

SUSTAINABLE AGRICULTURAL PRACTICES IN ARID ECOSYSTEMS – ORGANIC FARMING, AGROFORESTRY AND PERMACULTURE APPROACHES

Abstract

The concept- food security is recognized worldwide which affects individually. Historically, efforts to increase production and yields have harmed the poor by destroying the environment and decreasing biodiversity. A practical approach that guarantees global food security through minimum environmental degradation is sustainable agriculture. This involves farming in ways that take into account ecosystem services. Sustainable agriculture practices rely on ecosystem services to function effectively. Understanding the arid environment and the constraints of arid soils is required to mitigate climate change's impact on global food security. Elevated aridity will restrict crop germination and growth and improve vital plant nutrient availability, endangering important ecological processes and services. Desert soils are far more fragile and extensively deteriorated than other soil types, there hasn't been much attention paid to determining their fertility status and improving it to maintain rain-fed agricultural systems. Through a variety of extension techniques, including material training, group discussions for the implementation of organic farming technologies were brought to the farmers' field. Permaculture is supported by a comprehensive sustainability idea and twelve guiding principles. This chapter describes the requirement for diverse organic farming systems through a moral outlook and a workable design process in arid regions. This is a socio-cultural phenomenon that can be found in both rural and urban areas. It centers on non-commercial gardening, such as in urban community initiatives, or self-sufficiency farming, such as in eco-villages.

Keywords: Arid regions, Agroforestry, Food security, Organic farming, Sustainable agriculture

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I. INTRODUCTION

Due to the growing global population, agricultural systems now have to take center stage in any solution to the food crisis [1]. The population growth is 3% and cereal grain growth is 1%, there has been a sharp increase in global food demand. Since, last two decades of the 20th century to the first decade of the 21st, there has been an increase in these expectations [2]. In Africa, the amount of cereal produced per person has dropped to 130 kg during this period, but in Asia and South America, it has increased to 250 kg per person [3]. It is commonly known that rising temperatures and variations in precipitation in agriculture are caused by climate change. The variability of climate conditions presents a significant obstacle to food security in emerging nations and necessitates a sustainable resolution [4]. The world's population is growing at an alarming rate [5], with roughly 9 billion people by 2050—the food demand (in calories) will rise faster than the area of arable land. This will raise pressure on currently available agricultural practices that ensure food and feed demand. For food insecurity to be eliminated, agricultural growth is required [6]. Agricultural land makes up around 43% of the world's land area when glacial and arid terrain are excluded. It is cultivated for food and non-food crops [7]. In order to secure food sufficiency with limited resources for farmed land, the majority of countries have moved, at least in part, from extensive to intense agriculture [8]. The main food crops' average yields are increasing linearly on a global scale, but their relative growth rates are decreasing. Given that agriculture dominates the local economy, the sustainability of the aquifer-agricultural system poses a significant barrier to the region of interest's sustainable growth [9, 10]. Inputs for enhancing agricultural yield and technologies have low outputs for the inputs investment. The average yields in important food baskets around the world are declining or stagnating. Furthermore, the biophysical factors that limit the yield are influenced by climate, soil, and water availability has attain an average farm yield [11]. Stakeholder pressures such as growing population, finite arable land, and growing climate change scenarios have forced specialists to evaluate agricultural stability [12]. Several indicators point to the fall in agricultural productivity, including the prevalence of food insecurity, occurrences of hunger, and malnutrition [13]. In Tanzania's semi-arid tropical regions, long-term monoculture practices have significantly decreased levels of total carbon, nitrogen, and other essential minerals [14].

The decline in soil quality and crop productivity has significantly impacted the livelihoods of over 70% of local smallholders [15]. These farmers are vulnerable due to ongoing stressors of climate change, which have led to increased food insecurity and extreme poverty [16]. The meager crops only last three to six months, leaving the population severely starved for the rest of the year. As a result, the annual food shortfall in the area is estimated to reach 50%. The region has experienced devastating years, leading to a sharp increase in food insecurity and extreme poverty among smallholder farmers [17]. Agriculture releases about one-third of greenhouse gas [18], which is also quite susceptible to climate change [19] and thus affects global food security. The production of food and labor productivity has increased due to intensive crop farming. However, this costs the degradation of land through various means—soil erosion, improper irrigation, degraded soil quality, increased emissions of greenhouse gases (GHGs), loss of biodiversity, and ecological resilience [20].

Over 60% of the surface of the globe is covered in drylands. Part of the drylands, arid zones are characterized by the harshest edapho-climatic conditions. The main characteristic that sets apart the arid zone for planning and defining purposes is its low levels of precipitation (less than 500 mm or Aridity Index <0.20) and more than 50% inter-annual variability. This significantly impacts the ecosystem's characteristics, the socioeconomic setting, and the sustainability concerns. Elevated wind and sun regimes amplify the impact of rainfall fluctuations, and the combined effect creates a delicate ecosystem wherein little perturbations can result in significant and occasionally irreparable losses to sustainability [21]. The hot, dry areas of India encompass seven states: Rajasthan, Gujarat, Punjab, Haryana, Andhra Pradesh, Karnataka, and Maharashtra spanning over an area of 31.70 million hectares. The Great Indian Desert, sometimes called the Thar Desert, comprises the desert regions of Rajasthan, Gujarat, Punjab, and Haryana. Together, these regions make up 89.6% of all of India's hot arid regions and are the main hot dry zone [22]. Arid lands make up over 25% of the world's land area (about 2.6 billion hectares), and are home to nearly 1.7 billion people [23]. Over 700 million productive hectares in arid regions have been degraded worldwide, with an annual degradation rate exceeding 400 million hectares [23]. The primary causes is lack of public policies dealing with potential socioeconomic effects of climate variations, especially during protracted droughts, the excess demand for a small number of products on the market, and the lack of sustainable livestock and agricultural practices [24]. Food production is one of the primary causes of environmental degradation in Tanzania's semiarid regions, and if left unchecked, it has the potential to wipe out the ecosystems. Therefore, to create a situation where both sides benefit, food policies should be considerate to the environment, particularly regarding fragile ecosystems[25].

II. IMPORTANCE OF ORGANIC FARMING IN ARID REGIONS

- 1. Water Scarcity:** Arid regions experience low rainfall and have limited water availability, making irrigation a major concern. Droughts, desertification, and water scarcity permanently characterize drylands. In arid regions, an increase in evapotranspiration negatively influences human activities and agriculture, horticulture, and forestry [26]. Water is scarce in an area that is primarily made up of arid and semi-arid lands. Since the soils in these regions are usually shallow, most rainfall flows off the surface and only penetrates deeper soils downslope or along river beds, which accounts for a major amount of degraded land caused by aeolian processes [27]. The number of recharge episodes will be impacted by variations in the frequency and intensity of rainfall events. Considerations for crop enterprises should focus on maximizing the use of available moisture based on the type of soil. Crops in drylands have adapted to efficiently utilize stored moisture. To ensure water availability during periods of moisture stress, it is essential to store water received on days with limited and irregular rainfall. There should be a greater emphasis on water conservation techniques. It has been found that watershed-based strategies are more effective in conserving soil and water [28].
- 2. Soil Quality:** Soils in arid regions typically consist of sandy, saline, and low-nutrient content with minimal organic matter. Organic farming has the potential to enhance the ecological and economic well-being of dry regions by avoiding pollution and utilizing local labor and resources effectively. It also emphasizes the preservation and improvement of soil health. Arid or dryland soils typically have low levels of organic

matter and limited water retention capacity [29]. Incorporating organic matter into dryland soils will improve their physical condition and significantly increase ability to provide well-balanced nutrients necessary for plant growth. According to [30], the overuse of natural resources in drylands is mainly due to the improper use of production-enhancing technology. Temperature Extremes: High temperatures can stress plants and soil biota, affecting growth and yield.

3. **Pest and Disease Pressure: Arid climates can favor certain pests and diseases that are difficult to manage organically:** Moreover, very little pesticide is used. Additionally, a considerable share of the drylands area is classified as "virgin," which means no artificial inputs have been applied yet. This facilitates a transition towards organic farming without sacrificing yield. Due to climate fluctuation, dryland farming methods have historically mixed crops, trees, animals, grasses, etc. The main goals of organic farming, nutrient cycling and soil fertility restoration, have been proven to be effectively achieved by such diverse systems, which also reduce insect prevalence. Moreover, India's traditional farmers have a wealth of information about managing soil fertility as well as controlling pests that is based on years of observation and experience; this knowledge can be utilized to enhance organic systems [31].

III. SUSTAINABLE AGRICULTURE ENSURES FOOD SECURITY

1. **Sustainable Agriculture Management through Agroforestry in Arid Regions:** The abiotic constraints of dry regions have spurred ongoing research into ecological restoration and sustainable land management strategies that could ensure the production of food for human populations while protecting biodiversity [32]. Agroforestry Systems (AS) are acknowledged as a viable social and ecological substitute. Productive restoration is another term for this strategy that improves local communities' quality of life as well as biodiversity recovery [33]. Both management theories advocate promoting production and profitability as a result of increased productive diversity, bolstering communal engagement, and defending cultural multiplicity, as opposed to optimizing the output of a single system element (monocultures). While reforestation of arable land is not a novel idea, it is one of the most significant global efforts to enhance the management of land resources. Approximately one billion hectares of cultivated land currently have a protective forest cover of over 10% [34], and projections currently in the public domain indicate that trees will shield 1.6 billion hectares of land shortly. Growing trees, crops, and cattle in harmony with one another is known as agroforestry [35]. When considering sustainable reforestation over the long run, one must consider the benefits that forests offer land users through ecosystem products and services [36].
2. **Advantages of Agroforestry in Arid Regions**
 - The soil and other ecosystem functions improve when a farmer implements agroforestry, leading to better water infiltration and reduced nutrient runoff. This, in turn, increases crop yields or lowers production costs, ultimately boosting returns [37].

- In addition to providing a reliable source of income and other benefits for human well-being, agroforestry has the potential to prevent environmental degradation, increase agricultural productivity, enhance carbon uptake, and promote healthy soil and ecosystems [38].
- Agroforestry systems offer tremendous potential for achieving various sustainable development goals. These systems have proven to be successful in promoting environmental and social sustainability by improving land use efficiency, creating more job opportunities on farms, and fostering engagement with local communities. Nevertheless, it is important to recognize that financial barriers still exist and may hinder the further implementation of agroforestry practices [39].
- To reduce the exploitation of protected areas, agroforestry systems can be integrated into biodiversity corridors for various purposes, such as cultivating timber and non-timber forest products [40]. In these systems, native fruit and timber trees are planted alongside each other to help restore ecosystems in regions where the forests have been lost. In Tanzania, farmers are being trained in agroforestry techniques to help preserve environmental reserves. According to Huang et al. (2002) [40], agroforestry significantly enhances Tanzania's nature reserves' capacity to protect biodiversity.
- It is commonly known that agroforestry can help prevent desertification. Increasing forested areas may be considered a strategy to reduce desertification in dry and semi-dry regions. The agroforestry project initiated by IFAD in Senegal has enhanced soil fertility, water availability, and the regeneration of tree cover in two sequential phases. Not much work has been done in the Miombo ecoregion to promote agroforestry as a way to reduce desertification [41].
- Farmers often face a fodder shortage, especially during the dry season when most meadows have dried up. To address this issue, they can use fodder bank agroforestry, which involves planting fodder plants and shrubs. These trees and bushes are planted along borders, paths, and across contours to prevent soil erosion. The fodder can be harvested and fed to animals in an enclosure, or used for controlled browsing. Research in East Africa has shown that 500 bushes of species like *Calliandra calothyrsus* can provide enough fodder to serve as a dairy cow's annual feed source, replacing or supplementing the more expensive dairy concentrate [42].

3. Challenges of Agroforestry in Arid Regions

- Adoption and use of agroforestry are still not well known and documented. Gaining a better knowledge of farmers' decision-making about agroforestry techniques is necessary to increase the efficacy of agroforestry diffusion. There is a large body of research on the factors influencing the adoption of agricultural techniques, most of which focus on agronomic issues and complementary treatments like better varieties, innovative crop protection sprays, or subsidies for mineral fertilizers [43, 44].
- Many smallholder farmers lack the expertise needed to oversee agroforestry. Additionally, they lack access to basic supplies like seeds. Farmers require basic

education as using trees to enhance soil fertility involves innovative concepts [45]. It is challenging for extension workers to reach a significant number of farmers due to their limited capacity in terms of manpower, time, and agroforestry knowledge.

- Another issue is the scarcity of suitable tree species and tree seeds. For rural farmers, access to high-quality seed is a recurring challenge [46]. Better seeds and planting materials are in scarce supply. Just 10% of planting material is of a high caliber; the remaining 90% is not guaranteed to meet any particular standards [47]. Agroforestry models that are appropriate for the various agroclimatic zones, for native species that serve several purposes (like *Prosopis cineraria*), or for the domestication of species—which leads to an excessive focus on a select few species like Poplar, Eucalyptus, Kadam, etc.—have not received enough attention[48].
- Agroforestry produce in India lacks marketing infrastructure, with the exception of a few states. Because of this, the market is mostly in favor of buyers, and middlemen make up the majority of profits [48]. Agroforestry-adopting farmers are also faced with complicated, expensive, and aggravating regulations regarding the felling of trees, the shipping, processing, and marketing of wood, all of which have a big impact on their decisions[48]. Likewise, taxes are levied by numerous authorities at different phases of the processing. Consequently, the domestic agroforestry produce is falling behind the imported counterpart. Therefore, these regulatory limitations must be lifted [49].

Case study

- Numerous agroforestry methods have been created, and farmers in semi-arid areas of India have embraced some of them. A few of these are based on fruit trees while others are based on pulpwood and timber, spread across a 13 m ha area. In mango, aonla, and guava, fruit tree-based systems are said to yield net returns of up to Rs. 32,000/ha/year, Rs. 24408/ha/year, and Rs. 3916/ha/year. The net returns from wood-based systems are approximately three times higher than those from annual crops. These systems have a benefit-cost of up to 5.5 and yield respectable returns in years with little rainfall. Improved returns can be achieved by management techniques such as high-density planting, canopy control, adding animal components and high-value intercrops, and using organic production methods for fruit trees [50].

IV. PERMACULTURE

Bruce Charles "Bill" Mollison, an Australian ecological visionary and David Holmgren, coined "permaculture" (a portmanteau word) in 1978. It refers to an integrated system of eco-environmental design connected to the concept of a primarily perennial kind of agriculture. The words "permanent" and "agriculture" make up its composition [51]. Permaculture is described as "the intentional establishment and maintenance of a productive agricultural ecosystem that integrates all ecosystem components to achieve multiple community objectives sustainably and is characterized by sustainability, diversity, stability, and durability" [52]. By combining "permanent" and "agriculture," the term "permaculture" denotes a design system and set of best practices for creating and sustaining resilient and sustainable agroecosystems. Advocates of permaculture view it as a concept for establishing

socio-ecologically sustainable land use systems that recognize the interconnectedness of social and land use systems. Holmgren defines permaculture as purposefully designed landscapes that imitate natural patterns and relationships while providing an ample supply of food, fiber, and energy to meet local needs. Permaculture is a "hopeful" response to the environmental crisis. There is little doubt that the current global industrial society will go through significant changes due to the severity of the environmental problem. The process has an immediate impact on the existence and general well-being of the world's growing population [53].

The goal of the permaculture system is to lessen the risks and hazards associated with traditional agricultural products including pesticides, herbicides, fertilizers, and insecticides [53]. Agroforestry, agroecology, biodynamic farming, and organic farming are just a few of the alternative farming methods that are related to the real use of permaculture in agricultural production. Permaculture is similar to agroecology and agroforestry in that it places an emphasis on intercropping methods, diverse landscapes, and spatial species association, or the coexistence of crops, animals, and trees. Like organic and biodynamic farming, permaculture places a strong emphasis on soil fertility [54].

The process of permaculture design is not linear, so it's important to avoid common mistakes in managing complex systems by using observation, analysis, and design methods. The design approach mainly consists of permaculture principles and spatial strategies [55]. The public is becoming increasingly interested in the global movement of permaculture. Nonetheless, permaculture receives very little attention in the scholarly literature. Permaculture practitioners contend that institutions and scientists reject the radical ideas they present, but their credibility is damaged by their peculiar application of scientific terminology and dissemination of unproven scientific claims [55, 56].

1. Importance of Permaculture Approaches in Agriculture

- The agricultural sector has undergone significant changes in recent decades due to the Green Revolution, leading to a boost in food production. Progress in technology has played a key role in this shift by enhancing the yield per unit of land, reducing manual labor, and raising food safety standards [54, 57]. However, these advantages have been accompanied by unanticipated drawbacks, such as extensive land use for intensive agriculture, excessive reliance on artificial fertilizers and pesticides, and a range of other incidents that have cumulatively caused severe harm to the environment, ultimately impacting the ecosystem and natural elements.
- The increase in human population and competition for land leads to land scarcity and the conversion of natural areas to agriculture and other uses. Land use, especially agriculture, is a major factor influencing biodiversity. The conversion of natural ecosystems into semi-natural ecosystems or manmade systems has significantly changed ecological processes and the composition of biodiversity. As agriculture becomes more intensive, biodiversity decreases [58].
- Soil compaction is a major issue in agricultural areas all over the world [59]. Intensive farming has led to a decline in the quality and condition of the soil. The use of

intensive farming techniques has had a significant impact on the level of soil organic matter (SOM). Intensive agricultural practices have resulted in the destruction of soil organic matter and soil structure [60].

- An overreliance on diminishing groundwater resources poses serious threats, imperiling food production sustainability and ensuring global food security as arable land suffers from decreased productivity and occasional salinization [58].
- Greenhouse gas emissions from intensive agriculture contribute significantly to global warming. The primary production stage in intensive agriculture accounts for the majority of agricultural GHG emissions [61]. The application of synthetic nitrogen fertilizers is a major factor in agricultural soil emissions of nitrous oxide gas. The mentioned elements can severely disrupt the vital functions of different ecosystems on Earth and hurt food security [62]. The purpose of this review is to examine and highlight permaculture's potential to replace intensive agriculture methods.

2. Importance of Permaculture

- **No-Tillage practices:** No-till farming, which involves planting crops straight into a field without first plowing it, is one of the most important permaculture techniques. Adopting no-till management has several advantages, such as improved soil structure, increased soil moisture retention, less soil erosion, and carbon storage [63]. When crop leftovers accumulate in the soil during the no-till management technique in soil, the soil's upper surface becomes enriched with organic matter, which boosts the microbial population [64]. No-till farming results in more water in the soil, less erosion, a greater variety and quantity of life in and on the soil, and a higher need for herbicides. It's becoming common knowledge that using no-till can effectively slow down soil deterioration. This farming method minimizes soil disturbance during sowing and fertilization while retaining agricultural wastes or other organic goodies on the soil's surface [65].
- **Mulching:** Drastic rainfall patterns and global warming are to blame for the depletion of water supplies that restrict agricultural output in semi-arid and arid regions [66]. Consequently, conserving soil moisture through mulching could be a cost-effective way to increase dryland farming productivity while saving water. Mulching maximizes water use while also assisting in the improvement of crop development and output. By reducing soil evaporation and regulating soil temperature, mulching conserves soil moisture and reduces the need for irrigation during crop growth [67].
- **Polyculture:** One common practice in Permaculture is the use of polyculture for crop cultivation. This approach involves planting a mixture of different crops in the same area. By doing this, it becomes possible to increase the overall production obtained from the land while also providing resilience against adverse climate events and diseases. This diverse planting strategy helps to ensure that the failure of a single crop does not have a significant impact on the overall harvest [69].

- **Stacking:** Stacking is the practice of growing food vertically—that is, on walls, fences, trellises, and balconies. It entails combining small and tall plants in one location to maximize the amount of space that is available. Growing sweetcorn alongside vegetables from the pumpkin family, such as squashes, marrows, and courgettes, in the same location is an example that suggests this technique [70].
- **Agricultural Forestry:** Agroforestry is a permaculture practice that aims to maximize agricultural productivity in arid and semi-arid regions. It can help reduce the effects of climate change and implement resilient farming systems. Current research suggests that planting trees on farms has the potential to slow down environmental deterioration, improve agricultural output, increase carbon sequestration, and support healthy soil and ecosystems. This can all be achieved while maintaining consistent profits and other benefits for human welfare.

V. CONCLUSION

Although the environment is unavoidably impacted by all agricultural systems, Organic agriculture systems are thought to have fewer negative consequences than conventional systems. Nevertheless, there is conflicting scientific evidence supporting such environmental benefits. Synthetic pesticides and herbicides are rejected by Organic agriculture and soluble mineral fertilizer inputs are forbidden, organic yields are typically roughly 19% lower than conventional yields. Although organic agriculture may improve the quality of the soil, air, and water and require less energy than conventional approaches, its impacts on biodiversity are controversial. As consumer demand increases, more agricultural land will be farmed organically in the future. However, to more thoroughly evaluate the environmental effects of Organic agriculture, long-term field trials are required in significant worldwide agricultural regions. While organic farming and agroforestry are two different disciplines, combining them can result in highly productive and sustainable agricultural systems that take advantage of each other's advantages.

In regions with low rainfall, agroforestry provides a sustainable and eco-friendly way to support livelihoods. It's important for policies to promote the development of agroforestry methods with traditional inputs that work in harmony with nature to fulfill current and future needs. Agroforestry in dry regions is also employed to tackle worldwide challenges such as protecting biodiversity, addressing climate change, and combating desertification; however, this will require more robust support from international policies.

To design systems that are resilient, regenerative, and productive in addition to being sustainable, many practitioners combine the ideas of permaculture and organic farming. To improve its ecological balance and community involvement, a farm may use permaculture design concepts in addition to being certified organic. In conclusion, organic farming concentrates more on sustainable agricultural methods, whereas permaculture offers a more comprehensive, all-encompassing approach to creating sustainable human habitats. Despite this, both permaculture and organic farming are dedicated to sustainability and ecological health.

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