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Building Climate-Resilient Agricultural Systems: Adaptive Approaches for Sustainable Crop Production and Environmental Stewardship

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Overview

Climate change is the global issue affecting agricultural and livestock production. Change in rainfall, atmospheric temperature, heat waves, wind velocity, and atmospheric carbon dioxide are the major cause of climate change. Such type of change in the climatic conditions may affect environmental sustainability, agricultural system and livestock production. Development of conservational agricultural system like restoration of soil fertility, soil moisture, water, and minimization of crop duration by adapting short duration varieties may provide strength to agricultural sustainability and livestock production. Several adaptive frameworks have been designed to enhance environmental sustainability to reduce the effect of climate change. Additionally, the crop improvement strategies against drought, soil salinity and early maturity and their cultivation in the abiotic stressed prone area may give sustainability to the crop production. In context to savior mechanism, saving of natural resources, recharge of water reservoir, reforestation, and conservation of rain water strengthen sustainability for durable crop and livestock production.

Keywords: *Climate change, adaptation, environmental sustainability, drought, global warming, sustainability, agriculture, resilience.*

1. Introduction

Environmental sustainability provides favorable condition for agriculture and livestock production. Balanced agro-ecosystem is one of the robust platforms for the living being on the earth (Fan, 2012). Most of the agricultural crops grown for food and fodder production are directly affected under unfavorable climatic condition. Soil moisture provide medium for the proper growth and development of any crops. Long-term water deficit condition and evapotranspiration are the major failure of crop production. Due to climate change, several unfavorable conditions like drought, high temperature, soil salinity, flood and other threats directly influence the agriculture system. Agriculture system and crop production is directly depends on the environmental conditions and climate change. In addition, some changes like

change in the rainfall, change in the temperature and increase in the atmospheric CO_2 concentration expected to be significant impact of the growth and development of plants. Water cycle is one of the important factors for agriculture production and sustainable development. Water cycle is also affected by unpredictable climate change. Unfortunately, increase in the see level has to boost the seasonal salinity may use for crop production affects the crop productivity up to certain level. Use of saline water for irrigating may cause long-term effect on the soil salinity due to increase of the salt ion in the soil strata. Furthermore, low temperature during dry season, accompanied by decreasing in rainfall and extreme low rainfall in the dry season leads to a scarcity of water for production and life (Mendelsohn, 2014). Reducing in irrigation water supplies because of shortfalls in rainfalls and also leading to reduce areas under irrigated crops and likely increased areas under rain-fed crops in the ensuing season. Global warming and continuous increase in the temperature in another important factor affects agro-ecosystem and creates severe climatic condition. When the temperature is lower than optimal or higher may affects several physiological activities of the plants related to growth, development, flower initiation, fertilization and grain filling (Bhaskaran, et al., 1995).

2. Factors Contributing to Climate Change

Climate change is the global issue, which increase the average global temperature and may cause the continuous global warming. Global warming not only increases the average global temperature, it may also increase the frequency of unfavorable environmental conditions like floods, droughts, heat waves, intensity of typhoons, and hurricanes. Such type of change in the environmental condition affects the efficiency of crop and livestock production that may affects the socio-economic status of the peoples. Long-term awaited rainfall and continuous increase in the temperature may decrease the water table and soil moisture. No single factor is responsible for the climate change; there are several factors responsible for climate change. Climatic threats like drought, salinity, high temperature, pollution, are due to loss of natural resources in the surrounding areas. In addition, human-induced activities like deforestation, loss of agro-biodiversity, loss of water reservoir, urbanization, and industrialization are the major cause of climate change and global warming (Elhassnaoui, et al., 2021). Change in climate increase the incidence of pests and diseases, which causes a huge loss in crop production. The effects of climate change significantly perturbations and can be expected to be natural systems that have possible effects on the fiscal policies of highland range through both direct and indirect means.

3. Effects of Climate Change on Environmental Sustainability

Environmental sustainability facing problems in many countries of the world due to industrial pollution, degradation of land as well as natural disasters caused by the global warming (Gaglio, et al., 2019). Most of the environmental are associated with climatic factors and weather condition. Due to long-term change in the climate, most of the environmental factors are irregular and cause the uncertainty. Such type of uncertainty in the weather condition due to climate change may loss the environmental sustainability. Environmental sustainability are depends on the climatic factors. Uncertainty in the climatic conditions loss the environmental sustainability across the world has been observed. Agro-ecosystem and environmental sustainability are directly depends on the climatic factors. However, most of the environmental factors that provide sustainability to nature are positively correlated with the favorable climatic conditions. In context to favorable environmental condition, the factors like temperature, humidity and precipitation may determinate the environmental sustainability.

4. Impact of Climate change on Agriculture system

Agriculture system and crops production are directly depends on the climatic condition because most of the physiological activities of the plants related to growth and development are directly depends on the favorable environmental condition. Water is the important resource for agriculture system and livestock production. Most of the crops are unable to survive under water deficit condition. The land suitable for crop production, pastures and forests cover almost sixty per cent area on the earth are being expose to several types of climatic threats. Most of the human-induced activities create abnormal changes in the temperature and rainfall. Such types of changes may increase the intensity of drought and flood. However, change in the pattern of climatic condition may also invites the attack of insects, pests and diseases to the crops and living beings. On an estimate, approximately 40 per cent of the plant species are lost in both food crops and vegetation. Such type of critical conditions due to unpredictable climate change may leads to change in the plant and species diversity (McClean, 2005). Climate change can affect both biophysical and socio-economic status of the influenced area. The biophysical impact due to unpredictable climate change affects crop production, pastures, livestock due to changes in the water resources, soil nutritional status. The socio-economic status affected due to decline in the yield and production.

Table–1: Impact of Climate Change on the Agricultural System

Climatic Factors	Agricultural Consequences	Impact on Agriculture
Rising temperature	Reduced crop productivity, crop duration, heat stress	Alters plant physiological processes including growth
Changes in precipitation	Poor crop establishment, reduced irrigation efficiency	Irregular rainfall patterns and altered water availability
Drought	Crop failure, reduced biomass and livestock productivity	Soil moisture deficit and water scarcity
Flood	Root damage, nutrient loss, increased crop mortality	Waterlogging and oxygen deficiency in the root zone
Increased atmospheric CO_2	Changes in crop growth and physiological activities	Influences photosynthesis and plant metabolism
Soil salinity	Reduced seed germination, poor nutrient uptake	Accumulation of soluble salts
Wind velocity	Crop lodging of crops, reduced pollination and yield	Physical damage to crops and soil erosion
Loss of biodiversity	Reduced genetic resources and ecosystem resilience	Decline plant species diversity and ecosystem
Arable land degradation	Reduced agricultural production and food security	Declining soil fertility and land productivity
Impact on livestock	Lower milk, meat, and reproductive performance	Heat stress and reduced availability of fodder and water
Loss in food grain and fodder	Food insecurity and nutritional challenges	Reduced agricultural production under climate uncertainty
Socio-economic impacts	Poverty, livelihood insecurity, and migration	Reduced farm income and increased production costs
Impact on Indian agriculture	Reduced economic returns and increased production risk	Unfavorable weather causes soil infertility and yield decline

5. Adaptation Strategies for Climate-Resilient Agriculture

Adaptation is one of the best survival mechanisms under climate change and global warming. Proper adaptation strategy provides strength to the development of sustainability for crops production. It has been observed in several regions across the world, climate change affects groundwater recharge, water cycle, soil moisture, livestock, and aquatic species. Change in climate increase the incidence of pests and diseases, which causes a huge loss in crop production. Due to climate change deterioration in soil fertility, promote salinity, defiance many pesticides, herbicides and deterioration of irrigation water quality should be found. Adaptation is the potential strategy in the climate change situation for sustainable development. The effect of climate change can be mitigating by removing carbon dioxide gas from atmosphere by restoration of natural resources. However, ecosystem-based solutions will be far from sufficient, and there is still a need to address the issue of fossil fuel emissions as a primary approach to mitigating climate change. Since the beginning of international climate efforts, they have focused primarily on reducing greenhouse gas emissions as a means of combating climate change, not on restoring biodiversity (Chenet, et al., 2021).

Table–2: Scientific summary of adaptation strategies under climate change for sustainable agricultural development

Adaptation category	Climate-related challenge	Adaptation strategy	Expected outcome
Water resource management	Reduced groundwater recharge	Restoration of water resources	Improves irrigation reliability
Soil management	Soil fertility and salinity degradation	Soil fertility and salinity restoration	Sustains productivity and crop growth
Crop protection	Increased incidence of pests and diseases	Integrated pest and disease management	Reduces production losses and improves crop
Climate mitigation	Increased atmospheric CO_2	Forests Restoration for carbon sequestration	Enhances ecosystem resilience
Climate mitigation	Greenhouse gas emissions	Reduction of fossil fuel and greenhouse gas emissions	Mitigates climate change and global warming
Rural adaptation	Climate-induced crop failure	Cultivation of short-duration crops	Stabilizes crop production
	Drought and flooding	Adoption of drought- and submergence-tolerant cultivars	Enhances crop resilience under climatic extremes
	Fodder shortage during climatic stress	Fodder storage and preservation	Ensures continuous livestock feeding
	Water scarcity	Restoration of water reservoirs	Improves irrigation and livestock water
	Limited access to agricultural inputs	Government support through subsidies seed and fertilizers	Strengthens farmers adaptive capacity and agricultural productivity
Urban adaptation	High energy demand	Energy-efficient practices	Reduce greenhouse gas and conserves energy
	Freshwater scarcity	Water-saving and efficient domestic water use	Conserves freshwater resources for multiple sectors
	Resource imbalance	Efficient allocation of energy and water in urban and rural areas	Improves agricultural resource availability

Circular economy adaptation	Urban food waste generation	Utilization of food waste as livestock feed	Reduces environmental pollution by waste recycling

6. Sustainable development approaches

Sustainable strategy is depends on the prediction of climate change and adaptation approaches. Environmental sustainability under the era of climate change and day-by-day increasing temperature are the challenging issue. Three components *viz*. air, water and temperature are the important components of the environment and balanced amount of these three components in the atmosphere may make sustainable ecosystem and agro-climatic zones (Klenert, et al., 2020). Industrialization, urbanization, loss of forests and water reservoir are the major cause of the loss the environmental sustainability. Retaining these may increase the level of environmental sustainability. Several policies, projects and framework have been designed to make sustainable environmental development. Sustainability cannot be developing by targeting the single factor. Sustainability is loss by destroying the multiple factors, it means it is depends on the several factors related to the climatic conditions. Therefore, sustainable development by following multiple approaches may give strength to the various kinds of the adaptive approaches.

7. Crop production strategy

Adaptation of suitable crop production strategy under climate change is one of the important ideas for the food and fodder security. Global agriculture system and crop production is directly depends on regional weather and climatic condition. However, increase in temperature, unpredictable rainfall, precipitation, and increased carbon dioxide condition in the atmosphere influences crop production. In addition, climate change also affects agro-ecosystem. Activation of smart agriculture system is one of the significant initiatives that call for agriculture to be part of solution in the era of climate change. Several policies have been designed and implemented for the strategic crop production in context to make resilient agriculture system. Conservation agriculture may become an important part of the smart agriculture in the situation of climate change (Morton, 2007). The Food and Agriculture Organization (FAO) suggested food security and climate change should be addressed together, by transforming agriculture and adopting practices that are "climate-smart" to eradicate hunger from the world (FAO, 2010). Adaptation of crop varieties play important role under the unfavorable environmental condition. Keeping the effects of climate change and uncertainty of rainfall, breeders has developed crop cultivars suited to climate change may provide strength to the crop production in the era of global warming and climate change (Mishra and Sahu, 2014). Using biotechnological and molecular breeding approaches, scientists has identified genes and QTLs conferring tolerance under abiotic stressed conditions and these genes have

been introgressed in to popular crop cultivars to develop smart crop cultivars. However, used of gene pyramided crop cultivars in the said region may provide opportunity of crop production. Change in the cropping pattern is another strategy of crop production in dater deficit condition. In drought prone area, raising early maturing crop cultivars, deep-rooted cultivars and drought tolerant cultivars may provide sustainability and gives significant strength.

8. Conclusion

Broad ranges of natural resource management practices and adaptation strategies are available to renew the environmental sustainability and agriculture production system. Reforestation by planting, water conservation, soil conservation, conservation of agro-biodiversity, and change in the cropping pattern provide strength to the environmental sustainability for crop production and development of durable agricultural system. Change in frequencies, types, and intensities of various livestock pests and crops; the availability and limit of irrigation water supplies; and the harshness of soil erosion changes because of climate change. Reducing in irrigation water supplies because of shortfalls in rainfalls and leading to reduce areas under irrigated crops and likely increased areas under rain-fed crops in the ensuing season. In warmer climates, some crops are growing faster and leading to higher production and incomes. Implementation policies and framework may help in the development of sustainability in the coming future for livestock production, crop production and income generation from these sectors.

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