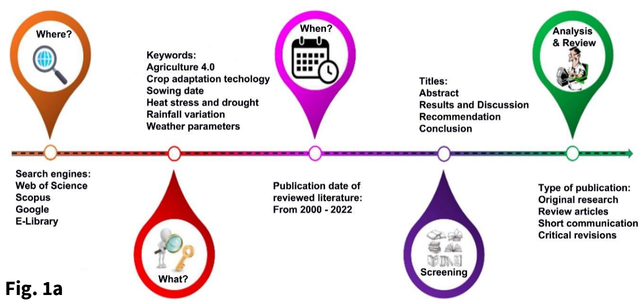
This review presents the latest systematic data published between 2000-2022 based on planting dates and climate change strategies for maize. It presents information using Scopus, Web of Science, Google, and worldwide virtual library-agriculture for enhanced agriculture productivity by searching the significance of adaptation strategies and global mitigation in agriculture, agricultural automation, agriculture 4.0, applications of biosensors in agriculture, and precision farming. An emphasis has been given to the recent systematic reviews on diverse strategies for mitigating climate change for increasing maize crop productivity through evaluating cross-references and bibliographies of existing journals citing 73 research publications. A roadmap of the review methodology and a year-wise selection of articles are presented in Figures 1a and 1b, respectively.

The present review systematically outlines these studies under the following heads:

Effect of temperature on growth and yield parameters of maize:

The rate of plant development is affected primarily by temperature. The rise in the temperature with the climate change impact greatly influences the productivity of Kharif and Rabi crops (12). Among different stages of plant development, the pollination stage is most affected by temperature. The duration of the bee activity gets affected as the temperature rises, ultimately affecting the productivity of the crop. Few adoption techniques are available for warmer temperatures during different plant growth and development stages. These exclude the selection of plants that shed the pollen during a cooler period of the day or flowering occurs over a longer period of the day/ the growing season. The maize yield was reduced by 80-90 % due to warmer temperatures at the reproductive stage compared to the normal temperature regime. The grain yield and biomass decreased by 9.5 % and 8.8 %, respectively. A rise in temperature just by 1^{0} C and 0.5 ^{0}C from the baseline has reduced yield by 36.9 and 27.7 percent, respectively (12, 13). Reduced water availability increases the temperature effect, and the application of excess soil water demonstrated the interaction of temperature and water which helps to come out with effective adoption strategies to reduce the impact of excess temperature and other extreme events associated with climate change.

Maize yield and biomass are negatively affected by raising the temperature. The temperature rise of 1 ^{0}C from the base reduced the yield and biomass by 40 % and 28 %, respectively. Further, rising of 1 ^{0}C could reduce the yield by 10 % and biomass by 8%. But the yield was increased with a 10 percent reduction in rainfall. However, a rainfall increase of 10 % or a rainfall decrease of 20 % would result in lower yields (4). Global Climate Models (GCMs) have reported an increase of 3.4 ^{0}C and 3.8 ^{0}C increase in maximum and minimum temperature for the period 2040-2049, respectively, and a 29% decrease in future maize production (8). A lower yield of maize was when the temperature increases resulted in a decrease in the GDD (Growing Degree days). The rise in temperature by 1 ^{0}C may reduce the crop duration by 4.3 days. A higher temperature (> 30 ^{0}C)



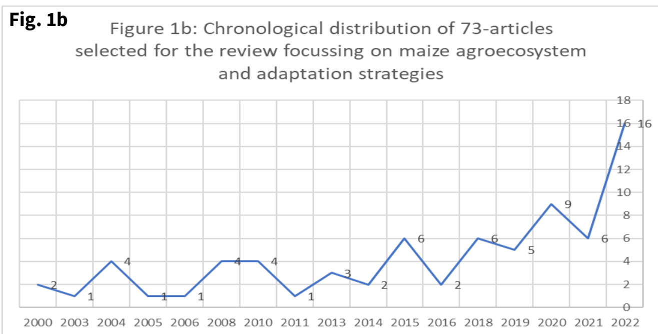


Fig. 1a: A roadmap of review methodology; **1b**: Chronological distribution of 70-articles selected for the review focusing on maize agro ecosystem and adaptation strategies

has been found detrimental for maize production. Each day spent above 30 ^{0}C during anthesis reduced crop production by 0.5 and 2%, respectively under irrigated and rainfed conditions (6). Different crop modeling have predicted that maize production will decrease by 14-17 % by 2041-2060, and sowing date and cultivar types are significant factors in mitigating climate change (10). Another study forecasted that maize production will decrease by 23.8% and temperature in the winter season will rise by 50 % as per the projection of a model (Environmental Policy Integrated Climate or EPIC) for the period 2070-2099 (14). As per the studies, the impact of climate change can be reduced considerably by proper agronomic management practices such as delaying sowing dates, and developing new germplasms through molecular plant breeding. In central India, sowing of maize crops between the 7th and 14th of July could reduce the impact of temperature on maize grain and biomass yield. The new maize germplasm is targeted for stress-prone environmental conditions (11).

Effect of Rainfall pattern on growth and yield parameters of maize

Climate change impacts Kharif crops like rice, maize, jowar, and bajra, and Rabi crops like wheat and barley. The observed trends in the climatic variability and productivity of Kharif and Rabi crops were simulated under controlled climatic conditions by variations in temperature, solar radiation, and carbon dioxide (15). The productivity of *the* Kharif and Rabi crop decreased with an increasing temperature or reduction in solar radiation. But the productivity increased with an increase in the concentration of carbon dioxide. The increase in temperature by 3^0 C from normal showed the highest (40%) decrease in productivity whereas paddy showed the lowest (5%) loss of productivity. Positive effects of elevated CO_2 (550 ppm) and negative effects of increased temperatures (+1.5 and +3.0 ^{0}C) were observed on the growth and yield parameters of maize (13). An enhanced biomass partitioning in maize (a C_4 plant) and thereby improvement in biomass by 32-47 % and grain yield by 46-127 % was observed with elevated CO_2 (550 ppm) as compared to control (16, 17). A slightly negative change in the yield of maize has been observed by the years 2035, 2065, and 2100 (18).

The rainfall amount and distribution significantly influence the grain and biomass yield of maize. A decrease in 10 to 20 % of rainfall from the base increased the yield of maize; however, a reduction in the rainfall to 30% reduced the yield by 9% (12). Seasonal variability in rainfall affects the soil moisture availability throughout the growing period of the crop inducing stresses and adversely affecting the yield. Variation in temperature and space with the date of sowing at the regional level was investigated through several studies, spatial and temporal variability of water availability in the soil, availability of seed or other critical inputs management like fertilizers and harvest of the preceding crop, and its effect on growth and development of the crop (19-21).

A maize crop requires 700 mm of rainfall to complete its life cycle and the variability in rainfall above or below normal harms maize productivity. The maize crop is more sensitive during its critical stages, i.e. from flowering to grain filling stages. Water requirement is higher to meet the demand for evapotranspiration at critical stages. It is due to more activity of yield parameters like the number of ears and kernels, and the movement of photosynthates from source to sink (22). In one of the site studies, rainfall variation from 755 to 1487 mm increased the maize yield by 10-20 %. Although positive deviation from baseline rainfall decreased crop growth and yield due to the normal rainfall sufficient to grow any crop in any season. The above-normal rainfall harms maize as shown by the simulation model. Lower eastern Kenya and other arid and semi-arid countries are threatened by climate variabilities affecting their yield and food security (22). There is an urge to develop climate adoption strategies to combat climate change like in maize, development of water stress-tolerant varieties, short duration, early planting, soil, and water conservation, and awareness programs on climate change and its effect on agriculture and mitigation strategies. The climate-resilient technologies are crucial to enhance maize production to meet food security. The Kharif and Rabi crops were stimulated by a decrease in temperature by 3^0 C and solar radiation by 2.5 percent. The yield of Kharif crops like barley, rice, maize, jowar, and bajra decreased by 45%, 7%, 14%, 21%, and 41 %, respectively (13). Sustaining the yield under changing climate situations is a key challenge (23). The Kharif and Rabi crops were generally affected negatively by rising temperatures and positively by decreasing temperatures. The simulation has shown an increase in temperature by 3 ^{0}C resulting in maximum yield losses of up to 40.7^0 C in barely during the Rabi season and minimum yield losses in rice (5%) during the Kharif season. In other crops like maize (11.8%), jowar (19.3%), bajra (37%), and wheat (18.9%), the productivity decreased because of an increase in temperature by 3^0 C from normal. When the temperature was decreased by 3^0 C from normal, it increased productivity in rice (13.1%), maize (22.9%), jowar (25%), bajra (55.1%), wheat (6.3%), and barley (34.9%).

Interactive effect of temperature and rainfall on yield and biomass of maize

The interaction effect on maize yield and biomass was studied through APSIM Model. The variation in rainfall (+/- 10 to 30%) has shown less impact compared to temperature on maize yield and biomass; however, uncertainties in temperature than rainfall have a significant contribution to climate change and crop production (24).

Effect of Rainfall variability on seed quality

In the plant life cycle, germination, emergence, and establishment phases are critical to determine the overall densities along with other factors like soil moisture availability to decide the rate of germination (25). The density of crop stand is determined by germination, emergence, and establishment which decide the overall plant growth cycle. Moisture availability in soil decreases seed germination and varies according to species to species. A pot experiment was conducted at different soil moisture to examine the maize germination response. The soil moisture contents at 25%, 50%, and 100% field capacity were taken to conduct experiments on 10 varieties of maize. An experiment was conducted in a pot (10-liter) filled with 10 kg of topsoil, 25 maize seeds were sown in the pot. Germination speed i.e. mean germination time (MGT), germination percentage (E%), and final germination percentage, were recorded. At inadequate soil moisture content (25%), the speed of germination and final germination percentage significantly decreased in maize. Seed size, the number of seeds, seed weight, and seed quality were significantly altered by drought and heat stress (26). The physiological processes like biosynthesis of various metabolites in the leaves and translocation of photosynthates to reserve parts and activities of enzymes are highly affected by heat and drought.

Effect of sowing date on yield of maize

The impact study of delayed sowing of maize (from September to December) on the quality of grain was carried out in the central temperate regions of Argentina using 18 commercial genotypes having different grain hardness (27). Late sown and early sown maize plants yield 11003 kg ha^{-1} and 12737 kg ha^{-1}, respectively, and later sown genotypes produced higher dry milling quality. Rainfall and distribution patterns affect maize biomass and yield. An increase in maize grain and biomass yield was observed after a decrease in rainfall by 10% and 20% from a baseline rainfall; however, an increase in rainfall by 30% from the baseline caused a decrease in grain yield (by 9%) and biomass (by 6%) (28). Three maize hybrids, i.e. FAO-290, FAO-350, and FAO-420 were investigated during 2011-2015 to know the effect of modeling emergence, silking, and sowing dates on the maturity of different hybrids (29). Sowing was between 4^{th} April to 10^{th} May. The maize hybrid FAO-290 was sensitive to the sowing date and had the lowest yield of 11.534 t ha^{-1} and the highest yield of 12.788 t ha^{-1} on sowing date 3. The maize hybrid FAO-420 had the highest yield of 13.494 kg ha^{-1} in a wide sowing interval, i.e. from 4th April to 10th May. Overall, adapting maize to early sowing in a warmer area provides better establishment of catch crops which improve residual soil-N uptake by plants under multiple crop rotations (30).

Time of scheduling irrigation: The crop yield was reduced to a greater extent in maize due to water stress during the critical stage. Anthesis and maturity were greatly affected by climate change. The common planting date has reduced yield from 38 % to 11 % in maize and further reduced from 61 % to 48% due to changes in sowing dates at different irrigation regimes (31). Similarly, the Info Crop-SORGHUM simulation model shown that change in the sowing date of a variety in sorghum reduced the impact of climate change and vulnerability to 1- 2 % in 2020 and 3-8 % in 2050 and 4-9% in 2080 (32). Planting earlier (1 May) has reduced the irrigation intervals during the anthesis. The management of irrigation water and planting date resulted in beneficial management strategies under climate change situations.

Adaptation strategies

Risk-based adaptation strategies are becoming popular nowadays. We need to identify adaptation options along with their costs and benefits and exploit the available mechanisms for expanding the adaptation capacity of human beings and natural systems to address multiple risks appearing from climate change.

Adoption strategies

Climate adoption technologies can increase agricultural productivity and maintain farmers' climate resilience capacity at the same time. A schematic diagram of climate adoption technologies is presented in Figure 2.

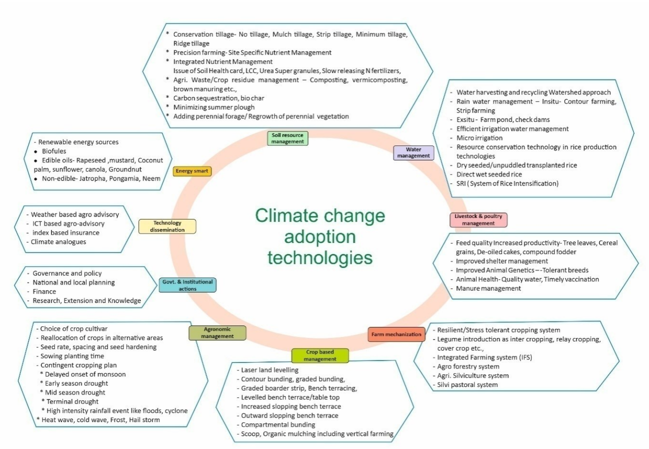


Fig. 2: Integrated management strategies through climate change adoption technologies

Farm mechanization

Laser land leveling

About 3-5 % more cultivable area can be brought under cultivation when laser land leveling is adopted. It also improves the efficiency of water, nutrient, and weed control efficiency compared to the conventional method of land leveling. The highest B: C ratio (2.25) was observed in laser land leveling compared to conventional land leveling (1.93) in rice (33). The gross return increased by 24 % compared to unlevelled land. The water productivity has increased from 0.33 kg m^{-3} (Uncultivated land) to 0.47 kg m^{-3} with laser land leveling.

Precision farming

Precision farming is an approach where inputs are applied based on the variability of land to maximize crop production by sustainably minimizing the cost of production without affecting the environment. The fertilizer applied through site-specific nutrient management (SSNM) yielded significantly more than the recommended dose of fertilizers in maize (34). The SSNM method recorded maximum uptake of N, P, K, S, Zn, and B (179.10 kg ha^{-1}, 44.68 kg ha^{-1}, 171.32 kg ha^{-1}, 40.13 kg ha^{-1}, 379 g ha^{-1}, and 253 g ha^{-1}) respectively was followed by 150% NPK application.

Based on the slope (%), rainfall (mm), and soil types, bunding is categorized into four types; (i) Contour bund (slope >1.5 %, rainfall <600 mm, and light soil), (ii) Graded bund (slope 1.5 %, rainfall < 600 mm, and all soils), (iii) Bench terraces (slope 6.0 %, rainfall > 1000 mm, and deep soil), and Graded border strip (slope >1.5 %, rainfall > 800 mm, and deep Alfisol and related red soils).

Contour bunding

A series of trapezoidal bunds constructed at an interval along the contour to impound runoff water behind the bunds. This improved the infiltration and enhanced the water availability in the soil profile for crop water requirements. The construction of a contour bund enhanced the productivity of sorghum by 33 %, from 1371 kg ha^{-1} (without CB) to 1826 kg ha^{-1} (with CB) (35). In groundnut, the yield increased from 1147 kg ha^{-1} to 1161 kg ha^{-1} in without contour bund and with counter bund, respectively. Similarly, the yield increased from 63 to 71 % in maize and 78 to 81 % in millets without contour bund and with counter bund, respectively.

Graded bunds

Graded bunds remove excess water from the field with safe velocity to avoid soil erosion. They are constructed at the upper streams.

Scoops/Pitting

Scooping is an *in situ* soil moisture conservation mainly practiced in semi-arid regions of Asia, Australia, and Africa. The opening of small basin depressions at close intervals with the help of a machine or manually retains the runoff water. It reduces soil losses by 65 % and runoff by 50 %. Through the adoption of scooping, the yield increased by 12 % in sorghum (36).

Compartmental bunding

It is the division of land into small parcels with the help of small bunds in a square or rectangular shape. In black soil, the collected water can be used after the rainy season for land preparation and upcoming non-rainy season crop. The construction of compartmental bunds conserved the rainwater received during the monsoon season and the enhanced yield of Rabi chickpea variety BGD-103 and JG -11 to 36.7 % and 43.9 %, respectively (37).

Organic fertigation and mulching including vertical farming

Organic material is a naturally available cheap material best suitable for mulching and it also adds organic matter which helps for the absorption of the water, adds nutrients, and helps in the proliferation of the microorganisms in the soil. Organic fertigation improves soil physicochemical conditions, microbial activities, and nutrient-water-use efficiency. It can restore soil health in saline-sodic soils (38). Silicon fertigation developed low water stress tolerance and enhanced production in maize crops (39).

Livestock and Poultry Management

In India, the agriculture sector contributes nearly 28 % to global greenhouse emissions. Out of this, 59 % is contributed by enteric fermentation in animals. The methane production potential is very low in tree leaves, cereal grains, de-oiled cake, and compound fodder compared to compound feed , local grasses (uncultivated), cereal products, and dry straws (40). Dry straw produces 6 ml per 100 ml of digested substance against < 2 ml per 100 ml in fresh tree leaves followed by cereal grains. Hence, the feeding material helps in reducing methane emissions from animals.

Improvement in shelter management

It is better to avoid feeding animals outside from 11.00 am to 4.00 pm during summer to avoid the direct sunlight and provide proper shelter during summer with appropriate maintenance of temperature inside the shelter house. The temperature maintenance varies from region to region depending on climatic conditions. (40)

Improved plant-animal genetics

Genetically modified (GM) crops reduced an equivalent 7.5% global GHG emissions in Europe (41), and supported climate change mitigation globally. Morphological, behavioral, physiological, neuroendocrine, and blood-chemical improvements are necessary to maintain the sustainable yield of animals under climate change conditions.

Animal Health

Quality food and timely vaccination are basic needs to maintain the proper health of animals and livestock as they require a large amount of water in summer. Pasture and grazing animals can affect positively and negatively the water bodies, respectively (42). Good fodder production can minimize soil erosion compared to conventional crop cultivated areas and grazing animals may increase the soil erosion and sediment deposited like urine, faeces of animals , and other wastes in the water bodies' impact on water quality. Human population pressure, untreated wastewater, poverty, erratic precipitation, and loss of biodiversity are severely causing the deterioration of water quality around rivers (43). Nitrogen and phosphorus are primary concerns, as its higher NO_3^- concentration in the drinking water causes methemoglobinemia (blue baby disease) and excess PO_4^{3-}. Their higher concentrations lead to the eutrophication of water bodies.

Manure management

Proper manure storage and management reduce nitrous oxide (N_2O) and methane (CH_4) emissions. A higher amount of methane and carbon dioxide is released from manure in warm and wet conditions, especially in an open environment. Anaerobic conditions cause higher production of methane. Hence, it is better to avoid the usage of liquid manure. Manures are covered with roofs for solids and tanks for liquids. The accumulation of manures for a longer period is avoided. Liquid manures should not be disturbed. It may increase the aeration and reduce the release of methane but increase the nitrous oxide emission. Overall, different adaptation strategies have different levels of effectiveness or responses on climate change mitigation on maize crop. For example, such responses were using improved maize varieties ($P=0.0001$), crop rotation ($P=0.0001$), changing planting dates ($P=0.001$), and using drought-tolerant crops ($P=0.014$) (44).

Soil resource management

Conservation tillage

It is a type of residual management system where tillage aims to avoid runoff water, and wind erosion. It maintains the land surface with roughness for sowing and leaves most of the field residues which provide a suitable seed-bed for sowing and weed control for upcoming crops. No-tillage is capable to reduce yield losses and increase SOC levels by 1.4-2.0 t ha^{-1} but not able to reverse the climate change (45).

Precision farming

Application of tools and technologies to maintain the spatial and temporal variability concerned with crop production to improve crop production sustainably without affecting the environmental quality.

Site-specific nutrient management

Maize and rice yields increased by an average of 69 % and 24 %, respectively, under the blanket recommendation compared to farmers' practices. This practice also improved nutrient use efficiency and profitability of both crops (46).

LCC (Leaf color chart)

It is a spot indicator of plant nitrogen status that helps in minimizing the excessive application of nitrogenous fertilizers. LCC is commonly used in rice and wheat crops. LCC is a plastic strip containing four or more panels with varying colors from yellowish green to dark green. In the rice-wheat cropping system, the LLC-based nitrogen fertilizer management got the highest return (19 to 31%) compared to fixed-time nitrogenous fertilizer application (47).

Slow-releasing nitrogen fertilizer

The use of neem-coated urea showed the highest nutrient use efficiency i.e. 20 kg yield per kg nitrogen applied, and has resulted in an increase in the sunflower yield (2322 kg ha^{-1}), biological yield (9000 kg ha^{-1}), and harvest index of 25.8 % and for sustainable sunflower productivity, neem coated urea with 100 % and 80 % of recommended nitrogen helps to get higher productivity and reduces the environmental impact (48).

Agriculture waste residue management

India produces nearly 620 MT of crop residues per year (49). Out of that, 50 % of crop residues are generated by rice, wheat, and oilseeds. Rice straw contains a good amount of nutrients on a dry weight basis it contains 5-8 kg N,12-17 kg K, 0.5-1 kg S, 3-4 kg Ca, and 40-70 kg Si per ton of straw (50). Soil organic carbon (SOC) can be enhanced through proper adoption strategies like restoration of lands, soil and water conservation measures, adoption of conservation agriculture, and use of compost and manure (51). The application of FYM and compost under a 40-year integrated nutrient management system improved SOC and soil health in a semi-arid-dry region of Karnataka, India (52). The recommended management practices restored the SOC in the range of 50 to 1000 kg ha^{-1} $year^{-1}$. The application of straw-based biochar increased SOC by 8.5 to 47.5%, electrical conductivity (EC) by 5.9-19.3 %, available phosphorus by 6.0 to 14.9 %, and available potassium by 47.5 to 148.4 % (53). The straw-based biochar retained these nutrients in the soil.

Renewable energy sources

Biofuels are a promising technology to reduce greenhouse gas emissions by replacing fossil fuels used for transportation and the generation of electricity (3). Sugar and starch crops can produce ethanol (biofuel) and oilseed crops can produce biodiesel. As per a model estimate, a reduction of 500 million tons (2008-2018) of CO_2 was possible using biofuel (54).

Breeding approach

Development of high-yielding varieties or hybrids tolerant to heat, drought, and waterlogging, and resistant to various biotic and abiotic stresses are necessary under the climate change situations. The development of varieties/ hybrids resistant to biotic and abiotic stresses requires more heat requirement and more photosynthetic efficiency coupled with improved agronomic technologies to overcome the yield impact of climate change in maize (55). In a warm and dry climate, the selection of crops should be focused on adoption to low water availability and higher temperature (24). For example, corn and millet have been recommended as more suitable crops in arid and semi-arid regions than other cereal crops, especially under climate change scenarios (56).

The 21st century is facing climate change as the biggest threat to soil fertility and agricultural sustainability. Change in vegetative cover, land uses, and soil and water erosion, are causing soil degradation. Adoption technologies are becoming popular (Figure 2), mainly conservation agriculture, crop diversification, cover cropping, and agroecological soil processes (Figure 3), to restore SOC and maintain soil health (57). Long-season cultivars sown earlier at high and medium latitudes and medium season sown cultivars sown medium in low latitudes have performed better for maize production (58). These adaptation strategies also provide valuable information for plant breeders to mitigate the climate change.

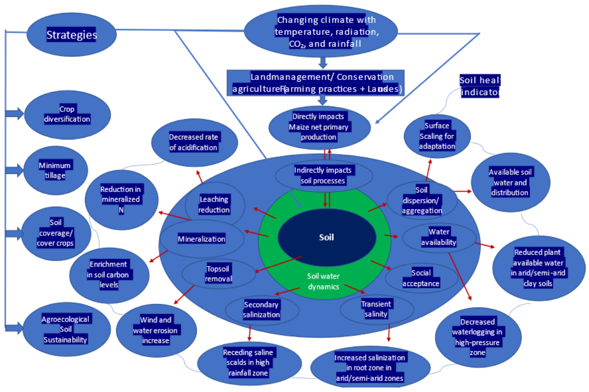


Fig. 3: Schematic representation of the linkage between climate change and soil health and strategies for soil sustainability (45, Modified from Nuttall et al. 2008).

Application of sensors in climate change mitigation (this heading can be AGRICULTURE 4.0)

Agriculture 4.0 (Monitoring, Control, Prediction, and Logistics), or the use of sensors in agriculture, is trending after the green revolution (Figure 4). Digital and controlled systems are emerging in the field of precision agriculture leading to the foundation of sustainable agriculture. The target of this approach is to improve the productivity of individual plants, animals, and microbial bioresources. It focuses on individual farms to improve resource use efficiency in a less labor-intensive manner by doing the right thing at the right time and place. Recent advances in machine learning, cloud computing, the Internet of things (IoT), smart sensors, remote sensing, geographical information system (GIS), global positioning system (GPS), weather forecast-based agro advisories, and robotics, are applied in modern agriculture for bringing automation in agricultural systems. Integrating remote sensing with a crop model can monitor crops and forecast yield in better ways (59).

Robotics

Robotics in agriculture plays a very important role in working under harsh climatic abnormality conditions and carrying out dangerous tasks like pesticide application. The automation of agricultural equipment reduces human interference and makes it more efficient, precise, and reliable (60). The current problems in sustainable agriculture can be solved by autonomous robots in agriculture (Figure 4), which maintain the current need for production efficiency—working 24 hours per day—and reduce human labour for farm activities (61).

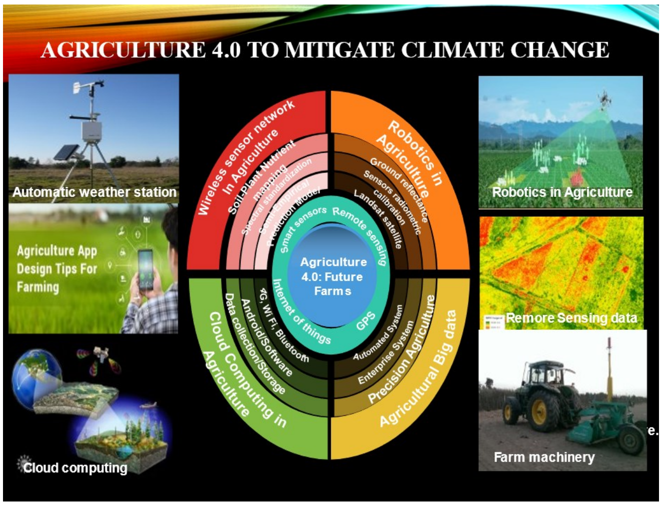


Fig. 4: Developing future sustainable agricultural farms through Agriculture 4.0 (from GPS to Big data, IoT to Cloud computing, Sensors to Wireless sensor networks, and Remote sensing to Robotics)

Internet of Things

Data obtained through Low Power Wide Area Network (LoRaWAN) built on LoRa modulation techniques and weather-forecast agro-advisory services use different sensors applied to use through a decision support system under precision agriculture. Through web-based portals and android smartphone applications, this information can be made available for access to farmers (62).

Sensors

The quantification of disease severity through symptoms, disease identification, and the change in the health of a crop can be detected by using different advanced sensors, thereby providing realistic and practically applicable management strategies to farmers (63-65). Smart farming systems are using digital photography (with red-blue-green imaging, or RGB), and multispectral sensors (with RGB-near-infrared wavelengths). The hyperspectral reflectance (narrow wavelengths), thermal (for temperature), and chlorophyll-fluorescence (for photosynthesis activity) sensors are becoming popular in modern agriculture. Drones, satellites, or unmanned airborne vehicles recognize the volatile organic compounds emitted by plants infected by pathogens, which aides in developing specific management tools to overcome the disease (66, 67). The yield obtained in Climate Smart Agriculture High (CSH) was significantly higher (33.90%) than in farmer practices (68). Therefore, initiatives to promote zero tillage, laser land leveling, residue management, legume inclusion, need-based water management using tensiometer, sensor-based site-specific nutrient management, and other climate-smart agricultural practices among smallholders certainly add value to achieving global food security.

Weather forecast-based agro advisories

Increase in extreme events, rise in temperature, snow melting, rise in sea level, dry spells, and drought affect soil moisture availability. The climate abnormal events favoring the development of new pests and diseases, affecting physiological processes in plants and animals, and loss of agriculture produced by floods and drought impose food insecurity (69). Accurate weather forecasts and dissemination to the farming community can minimize the impact of extreme events (70). Thus, an integration of modeling adaptation strategies like N-optimization, crop rotations with legumes, planting dates, breeding of cultivars for early maturity, and policy development on the mitigation of the negative impact of climate change can be effective adaptation strategies (71).

Micro-finance and Insurance

There is also a need for effective extension services to facilitate crop-weather insurances, and micro-finance services in addition to a change in farming practices, site-specific management, and watershed management (72). The farmers of developed countries have dominance over the farmers of the developing countries because of financial backup provided by the government of the developed countries for undertaking research in the field of developing weather insurance index for protecting emerging farmers against the weather risk, and improving the livelihood of their farmers (73).

Conclusion

Climate change is severely affecting global food and nutritional security, posing a challenge to eradicating hunger, malnutrition, and poverty. In India, part of the country is affected by floods and drought in the same season, and also, heat flue and cold waves are negatively impacting crop and livestock productivity affecting the rural economy and diminishing the contribution of agriculture to the GDP of developing countries. Change in monsoon behavior over the years is affecting the economy of most agriculture-dependent countries, mainly correlated with emissions of global greenhouse gases . There is an urge for all developing and developed countries to follow inter-disciplinary approaches to minimize the release of greenhouse gases by including diverse sectors like agriculture, industries, health, infrastructure, water, forestry, fishery, land and ocean biodiversity, sea levels and oceanography where roles played by a human should prioritize minimizing the greenhouse gas emissions. In the agriculture sector, there is a need for district-level crop mitigation and new cost-effective technology adoption for farmers to overcome the ill effects of climate change.

Prolonged heat stress and drought minimize microbial colonization, slow down the mineralization of C and N, and imbalance nutrient cycles in soil-plant systems. The disruption in nutrient cycles and a change in soil organic carbon pools adversely affect the soil moisture regime in maintaining soil hydraulics, leading to a decline in soil fertility and overall soil health. There is a need for integrating biophysical, climatic, organic, and socioeconomic variables for better land-use management. A comprehensive and long-term planning is required to collectively address the issues of optimizing inorganic fertilizers, organic inputs, watershed management, biophysical research, and capacity building under climate-resilient agricultural practices. Agroecological crop diversification and conservation agriculture with minimum tillage and cover cropping are the emerging sustainable practices to mitigate the ill effect of climate change on agriculture. Transformative agriculture is adopting Agriculture 4.0, where farming practices are becoming digital and controlled, developing the three pillars (social, economic, and environmental) of sustainability, and shaping the future of agriculture.

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Authors contributions

Chitranjan Kumar (CK) mooted the idea and topic of this research. H.P. Rajath (HPR), CK, H.R. Bhanuprakash (HRB) prepared the original draft. CK, M. Hanumanthappa (MH), G.S. Yogesh (GSY), H. Chandrakala (HC), and Navinkumar (NK) prepared the revised version. All authors have seen the final version of this manuscript.

Compliance with ethical standards

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