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A Comprehensive Review of Potential Adaptation and Mitigation Strategies in Agriculture in the Current Climate Change Scenarios

Bhawna Bamniya [a], Kopal Singh [a] and Munish Kaundal [a*]

[a] Chandigarh University, Mohali, Punjab-140413, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Climate change has a major impact on agriculture worldwide, but in certain regions, like India, this impact is more pronounced than in others. India's large population, heavy reliance on natural resources, and lack of coping mechanisms make it difficult for the country to adapt to the changing climate. India has experienced a notable warming trend over the past century, with an approximate 0.60 °C increase in temperature. This trend is anticipated to continue, possibly having catastrophic consequences for agricultural productivity and food security. Climate change is predicted to result in increasingly variable growing conditions for many crops, making it more challenging for farmers to schedule the planting and harvesting of their crops. Rapid reaction times and coordination are required to mitigate the consequences of climate change on Indian agriculture. This means implementing adaptation tactics, such as cultivating crop varieties that can tolerate high

**Corresponding author: E-mail: munish.ihbt@gmail.com;*

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temperatures, promoting water-efficient irrigation techniques, preserving soil health, and enhancing climate resilience through integrated farming systems. India can lessen the negative effects of climate change on its agriculture sector and guarantee food security for its growing population by taking proactive steps and implementing sustainable farming practices.

Keywords: Catastrophic; productivity; resilience; agro-biodiversity; climate change.

1. INTRODUCTION

In India, 65 crore people are engaged in agriculture for their food and livelihood [1]. They frequently combine the management of plants, animals, water, soil, and other resources at the landscape scale, resulting in mosaics of diverse land uses. The local communities maintain these landscape mosaics, some of which date back hundreds of years, using customs derived from traditional knowledge passed down through the centuries [2]. Rural communities' ability to make a living is threatened by climate change, frequently in conjunction with demographic constraints. Shift, unstable land tenure and resource rights, deterioration of the environment, failures of the market, unsuitable policies, and the breakdown of local institutions [3]. Among the strategies for addressing these issues have been recognised as local community empowerment and fusing farmers' and outside knowledge. Nevertheless, not much has been written about their experiences. Traditional agricultural landscapes are considered linked social-ecological systems (SESs), and SESs are characterised by three resilience: the ability to self-organize, learn from shocks, and adapt [4]. Being resilient does not include a balance between enduring change and persistence. Rather, it describes how evolution and survival cooperate to enable living systems to absorb disruption, creativity, and shift while preserving distinctive processes and structures [5]. Agriculture is one of the most vulnerable systems to fluctuations in the weather and environment. Global food security is now more threatened by the effects of climate change than ever before [6]. Food prices rise as a result of decreased food production brought on by climate change.

Indigenous peoples are adept at observing weather and climatic changes and adjusting by using a variety of mitigating and adapting techniques [7]. The threat that climate change poses to development has drawn more attention in recent years. Global warming is posing problems to every country in the world, including increased mean temperatures, fluctuating precipitation patterns, and an increase in the frequency of extreme weather. India's agriculture sector, which employs a significant portion of the workforce and contributes significantly to gross domestic product (GDP), is the backbone of the nation's economy. Despite advancements in other industries, agriculture remains crucial for generating employment, guaranteeing food security, and decreasing poverty. The sector is confronted with numerous challenges, one of which is the imminent threat presented by climate change. It has an indirect effect on household welfare, income distribution, economic growth, and agricultural demand, among other things. It also directly affects the agricultural sector, particularly in developing nations where agriculture makes up a significant portion of the economy. Also, a lot of rural people in developing countries get their living from agriculture and related businesses, and climate change is causing significant losses in agricultural output.

Growing conditions for many crops are expected to become more variable as a result of climate change, which will make it difficult for farmers to plan when to plant and harvest their crops. Climate change's effects on important crops like, wheat and paddy are among the main agricultural issues in India. Variations in yield reduction between 4.5-9% are anticipated, contingent on the degree and rate of global warming.

2. NEED FOR CLIMATE-RESILIENT AGRICULTURAL SYSTEMS IN INDIA

India will have 1.38 billion people living there in 2020, accounting for 17.7% of the world's population, according to population statistics. Following independence, the population of the nation has increased 3.35 times. With just 2.4% of the world's land area, India accounts for approximately 8.1% of all species worldwide [8]. The average field grip size in each state is 1.08 hectares (ha), following the most current agricultural census. Less than 1 ha of land is what makes up minimal cultivators in the majority of Indian states; the remaining ones have small cultivators (1-2 ha).

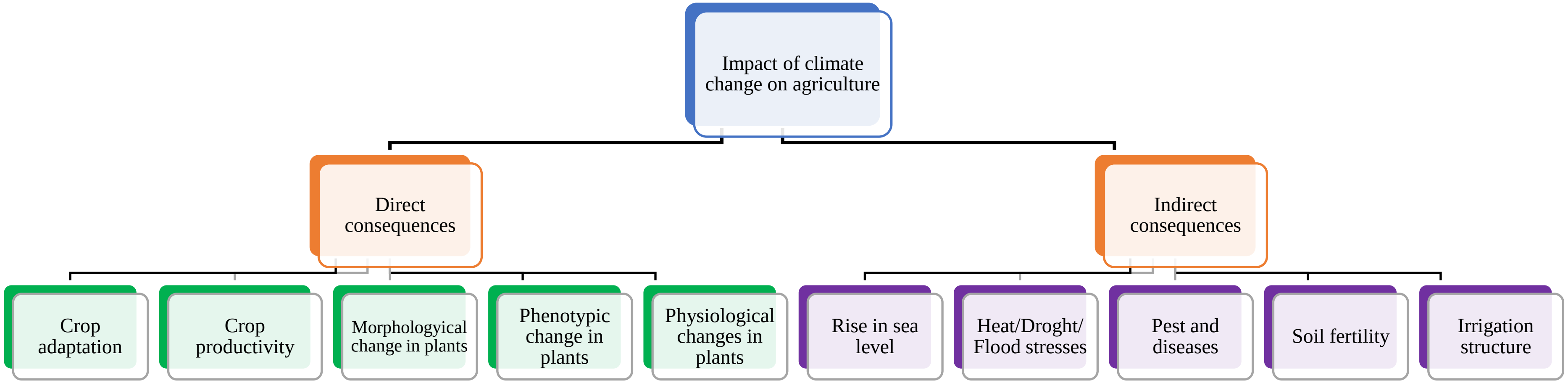

Fig. 1. Climate change's effects on agriculture

Numerous obstacles have been encountered by the majority, such as adequate transportation, financing accessibility, input supply, and market accessibility. Nearly 60% of all food cereal production is produced by them, including 49%, according to the Agricultural Census, comprising almost half of the country's fruits and foods, as well as 49% rye, 40% gluten, 29% coarse maize, and 27% pulses [9]. Approximately 58% of India's population makes their living from agriculture. The country's commercial success also depends on other firms with natural origins. Field crops, arboriculture, fisheries, and pullets are closely associated with several Sustainable Development Goals (SDGs) of the United Nations, such as environmental activity, nutrition, and zero hunger [10].

According to the State of Food Security and Nutrition in the World 2020 assessment, 189.2 million people, or almost 14% of the country's population, are still undernourished. India is placed 94th in the world out of 107 nations on the Global Famine Index 2020. It will take a massive effort to achieve "zero hunger" by 2030, requiring an integrated and multifaceted approach to the nation's sustainable agriculture and food systems. The greatest serious threat to a nation's food security is climate change, particularly as it relates to extreme weather occurrences. The anticipated 8-year temperature change of 1-2.5 °C will probably have a major effect on product output. Elevated temperatures have the potential to reduce crop life, permit fluctuations in photosynthesis, elevate crop gaseous exchange rates, and impact insect populations [10]. The climatic shift causes an increase in soil evapotranspiration, a decrease in fertilizer use efficiency (FUE), and an acceleration of nutrient mineralization.

Crop yields, soil fertility, microbial populations, crop availability, intensity of droughts, and the concentration of organic matter in clay soils are affected by climate change. For communities dependent on agriculture, these consequences result in severe financial losses, food shortages, and health hazards. As such, South Asian nations, from the Himalayas to the seashore, are more susceptible to the negative effects of climate change.

Changes in climatic patterns have a direct impact on water availability, which in turn causes changes in precipitation patterns and exacerbates drought situations. Farm income is significantly reduced as a result of this scarcity, which impacts both irrigated and unirrigated agricultural areas. According to a 2017-18 economic survey, income decreases in irrigated areas might be as high as 15-18%, while in unirrigated areas the drops could be much more significant, reaching 20-25%. Communities that experience such financial losses become more vulnerable to health problems as a result of food shortages and nutritional deficits [11].

Furthermore, rising global temperatures and rising carbon dioxide concentrations exacerbate the problems facing agricultural systems. Over the twenty-first century, it is predicted that South Asian regions will see significant warming, with temperature rises ranging from 2-6°C. The main cause of global warming is carbon dioxide levels have already risen to dangerously high levels above 410 parts per million (ppm) [5]. To improve the resilience of agricultural systems, it is essential to put adaptive solutions into practice, such as drought-tolerant crop types, water-saving irrigation techniques, soil conservation measures, and climate-smart agricultural practices.

3. NATIVE FARMING METHODS IN FOUR DISTINCT HOTSPOTS FOR AGRO-BIODIVERSITY

Previous studies on the farming practices of Indigenous people in four distinct agro-biodiversity hotspots have not necessarily focused on climate-resilient farming. The authors of these publications thoroughly discussed agro-biodiversity, farming techniques, the current state of affairs, and economic sustainability within the historical and modern framework of the socio-ecological paradigm. To the best of our knowledge, no studies have been conducted on the direct climate change resilience of indigenous agricultural practices used throughout the Indian subcontinent. The main focus of the part that follows will be on Indigenous tribes agricultural practices and how they might be applied to the current eco-agricultural scenario in the context of climate change [12].

3.1 The Tribes of Apatani (Eastern Himalaya)

The Apatanis use finger millet on the bund (small dam) for paddy cum fish culture in addition to terrace and wet farming. Owing to these unique characteristics of sustainable farming practices and the indigenous biological understanding of maintaining ecosystems, the plateau is currently being considered for designation as a World Heritage Site [13]. In the northeastern part of India, the Apatanis are considered to be among the most evolved tribal people due to their long history of developing rice farming in the valley [14]. It has a long history of prosperity and is well-versed in land, forest, and water management. Canal systems that are properly maintained provide irrigation for the wet rice fields. Diverting multiple streams that originate in the forest into a single canal allows for its management. It is controlled by combining several streams that emerged from the forest into one canal, which is then used to connect each agricultural field with bamboo or pinewood pipe. The Apatani tribes cultivate their land entirely organically, without the use of synthetic soil additives. In addition to being ideally situated to absorb all runoff nutrients from the hills, the paddy-cum fish agro-ecosystem is regularly supplemented with livestock manure, agricultural waste, kitchen trash, and rice chaff to preserve soil fertility [15]. The paddy-cum- fish agricultural system's irrigation, cultivation, and harvesting require teamwork, expertise, backup plans, and a disciplined work schedule. The Apatani tribes have arranged for the building and upkeep of irrigation systems, fences, field side pathways, weeding, field preparation, transplanting, harvesting, and storing.

3.2 In the Western Himalaya, at Lahaula

The Lahaul tribe has managed to preserve a significant amount of livestock and agro-biodiversity, which together demonstrate a high degree of germplasm conservation [16]. Because the area is covered in ice for the remaining six months of the year, Lahaulas who live in the chilly desert of the Lahaul Valley are facultative farmers who may only crop for six months, from June-November. The Lahaula people use ice-water collection, combine cash and traditional crop production, and use mixed agriculture-livestock systems to maintain a high level of agro-biodiversity despite the hard weather. Indigenous methods are unique in the way they make effective use of water resources in such a harsh, dry climate with precipitous hills. Channel lengths range from a few meters to over 5 km. Transverse ridges and furrows on a slope slow down soil erosion and water flow [17]. Fertile soil gradually becomes unproductive due to the thick snow cover's nutrient leaching. In a specifically constructed communal composting room, cattle manure, night soil, kitchen scraps, and forest leaf litter are composted to meet the demand for high quantities of organic manure. As summer approaches, compost materials are applied to the field to enhance the condition of the soil. Irrigation is accomplished by using earthen channels to collect snowmelt water.

3.3 Eastern Ghat is Dongria Kondh

Since their founding in the tropical dry deciduous hills forest ecoregion, the Dongria Kondh tribes, who now reside in the semiarid hilly range of the Eastern Ghats, have been using sustainable agro-forestry techniques and a distinctive mixed agricultural system for several centuries. The 18 distinct non-timber forest products, including medicinal goods, fruits, vegetables, seeds, mushrooms, bamboo, and leaves and grass, can be found in the forest.

The Kondh people make sustainable use of the natural capital of the forests to preserve the natural stock and guarantee a steady supply of goods. The tribes have used around 70% of the resources, while the remaining 30% are sold to raise money for further economic growth and the sustainability of the agro-forest [18]. Kondh farmers, on the other hand, have perfected an extremely intriguing farming method in which they cultivate eighty varieties of various crops at once, including paddy, millet, leaves, pulses, tubers, vegetables, sorghum, and legumes.

3.4 The Western Ghat Irregular Tribes

The Irulas, or Irular tribes, who inhabit the rugged Palamalai region of the Western Ghats and the Nilgiri hills, follow three fundamental ancient agricultural methods. These practices include traditional methods of managing pests, storing food and seeds, and predicting the weather using generations-old wisdom. The mixed agricultural Irular tribes are like the Kondh tribes. The tribes have created and strictly follow unique methods for storing harvests, vegetables, and seeds because of the excessive humidity in the area. As of right now, there are 11 distinct methods that the Irular tribes use to preserve their crops and seeds. After 2-3 days of sun drying, they store pepper seeds maize, oil, etc. in gunny sacks above a bamboo pole platform. In a tiny mud house, paddy grains are kept with the leaves of aromatic plants that are growing nearby, such as *Pongamia pinnata* and *Vitex negundo*. Millets are kept for up to a year after being coated with a slurry made from cow dung and buried beneath the ground. They prevent rodent and insect infestation with their specialized aeration-allowing storage structure [19]. Indigenous lines of drought-resistant, pest-tolerant, and disease-resistant millet, ragi, and sorghum are preserved, and traditional knowledge of cross-breeding and selection aids the Irular in optimizing the genetic potential of the crops [20]. Irular tribes are also skilled nature observers who transmit their traditional knowledge of weather phenomena associated with atmospheric conditions or biological activity. Irular forecasts the likelihood of rain by studying the behavioural variations of sheep, termites, dragonflies, and ants. The ring of the moon, an evening rainbow, and cloudiness in the morning are examples of atmospheric phenomena that are seen to be favourable indicators of rainfall, whereas, dense fog is thought to be a negative indicator. The Irular tribes also hold and use traditional knowledge of weather, climate, rainfall prediction, and forecasting [19]. Because 16 distinct plant-based insecticides with entirely biological properties have been identified, the Irular tribes also acquired substantial expertise in pest management. These natural pesticides have the following modes of action *viz.,* growth inhibitor, stomach poison, anti-feeding, anti-repellent, and contact poisoning. These insecticides are made from extracts of tobacco, babul, chilly, and neem plants.

4. AN EXPLANATION OF A FEW CHOSEN CLIMATE-REBOUNDING AGRICULTURAL TECHNIQUES

For agricultural yields and farm income to be sustained, farmers must carefully adapt to the changing environment. Protecting small and marginal farmers' livelihoods requires enhancing agriculture's resistance to climate risk. In the past, the goal of agricultural technology transfer has been to increase farm productivity. Farmers must, however, adjust swiftly in the context of climate change and variability to strengthen their resistance to the growing hazards of climatic variability, such as floods, droughts, and other extreme weather events. The 8 main categories of agriculture management system practices that comprise Climate-smart agricultural (CSA) practices have been established. They consist of livestock management, crop management, pest control, risk management, conservation management, post-harvest management, soil and land management, and water management.

Sixty seven % of the recorded climate-resilient agricultural (CRA) practices involve institutional implementation, whereas 33% of the practices have been implemented at the farm level. The National Innovation on Climate Resilient Agriculture (NICRA), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Indian Council of Agricultural Research (ICAR), CGIAR (The Consortium of International Agricultural Research Centres), Department of Animal Husbandry and Dairying (DAHD), National Institute for Organic Farming, Indian Institute of Water Management, Department of Agriculture and Corporation (MoA), Indian Grasslands and Fodder Research Institute, National Centre for Agricultural Economics and Policy Research, and Central Insecticides Board are among the organizations involved in promoting, investigating, or putting the practices and technologies into action. The research is spread throughout India's 18 states, where Telangana and Rajasthan are next with 4 studies, and Haryana has the most with 5 [21].

4.1 Water Resource Management

India is thought to contain 4% of the world's water resources, with the agricultural sector using 80%. The Indian government has launched several new initiatives to boost agricultural productivity, including Per Drop More Crop, Doubling Farmers' Income by 2020, and Har Khet Ko Pani (Water for Every Farm), which aims to improve the state of agriculture today and broaden the irrigation system's application [18] The government may need to impose additional intervention measures to address the growing water demand in the coming years. Roughly 12% of India's landmass is made up of arid zones with limited water supplies, making them more susceptible to the negative effects of climate change, such as little rainfall.

One way to guarantee a sufficient yield is through Supplemental Irrigation (SI), which can compensate for the lack of seasonal rain. In dry land and semi-arid regions, the combination of SI with water harvesting leads to effective water use and enhanced productivity. Planting on a bed, as opposed to flat ground, promotes root development, plant height, biomass, uniformity, and yield in poorly drained soil. The skip row furrow irrigation system maximizes net return, irrigation water use efficiency, and peanut pod production [15].

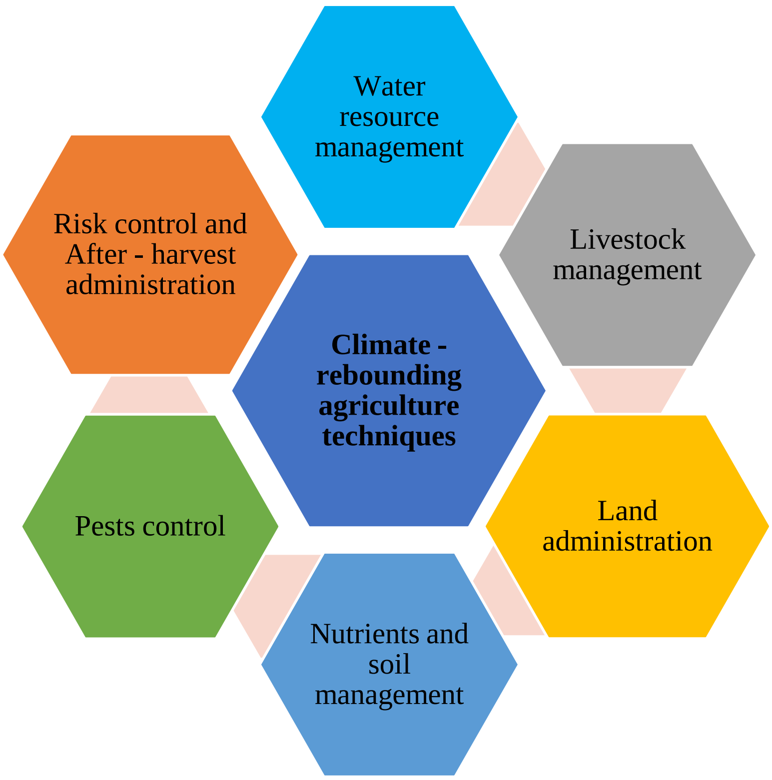

Fig. 2. Climate-resilient farming methods

Fig. 3. Development objectives for water resource management

Around 700 million Indians live in rural areas and depend only on groundwater for their everyday needs [16]. The adoption of the furrow bed irrigation method increased farmers' net income when compared to the flat-bed system, according to research done by Naresh et al. [17]. Large-scale groundwater consumption for irrigation has been alarmingly reducing in North-West India. According to estimates, the need for irrigation water will increase by at least 10% for every 1 °C increase in temperature [21]. Another issue is the increased use of electricity for groundwater pumping for irrigation [18]. As a result, Laser Land Leveling effectively lowers water loss. Traditional techniques like, dumb animals, levelling boards, and scrapers have not shown to be successful in reducing irrigation water use [22].

According to Kaledhonkar et al. [23], the water table of the wells has risen as a result of the recharge tube wells when they are placed in front of the wells. Silt basins and flutter can also be utilized to extend the life of recharge tube wells, the distance between the two must be roughly 100 meters (m). The water table increased by 8-10 feet in the ensuing years, recharging roughly 60 tube wells and facilitating the irrigation of 242 ha of land [24]. A geo-electrical survey may be necessary to determine an appropriate location for tube well recharge, and an estimate of rechargeable water is crucial.

4.2 Land Administration

By growing multiple crops next to one another, intercropping increases the yield on a given plot of land. The financial benefits of intercropping over monoculture cultivation have been demonstrated. Relay intercropping has increased the amount of growing seasons and increased the efficiency of land utilization, which has increased the amount of resources captured overall. Moreover, it has led to higher yields per unit of land [20]. The International Rice Research Institute (IRRI) and the International Fund for Agricultural Development (IFAD) carried out a demonstration trial study with groundnut and soybean in 5 locations in the Ri-bhoi district of Meghalaya, India [19]. The usage of improved cultivars produced an extra income per acre of more than 263.19$. Diverse techniques such as farming with trees on contours, intercropping, multiple cropping, bush, and tree fallows, creating shelterbelts and riparian zones/buffer strips with woody species, etc. are all included in agro-forestry. By promoting permanent cover, a suitable micro-climate, improved soil structure and organic carbon content, higher infiltration, enhanced fertility, and improved fertility all while using less fertilizer these methods can increase land production (WOCAT 2011). According to Roy and Tewari [20], ethno-forestry techniques and traditional knowledge of trees' many uses have been shown to improve soil health, act as a carbon sink, and provide a means of subsistence and feed. Gum Arabic plantations brought in large profits for the farmers in India's hot and dry regions, where the gum was sold for 3.15$ per kg.

4.3 Livestock Management

Changing the crop-livestock system is a good way to increase food security through adaptation [25]. Around the world, two-thirds of all crops, including cereals, rice, and sorghum, are produced using this approach, which is essential in the production of more than half of milk and meat. Mixed crop-livestock systems can provide more food in less space with fewer resources used [25]. By increasing plant density and fertility, produced high-quality green fodder [26]. The efficiency of cattle production may be indirectly increased by better feeding methods used as an adaptive approach [27]. The control of diet composition ought to be a part of feeding procedures. During drought years, farmers fail to make significant plans for pasture and forage management, which causes a fodder problem. Feed and fodder stockpiles rose significantly at the family and village levels in Phutahola village, Dibrugarh (Assam), India [24].

Breeding strategy modifications can assist animals become more resilient to diseases and heat stress, as well as enhance their growth and reproduction [28]. Establishing global gene banks could be a tactic to enhance breeding initiatives and function as a safety net. According to Thornton et al. [29], this has been completed for plants that are part of the gene banks' In-Trust plant collections. To create data banks on indigenous animal genetic resources, the National Bureau of Animal Genetic Resources (Bureau) in Karnal, Haryana, India, is conducting studies on the subject. Climate change, particularly rising temperatures, can have a direct or indirect impact on animal health [30]. Customized technological interventions are being developed to cater to the requirements of animals, pets, and livestock. The rate of purchasing goods like tracking collars, medicine patches, and electronic saddle optimization is rising [31]. Increasing livestock production may benefit from the use of better grazing management techniques like rotational grazing and stocking rate management. According to Derner et al. [32], average daily gains (kg/head/day) declined when stocking rates increased along with grazing pressure.

4.4 Management of Nutrients and Soil

Improved soil aeration is a proven method for soil management, composting, cover crops, precision agriculture, and the use of organic fertilizers. Micro-dosing, which can help farmers and the long-term sustainability of the environment, involves applying the right amount of fertilizers and other agrochemicals at the wrong time of planting and growth. According to ICRISAT studies, 25,000 smallholder farmers in Western Africa may have learned the techniques and seen a 50-130% boost in their revenue (ICRISAT 2009). Crop rotation has been practised in several Indian states, including Punjab, Rajasthan, and others, and has improved long-term productivity [33]. Long-term economic benefits of cover crops include increased microbial activity, moisture content, soil water retention, and overall soil health [34].

According to Jakhar et al. [35], residue retention and decomposition in the field are highly advantageous for soil health, which aids in the system's nutrient recycling and increases crop output. Retaining harvest residue has enhanced the soil's carbon and nitrogen levels [36]. Mulching offers several advantages, including preventing evaporation, preventing sunlight from assisting weed growth, and partially preserving soil temperature. Priya and Shashidhara [37] found that mulching can increase water use efficiency and boost gain output. The idea behind site-specific nutrition management is to balance the supply and demand of nutrients based on how they change over time and geography. This definition of "site-specific" refers to the dynamic, field-specific nutrient management during a given cropping season. The majority of the crops cultivated in Aduthurai and Thanjavur, Tamil Nadu, have shown site-specific nutrient management to be beneficial [38].

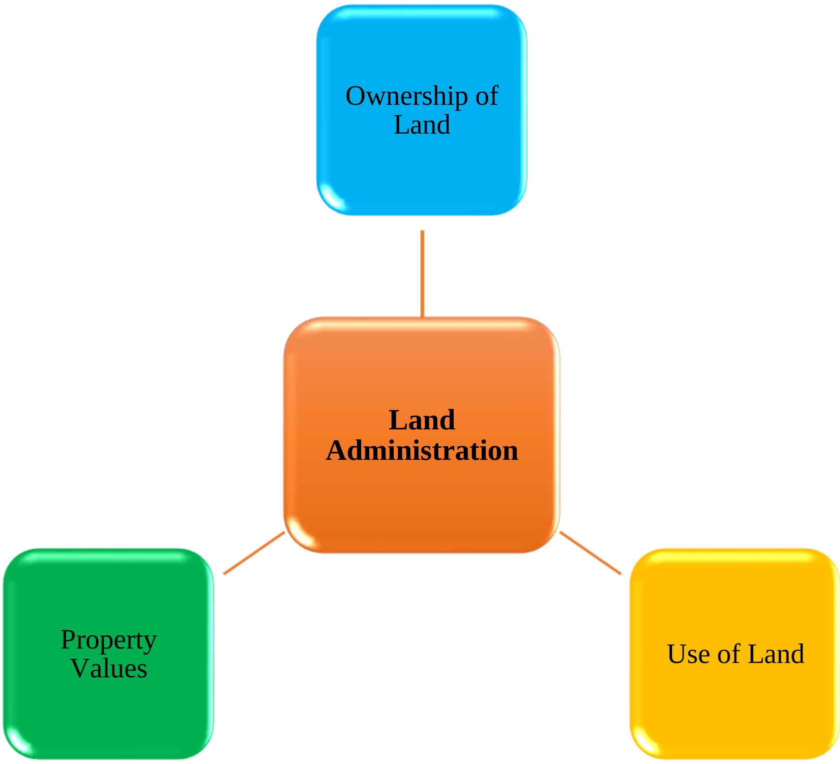

Fig. 4. Indian land administration practices

4.5 Risk Control

One of the main causes behind the government's implementation of insurance programs to combat uncertainty is crop failure. Farmer suicide has been linked to agricultural disasters. When implementing risk management measures, it's critical to evaluate market failure and financial uncertainty to prevent such misspending. In the event of crop failure, instruments like, forward contracting, crop insurance, and others could help farmers financially and grant credit for the following cropping season. The General Insurance Department of the Life Insurance Corporation of India launched the first scheme in India in 1972. Subsequently, several other programs were introduced but were unsuccessful. A new program called the National Agriculture Insurance Scheme (NIAS) was launched in the years 1999-2000. It covered all food crops and had premium rates ranging from 1.5-3.5% of the total amount for guaranteed crops. Another program, the Farm Income Insurance Scheme (FIIS), concentrated on price and yield through a single policy that compensated farmers for the minimum support price of two crops: rice and wheat. According to Mahajan et al. [39], the inadequacy of data regarding crop-cutting experiments and the absence of collaboration between banks and enterprises are the main causes of crop insurance's failure. By changing the shortfalls, Pradhan Mantri Fasal Bima Yojana replaced NIAS and MNIAS in 2016. For instance, they lowered the premium rate for Rabi and Kharif by between however, livestock has been growing in importance as a major source of income, a backup source of income, and a safety net for farming families. It is estimated that livestock accounts for a sizeable portion of revenue, or 16% for small farm households. Due to inadequate insurance delivery mechanisms, expensive premiums, mistrust of the insurance provider, lack of indemnity in the event of losses, lack of information about the renewal process, and challenges in obtaining insurance, approximately 90% of the households were not inclined to renew their livestock insurance 1.5-2% [40].

5. OBSTACLES TO CLIMATE-RELATED AGRICULTURE

It has been demonstrated that farmers' decisions on CSA interventions varied depending on their socio-economic status, where they were located, the agro-climatic zones in which they were located, the potential benefits of the technology, and the cost of implementation [41]. The adoption of effective climate-smart practices and technologies is hampered by several factors, including insufficient funding, inadequate institutional support, insufficient technical expertise, poorly implemented climate policies, a lack of coordination between national institutions and implementing agencies, and ownership gaps [40].

The administration does not give smallholder farmers enough financial or technical equipment support. The machinery and durable equipment needed for crop management, soil health, irrigation, and yield maximization are beyond the means of smallholder farmers. The farmers do not take advantage of the bank loans because they lack literacy and collateral. Middlemen who charge more, like neighbourhood money lenders, have a negative effect.

The knowledge of the market for the other crops that farmers can cultivate on their plot of land for a year's worth of cash flow is the main deterrent for farmers to diversify their crops. Despite their interest in rotation and diversity, farmers with disadvantaged landholdings might not be able to find new or additional crops to plant. Micro-level weather forecasts are crucial among the climate-related data that farmers should have access to make prompt and correct decisions. User-specific seasonal climate forecasts may lessen the risks associated with climate change for the participants in agricultural value chains [42]. No particular metrics are in place to monitor and evaluate a program to assess its progress. This might indicate the areas that require more attention and measure the success of an intervention. There is a need for more weather stations, therefore no system could offer climate information locally.

6. CONCLUSION

The scientific literature occasionally documents the implementation of CRA techniques. To pinpoint the activities that are only embraced when they are contextually relevant, more empirical research is needed. The main lesson in this example is that greater validation is required before upscaling farm-level adaptation measures which are primarily traditional to other geographic areas. Concerns have been raised about inadequate funding for climate-resilient adaptation practices, shoddy monitoring, and a top-down institutional initiative strategy. The farmers' evaluation of the dangers involved, their level of education, their access to technology, their financial situation, and their family needs all played a major role in their decision to implement CRA methods. Initiatives should be made in this direction to improve farmer ability to make effective decisions. A more systematic approach should be taken in the development, co-production, validation, and distribution of knowledge regarding adaptive measures. In addition to technological, institutional, and financial support, the creation of a knowledge base and a practical framework for knowledge transfer that is tailored to various agroecological zones and local requirements under changing climate conditions is required.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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