REVIEW ARTICLE

# The role of agroforestry in mitigating climate changes in arid regions of Rajasthan

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Climate conditions of northwest regions hinder production and life support system. The people in this region have developed an agroforestry-based drought protection system through generations of experience and ingenuity, that has been passed down from generation to generation. Agroforestry systems are environmentally and economically sound farming practices that improve overall farm productivity, enrich soil with fallen litter, and preserve environmental services like phytoremediation, biodiversity conservation, watershed protection, and carbon sequestration-all of which help to mitigate climate change. Agroforestry systems possess substantial potential for offering effective mitigation options; however, their capacity to sequester carbon depends heavily on well-managed practices. This paper describes the traditional agroforestry systems that prevail in the arid regions of Rajasthan and their role in mitigating climate change.

**Key Words:** *Carbon sequestration; Phytoremediation; Biodiversity conservation; Watershed protection*

## INTRODUCTION

Climate change is an alarming problem that is capturing global attention. The rise in $CO_2$ due to industrial activities, combustion of fossil fuels, can provoke subtle shift in the earth's climate patterns. The emission of greenhouse gases, including $CO_2$, $N_2O$, $CH_4$ and CFC etc, has raised significant alarm due to the potential escalation of global warming in the future. Concentration of $CO_2$ and other Greenhouse Gases (GHs) in the atmosphere have witnessed a substantial increase over the past century and predicted to continue rising. The impact of climate change, resulting from the surge in greenhouse gas emission is exacerbated for those living in the arid region because of the marginal and fragile nature of the resource they have access [1].

India's hot arid region lies between 24° and 29° N latitude and 70° to 76° E longitude, encompassing a landmass of 31.70 million hectares. The primary desert in this region is the Thar desert, also known as the Great Indian Desert, which extends across the western regions of Rajasthan, Gujarat, Punjab, and Haryana, making up 89.6% of the total hot arid region. Within the Thar desert, the predominant area is Arid Western Rajasthan, constituting 61% of the Thar desert's overall coverage [2]. The production and life support system in this region face considerable challenges due to environmental conditions such as low precipitation (100-420 mm/year), high temperature (45°C-50°C), high wind speed (30-40 km/hr) and high evapotranspiration (1500-2000 mm/year) as well as sandy, rocky, gravely, and saline soils with low fertility and water retention [3].In the face of the fragile environmental conditions and unpredictable climate changes prevalent in this region, agroforestry stands out as an appealing choice in this region since the trees have the inherent ability to fix and store carbon from the atmosphere over long periods. Moreover, it was noted that all agroforestry systems are able to effectively sequester more carbon than sole agricultural land use systems. "In the current context, agroforestry practices stand out as a promising approach, particularly in arid regions, to combat the adverse impacts of climate change."

## LITERATURE REVIEW

### Scope and potential of agroforestry system

Agroforestry-the incorporation of trees into farming system shows immense possibilities in addressing drought impacts, combating desertification and revitalizing degraded soils. Additionally, it facilitates the increase of food production for both human and animal consumption, providing an additional avenue for sustenance or financial support during periods of decreased crop yields [4]. Tree roots within agroforestry systems enhance the absorption of water, enhanced presence of beneficial microorganisms which improved the richness of soil nutrients [5]. Agroforestry system can decrease reliance on fossil fuel consumption by integrating tree planting in local agriculture fields, which effectively meets the demand for fuel wood, and lessens dependence on fossil fuels [6]. Agroforestry components like wind brakes contribute to improve air quality and mitigating pollution. Windbreaks and shelter-belts offer a wide array of benefits, such as alleviation of wind chill, preventing erosion, and reducing the presence of airborne particulate matter. Additionally, they actively extract carbon dioxide from the atmosphere, improve oxygen circulation, create habitats for wildlife, shield crops, lower wind speeds, lessen noise pollution and combating livestock odors [7]. Agroforestry practices play crucial role in securing farmers' livelihoods, particularly those who have minimal land holdings. It primarily focuses on addressing their basic requirements. Such as advancement of bio-fuels, creation of employment, carbon sequestration and upliftment of farm productivity.

Farmers residing in the arid region consider tree-based agricultural systems as exceptionally valuable, especially when rainfed crops face challenges during drought. These tree based systems serve as the sole source of essential resources such as fodder, fruit, vegetables, fuelwood, timber, and fiber, ensuring the sustenance of rural livelihoods. In addition, arid agroforestry meets 62% of the rural population needs for fodder, fuelwood and timber [8]. In arid agro-ecosystem, tree serve as a form of insurance against unpredictable climate change by mitigating crop yield losses and enhance resilience and diversify system [9-11]. Under such conditions integration of trees into conventional farming techniques emerged as a more favorable approach to combat climatic uncertainties, simultaneously bolstering ecological balance and ensuring food security [12,13].

### Traditional agroforestry systems practiced in arid regions of Rajasthan

Arid environment exhibits a wide range of diversity with respect to their biodiversity, vegetation, water resources, and human activities. Aridity serves as the common thread among all arid environments. In the face of adversity, the indigenous inhabitants of the Indian Thar Desert, recognized as the most densely populated arid region globally (127 person/$km^2$) as compared to global average of 6-8 persons per $km^2$ for arid zones [14], have ingeniously developed a sustainable farming system. Over successive generations of knowledge transmission, this system has demonstrated its critical role in safeguarding against drought. Traditionally, this region has been profusely endowed with a diverse range of native crops, trees, shrubs, and grasses. These natural resources have played an essential role in preserving the ecological balance required to sustain the local community's livelihoods,

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providing them with diverse array of products and services [15]. In arid regions of Rajasthan, traditional agro forestry systems are dominated by trees species like *Prosopis cineraria, Acacia nilotica, Tecomella undulata, Azadirechta indica, Zizyphus mauritiana* and *Ailanthus excelsa* [13,16,17]. Among the species, Prospois cineraria based agroforestry systems is globally renowned as traditional method of sustainability in arid regions, known as the "lifeline of the desert" [18]. It has been proven the fact that growing annual crops, especially millets, under or with tree canopy significantly increase their yield by 10-15% [19-21]. In a similar way, other trees like *Tecommela undulata, Acacia nilotica* and *Ailanthus* excels also offer life support benefits to the farmers during lean periods. The Central Arid Zone Research Institute (CAZRI) in Jodhpur initiated research and development initiatives in the 1970s, eventually resulting in the discovery of effective and productive systems (Table 1) [22].

**TABLE 1**

**The key elements of conventional agroforestry systems in different districts of Arid Western Rajasthan are outlined Harsh et al., [22]**

| District | Main trees/shrubs | Main crops | Major grass |
|---|---|---|---|
| Ganganagar and Hanumangarh | *Prosopis cineraria, Acacia nilotica* sub sp. *indica, Acacia tortilis* | Pearl millet, moong bean and cluster bean (rainfed). Wheat, cotton, rice and moong bean (irrigated). | *Lasiurus sindicus* |
| Bikaner | *Prosopis cineraria, Ziziphus nummularia, Calligonum polygonoides, Acacia jacquemontii* | Pearl millet, moong bean and cluster bean (rainfed). Wheat, cotton, rice and moong bean (irrigated). Moong bean, moth bean, cluster bean and pearl millet. | *Lasiurus sindicus* |
| Jaisalmer | *Calligonum polygonoides, Ziziphus nummularia, Prosopis cineraria, Acacia senegal, Capparis decidua* | Moong bean, pearl millet and cluster bean. | *Lasiurus sindicus* |
| Barmer | *Prosopis cineraria, Tecomella undulata, Ziziphus nummularia, Capparis decidua* | Pearl millet, Moon bean and cluster bean. | *Lasiurus sindicus, Cenchrus ciliaris* |
| Jodhpur | *Prosopis cineraria, Ziziphus nummularia, Capparis decidua, Acacia senegal* | Pearl millet, moon bean and cluster bean (rainfed). Wheat, chilli, mustard and moong bean (irrigated). | *Cenchrus ciliaris* |
| Churu, Jhunjhunu and Sikar | *Prosopis cineraria, Gymnosporia montana, Ziziphus nummularia* | Pearl millet, moong bean and cluster bean. | *Lasiurus sindicus, Cenchrus ciliaris* |
| Naguar | *Prosopis cineraria, Acacia nilotica* | Pearl millet and moon bean (rainfed). Wheat, moong bean and mustard (irrigated) | *Cenchrus ciliaris* |
| Jalore | *Prosopis cineraria, Salvadora persica, Salvadora oleoides, Acacia nilotica, Punica granatum* (fruit tree) | Pearl millet, moong bean, isabgol, sorghum and cumin | *Cenchrus ciliaris* |
| Pali | *Acacia nilotica* subsp. *indica, Acacia nilotica* var. *cupressiformis, Acacia leuco pholea, Acacia catechu, Salvadora* spp. | Sorghum, pearl millet, moong bean and cluster bean | *Cenchrus ciliaris, Cenchrus setigerus* |

**Other promising agroforestry techniques in arid region**

Approximately 61.11% of Rajasthan is encompassed by desert. These include Churu, Hanumangarh, Bikaner, Jodhpur, Jaisalmer, and Barmer in Rajasthan [23]. These are mainly covered by sand dunes. Vegetation is typically absent in these sand dunes. The excessive speed of the prevailing winds causes sand to drift away from dunes, ultimately engulfing the surrounding agricultural fields, canals, railway lines, highways, buildings, and more, causing significant issues. Central Arid Zone Research Institute (CAZRI) has been implementing a sand dune stabilization afforestation technique since the 1960s. This technology involving the following steps.

**Protection against biotic interference**

As a result of the increased numbers of humans and livestock, whatever vegetation grows on the dunes is either harvested by the inhabitants or grazed by the animals, resulting in the dunes becoming barren. Consequently, it is crucial to shield these dunes from the impact of living organisms. The most efficient method to achieve this is by implementing angle-iron barbed wire fencing.

**Establishment of micro-wind breaks**

Construct micro wind breaks by burying upside-down brushwood materials on the dunes, placing them at a height of one foot above the dune surface in either parallel rows or a chess board pattern. The brush wood of the following bushes can be used. Senia (*Crotalaria burhea*), Bui (*Aerva persica*), Kheep (*Leptadenia pyrotechinca*), Throns of Bordi (*Zizphus nummularia*) and Khejiri (*Prosopis cineraria*).

**Afforestation of sand dunes**

After construction of micro wind breaks, these dunes must be revegetated by suitable grasses/creepers/trees or shrubs. Species well-suited for stabilizing sand dunesare *Acacia toritili, Prosopis julifora, P. cineraria, Acacia nubica, Acacia senegal, Dichrostachys glomarata*, and *Callogonum polygonoides*.

**Shelterbelts**

Shelterbelts are the belt of rows of trees established at right angles to prevailing wind direction. Shelterbelt deflects the air current and thus by reduces the wind velocity and erosion. It provides protection to the leeward areas against wind erosion and decreases the desiccation effects on plants. It also provides food, fodder and timber. Shelterbelts have a typical pyramidal shape. This is achieved by raising tall trees in centre and medium sized trees in adjacent to both sides. Thereafter shurbs and grasses are planted in similar fashion. Shelterbelt upto 50 m width with suitable spacing is ideal. The ratio of the height and width of the shelter belt should be roughly 1:10. Shelterbelts are oriented right angled to the prevailing wind direction. Shelterbelts are raised in quadrangles if the wind direction tends to change very often. The minimum length of protection given by a shelterbelt is about 25 times its height. Grass species such as *Sachrum spontaneum, Sacharum munja, Cenchrus* spp and tree species such as *Acaia arabica, Acacia leucopholea, Tamarix articulata* are suitable for windbreaks in arid region [24].

**Windbreak**

Windbreak refers to the strip of trees and or shrubs planted in order to protect fields, homes, canals or other areas from wind and blowing soil. It protects the livestock from cold winds. Shelterbelt protects crops and pastures from hot and drying winds. It reduces soil erosion and provides habitat for wildlife. It reduces evaporation from farmlands and improves microclimate. It acts as a boundary. Wind break reduces the velocity upto 25 to 75 percent. Windbreaks are planted at right angle direction. The height of windbreak determines the length of the sheltered area. In the windward side, it protects the area occupying 15 times the tree height from the windbreak whereas in upwind side, it is only five times of the tree height. The length of the windbreak is effective when it is more than 12 times of the tree height. Species such as *Prosopis, Acacia, Leucaena*, etc. prove effective for establishing windbreaks in arid zones [24].

**The carbon sequestration potential of agroforestry systems**

Carbon sequestration is an approach used to mitigate the accumulation of greenhouse gases in the atmosphere, which arise from the burning of fossil fuels and human-induced actions. Carbon sequestration plays a vital role in mitigating climate change by regulating the optimal levels of carbon dioxide in the atmosphere. Agroforestry can be described as a land-use approach that intentionally combines, introduces, or blends trees and other perennial woody plants with agricultural crops, pastures, and/or livestock to harness the ecological and economic interactions of the different components [25-27]. The tree components found in agroforestry systems have the capability to act as significant carbon sinks in the atmosphere, due to their rapid growth and high productivity. In contrast to croplands, pastures, or natural grasslands, agroforestry systems possess a greater capacity to absorb and store atmospheric $CO_2$ [28]. The incorporation of trees, enhance soil properties and can result in greater net C sequestration [27]. Agroforestry systems effectively sequest carbon in both soil and woody biomass, thus mitigating greenhouse gas emissions. As per the studies conducted by Pandey [29], carbon sequestration in Indian agroforestry ranges from19.56 Mg C/ha/yr in Uttar Pradesh to a carbon pool of 23.46-47.36 Mg C/ha/yr in tree-bearing arid agro-ecosystems of Rajasthan. Silvopasture involves the deliberate combination of trees, forage crops, and livestock into a structured system, with the goal of maximizing benefits from planned biophysical interactions. The comparative studies conducted by National Research Centre for Agroforestry (NRCAF) found that the silvipastoral system, consisting of *Albizia amara, Dichrostachys cinerea* and *Leucaena leucocephala* as woody perennials, along with *Chrysopogan fulvus* as grass and *Stylosanthes hamata* and *S. scabra* as legumes, stored biomass carbon at a rate of 6.72 tC/ha/yr in 8 years. This was double the amount stored in natural grassland, which was recorded at 3.14 tC/ha/yr [30].

**Challenges inhibiting the growth of agroforestry in India**

The agroforestry system, widely recognized as a traditional practice, plays a crucial role in mitigating vulnerability, enhancing the resilience of agricultural systems, and safeguarding households against risks associated with climate change [31]. The benefits of agroforestry in India are evident, yet various challenges impede its successful implementation. The supply of high-quality planting material and advanced seed varieties is limited [32]. A mere 10% of planting material meets the desired quality standards, leaving the remaining 90% with no assurance of quality. The lack of adequate research on agroforestry models suitable for diverse agro-climatic regions, which integrate indigenous and multipurpose species such as *Prosopis cineraria*, has led to an unbalanced emphasis on a select few species like Poplar, Eucalyptus, and Kadam [33]. The research on agroforestry in India has primarily been conducted within restricted areas such as research stations or laboratories, limiting its applicability to larger field scenarios. Little or no research has been done on an ecosystem or landscape level and most of the studies are of relative short-term nature [34]. The marketing infrastructure for agroforestry produce is lacking throughout the country, with only a handful of states offering limited facilities. Consequently, it is predominantly a buyer's market, enabling middlemen to obtain a considerable part of the profits. The potential of institutional finance and insurance coverage in agroforestry has not been fully realized, primarily because of insufficient awareness regarding the technical and economic data of various agroforestry models [33,35]. Moreover, legislation regarding tree felling, wood transportation, processing, and marketing can be burdensome, expensive, and exasperating [35], which play a significant role in the minds of the farmer looking to adopt agroforestry [12]. Taxes are levied by multiple authorities at various stages of processing. As a result, the domestic agroforestry produce is facing a growing challenge from imported material. Therefore, it is crucial to eliminate these regulatory restrictions. Extension services play a crucial role in effectively sharing research findings on various aspects of agroforestry. However, due to the absence of a dedicated extension system, research results on agroforestry, available in both public and private domains, often fail to reach farmers on a regular basis.

In addition, it is evident that agroforestry-related schemes tend to favour farmers with larger land holdings over small and marginal farmers. Therefore, it is essential to implement targeted programs that cater to the unique needs of marginal and small farmers in the field of agroforestry [32]. Because 2/3rd farmers of Indian farmers are small and marginal farmers [35]. While the National Agroforestry policy [10], strives to tackle multiple challenges, the key difficulty lies in the successful implementation of the policy at the grassroots level. The adoption of the National Agroforestry policy [10], is intended to address a range of challenges, but the primary difficulty lies in the successful implementation of the policy at the grassroots level.

**The future potential of agroforestry in India**

In the future, agroforestry is set to play a pivotal role, not just in ensuring food and livelihood security, but also in tackling environmental challenges, given the constraints of land availability in the country [26]. The Central Agroforestry Research Institute (CAFRI), 2015 report indicates that by 2050 [30], the requirement for fodder is expected to rise by 1.5 times, while the demand for food grain and fuel wood is projected to double, and the demand for timber is anticipated to triple. In the face of diminishing land and water resources and the impending impacts of climate change, agroforestry emerges as a viable solution to meet the rising demand for food, fodder, firewood, and timber. Farmers believe that these tree-based systems in agriculture as a boon in the region, especially during droughts when rainfed crops fail. Trees become the sole source of fodder, fruit, vegetables, fuelwood, timber and fibre, essential for sustaining rural livelihoods. In addition, arid agroforestry meets 62% of the rural community's demand for fodder, fuelwood, and timber [34]. Furthermore, in arid agro-ecosystems, trees serve as a form of insurance against unpredictable climate conditions, mitigating crop-yield losses, improving resilience, and diversifying the agricultural system [8-11]. In such challenging conditions, trees integrated into traditional farming systems offer a viable solution to address climate uncertainties, simultaneously enhancing ecological balance and food security through mutual synergistic effects [12,13].

## CONCLUSION

All living things, including humans, are confronted with the greatest significant environmental challenge of our time: Climate change. It disrupts natural ecosystems, agriculture, and human health. In this context, agroforestry emerges as a strong farming technique that addresses the issue of food security by producing food for humans, improves environmental quality to lessen the negative effects of climate change, maintains economic viability, and improves quality of life. In India's arid regions, persistent farming and irrational resource use combined with an unbalanced man/resource ratio and the natural fragility of the resources have caused a serious degradation of the environment. Thus, the most effective approach to increase tree cover in an arid tract is to use a combination of protective producing systems and indirectly integrated systems. The most effective examples of combined protective-productive systems include sand dune stabilization surrounding farmed sandy plains and tree-based pastoral systems in village community areas, with appropriate management methods.

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