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AGRICULTURAL AND BIOTECHNOLOGICAL REFLECTIONS

# EFFECTS OF AGROFORESTRY PRACTICES ON SOIL HEALTH AND CROP YIELD IN SEMI-ARID REGIONS

**Muhammad Suleman Aziz**[1*]
[1]*Faculty of Agriculture Gomal University, Dera Ismail Khan*
**Corresponding Author E-mail: sulmanaziz@gmail.com*

## Abstract

This study investigates the impact of agroforestry practices on soil health and crop yield in semi-arid regions, comparing agroforestry systems with monoculture plots. The research highlights significant improvements in biomass yield, grain yield, microbial activity, infiltration rates, and water retention, demonstrating the multifaceted benefits of agroforestry. Agroforestry plots showed a 16.7% increase in biomass yield and a 17.6% increase in grain yield compared to monoculture systems. Additionally, microbial activity was enhanced by 41.2%, reflecting a healthier soil ecosystem. Water-related parameters also improved, with agroforestry systems exhibiting a 23.1% higher infiltration rate and a 24.5% greater water retention capacity. The findings emphasize the role of agroforestry in enhancing soil fertility, conserving water, and improving overall agricultural productivity. These results underscore the potential of agroforestry as a sustainable land management practice, particularly in water-scarce regions. The study advocates for the widespread adoption of agroforestry systems as a viable solution to address the environmental and agricultural challenges faced by semi-arid regions, contributing to the long-term sustainability and resilience of farming systems in these areas.

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## INTRODUCTION

Social science analysis indicates that mixed-agricultural methods using vegetation along with animals and woody species demonstrate beneficial effects on soil quality along with enhanced agricultural yields in dry climatic zones (Pralhad). The combination of low precipitation levels and hot temperatures and nutrient-poor soils creates major barriers for sustainable food production and environmental protection in this region (Arage). Through their ability to improve agricultural resources and soil quality while preserving water quantities these approaches gain recognition as problem-solving solutions (Ogunsiji). Agroforestry systems demonstrate environmental sustainability by combining multiple food defense mechanisms with wind-resistant soil protection capabilities (Fahad). Farmers combining forestry operations with agricultural practices generate improved organic matter content while achieving better water management and enhanced nutrient transfer (Pralhad). Under semi-arid farming conditions agroforestry methods guide farmers to sustainability improve their income while sustaining tree use in their agricultural systems to create stronger agricultural lands (Quadro).

Different agroforestry methods used in field practice help transform agricultural areas according to ecological conditions. Alley cropping stands out as a common agroforestry technique which positions tree rows beside crops to grow soil nitrogen and build soil fertility while constructing protective barriers. The implementation reduces wind speeds and simultaneously enhances water filtration while minimizing soil run-off (Sollen). The deep roots of trees combine with soil elements to build improved structural qualities within the ground. Placed trees and shrubs form windbreaks that offer two important benefits: the protection of damaging winds while also preserving soil water content for improved crop development. When pruning operations produce organic breakdown of leaves and trees it results in improved soil nutrients and better water retention. Cattle transformation of organic matter into soil nutrients occurs through the combination of trees and grazing cattle in Silvopasture systems that enhances pasture yields and provides animal shade (What). Soil erosion from grazing areas together with the impact of cattle compaction receive mitigation from tree integration in silvopasture systems.

Agroforestry developed as a modern practice in 1971 through the identification of productive synergistic cattle-tree interactions (Kaua). This approach leads to better biological quality standards as well as production output changes in land agencies (Mosquera). Agroforestry recently received growing interest because the public together with governmental entities have risen their alarm about how contemporary farming techniques inflict damage on both species and environment (Majaura). Agricultural systems that include trees provide financial advantages to farmers through improved soil quality and water conservation and biodiversity while generating economic benefits. Two distinct categories of agroforestry exist depending on how trees and crops spatially and temporally join together (Nguyen).

Agroforestry techniques cause a multiple-stage impact on soil quality which results in optimized performance of physical and chemical aspects along with biological activities. Soil organic carbon stocks increase through the application of organic matter resulting from tree litter breakdown and root decomposition and pruning waste materials (Eddy). This enhances important soil characteristics such as fertility and water retention and carbon sequestration. Soil structure becomes stronger due to agroforestry practices because these practices improve water absorption together with better root penetration and enhanced aeration through aggregate stability enhancement. When integrated into agroforestry systems trees improve nutrient cycling by making essential nutrients such as nitrogen and phosphorous and potassium more accessible to the ecosystem. Leaf litter breakdown and root turnover mechanisms within tree root systems allow trees to access nutrients from deep layers of the soil which benefit crops. Agroforestry systems contain higher rates of mycorrhizal fungus which form plant root partnerships resulting in enhanced nutrient uptake and disease protection. Research indicates that adding trees to agricultural fields reduces soil erosion by 50% in comparison to monoculture crop systems (Muchane). Soil quality responds differently based on both soil type and temperature and species of tree present in agroforestry systems.

The impact of agroforestry practices on agricultural production operates through numerous variables including tree types as well as cultivation patterns and meteorological conditions and land maintenance approaches. The research on yield declines from resource competition shows inconsistent results between studies while most present emerging evidence supporting agroforestry systems as yield increase over time. Planting suitable tree species alongside effective pruning methods and adequate spacing helps reduce competition between trees and agricultural crops. The combination of enhanced soil productivity and increased moisture and climate features within agroforestry schemes results in higher harvest levels. Because they improve soil health agroforestry systems enhance crop resistance to droughts and pests and diseases leading to more consistent and sustainable yield production. Rocketing farm profits through agroforestry becomes possible thanks to diverse income streams that include forest products such as lumber along with nuts and fruits which safeguard against crop losses and market volatility (Andriatsitohaina). Agroforestry utilizes the same land area to develop crops and trees (Edwina). Agroforestry systems help achieve economic sustainability for small-scale rural farmers according to studies (Mukhlis), (Ruhimat). Through this approach small-scale farmers can grow food crops and forest plants at the same time which boosts their income from two plant types (Ratnasari). Agroforestry represents an effective land-management strategy for combating slope-top soil degradation and protecting soil nutritional value particularly through contour planting methods (Hung).

Semi-arid environments benefit greatly from agroforestry methods which enhance soil condition and food yields because water shortages together with degraded soils restrict agricultural productivity. Agroforestry techniques control soil water loss and increase moisture intake which ensures irrigation availability for farmers throughout times of drought. The deep reaching roots of trees enable the extraction of groundwater supplies which acts as protective insulation for agricultural products. Agroforestry systems enhance semi-arid areas' soil fertility through organic matter build-up and atmospheric nitrogen fixation and improved nutrient cycling practices. Crops benefit from agroforestry systems that generate beneficial climate conditions by providing shade and reduced wind speeds which control evapotranspiration while defending crops from heat-related damage (Edwina). Agroforestry systems which combine trees with farming operations enable farmers to develop greater resilience while improving their economic well-being. A combination of these methods leads to both increased agricultural productivity and sustainable farming management (Hastings), (Pello).

## METHODOLOGY

The research approach combines field trials alongside laboratory studies and data interpretation to evaluate the influence of agroforestry methods on soil health and crop production in semi-arid regions. The key data comes from field observations of three different semi-arid regions that use distinct agroforestry methods. The selected areas took into account diverse climatic zones and agricultural environments to test agroforestry systems across many possible operational conditions. This research incorporates quantitative alongside qualitative data collection methods to achieve a full assessment.

Research field-tests conducted multiple agroforestry systems which included alley cropping combined with silvopasture and windbreaks on active farming plots. The collection of soil samples during different growth periods in these plots served to study soil health variations. The examination included both microbial diversity indicators and important soil characteristics such as pH and organic carbon content and nitrogen and phosphorous levels in these samples. The agroforestry plots measured crop production parameters that combined weight data from biomass and grain output and quality assessment information. Agroforestry plot measurements versus monoculture plot measurements provide a method to measure how agroforesting influences crop production levels.

Laboratory research alongside field data collection processes examined the relationship between agroforestry methods and soil microbial patterns and functions. Studies evaluating soil biological health included enzyme activity assessments (dehydrogenase and phosphatase) in addition to microbial biomass measurements with chloroform fumigation extraction. Research analysts conducted a straightforward infiltration test to determine soil water retention capabilities and infiltration rates which established water economy changes caused by agroforestry management systems. Research was strengthened by using statistical methods to analyze the relationship between various agroforestry techniques with both soil quality and crop yields.

Remote sensing technologies evaluated the extended impact of agroforestry methods on land production alongside soil condition changes through time. Scientists tracked crop development along with land cover variations and vegetation indices using multispectral cameras installed to UAV systems (drones) and satellite image processing. This addition of spatial elements enriched the research. The data collection process was supported by statistical programs SPSS and R to identify patterns which linked agroforestry systems with measurements of soil and crop health. Research at the plot and regional scales along with multiple analytical levels enabled an improved understanding of long-term soil benefits from agroforestry systems within semi-arid conditions.

## RESULTS

Research data came from three semi-arid locations that used agroforestry approaches. Researchers concentrated their investigation on soil condition and crop output as core research elements. Research output included four detailed tables that illustrated various data analysis aspects. Four tables present essential indicators to show how agroforestry practices modify both land quality metrics and agricultural plant outputs. These tables show both monoculture control plot performance alongside agroforestry system results.

Research findings comparing monoculture system plots to agroforestry systems appear in Table 1. Research examined a set of key parameters which included pH measurement along with organic carbon and nitrogen value analysis and phosphorous measurements and microbial biomass counts. Research data shows that agroforestry plots have higher organic carbon and nitrogen content than control plots. Agroforestry agricultural patterns produced soil containing 20% more organic carbon and 15% additional nitrogen when compared to control soil and the results reached a statistically meaningful threshold.

**Table 1:** Soil Properties of Agroforestry and Control Plots

| Soil Property | Agroforestry Plot | Monoculture Plot | Percentage Difference |
|---|---|---|---|
| pH | 6.8 | 6.5 | +4.6% |
| Organic Carbon (g/kg) | 15.4 | 12.8 | +20.3% |
| Nitrogen (mg/kg) | 25.2 | 21.9 | +15.1% |
| Phosphorus (mg/kg) | 12.3 | 10.4 | +18.3% |
| Microbial Biomass (mg/g) | 2.4 | 1.8 | +33.3% |

Court documents show crop yield results from each hectare as depicted through biomass measurements together with grain weight outcomes (Table 2). Table 2 shows how agroforestry systems produced biomass yields and grain quantities that were 10% to 18% higher than control area results. The combination of improved soil conditions and water management in agroforestry systems enhances crop yields during dry periods across three semi-arid research sites according to measured data..

**Table 2:** Crop Yield Comparison in Agroforestry vs. Control Plots

| Crop Type | Agroforestry Plot Yield (kg/ha) | Monoculture Plot Yield (kg/ha) | Percentage Increase |
|---|---|---|---|
| Biomass | 2800 | 2400 | +16.7% |
| Grain Yield | 1800 | 1530 | +17.6% |
| Legume Yield | 1400 | 1200 | +16.7% |

This research document demonstrates bacterial activities measured between control areas and areas treated with agroforestry methods in Table 3. The measurements of microbial activity involved enzyme activity assessments powered by phosphatase and dehydrogenase activity. Experiments performed on agroforestry plots produced elevated enzyme activity results indicating better soil biological operations. Through natural organically produced material and extensive plant life diversity agroforestry systems foster superior microbial functions.

**Table 3:** Soil Microbial Activity in Agroforestry and Control Plots

| Enzyme Activity | Agroforestry Plot Activity (µg/g/h) | Monoculture Plot Activity (µg/g/h) | Percentage Increase |
|---|---|---|---|
| Dehydrogenase | 2.4 | 1.7 | +41.2% |
| Phosphatase | 3.1 | 2.3 | +34.8% |
| β-glucosidase | 2.8 | 2.1 | +33.3% |

The data regarding water retention and infiltration appear in Table 4 between the monoculture and agroforestry systems. The data reveals how agroforestry systems enhance key drought-prone semi-arid features including both water infiltration rates and soil water retention in these areas. The agroforestry planting system demonstrated a 25% higher water infiltration capability thus benefiting crop survival rates during arid periods.

**Table 4:** Water Retention and Infiltration Rates in Agroforestry vs. Control Plots

| Soil Property | Agroforestry Plot (cm/hr) | Monoculture Plot (cm/hr) | Percentage Difference |
|---|---|---|---|
| Infiltration Rate | 3.2 | 2.6 | +23.1% |
| Water Retention (%) | 75.2 | 60.4 | +24.5% |

To further illustrate these results, the following figures present graphical visualizations of the data:

Biomass yield from agroforestry plots increased by 16.7% per year as Figure 1 demonstrates agroforestry performance versus monocultures. The data in figure 2 indicates that agroforestry systems produced 17.6% more grain than monoculture systems. Microbial activity levels between monoculture farming systems and agroforestry systems receive comparison through Figure 3. Research shows agroforestry systems enhance microbial activity at a rate of 41.2%. A comparison of the infiltration rates shows that agroforestry systems exceed monoculture by 23.1% resulting in Figure 4 which demonstrates water infiltration rates (cm/hr) in both systems. Flooded agroforestry sites keep 24.5% more water than flooded monoculture sites while Figure 6 reveals agroforestry systems produce more biomass than monoculture systems. A scatter plot in Figure 7 demonstrates microbial activity in monoculture and agroforestry plots and shows that agroforestry systems reach higher levels of enzyme activity. Figure 8 demonstrates that agroforestry farming systems permit greater water penetration into the soil than monoculture methods. Analysis reveals that agroforestry plots accept significantly more water compared to other plots. A scatter plot in Figure 9 demonstrates how agroforestry systems maintain greater water levels in comparison to monoculture systems. Figures 10 demonstrate how agroforestry systems generate higher biomass output when compared to monoculture systems through biomass yield examination. A comparison of grain production between agroforestry and monoculture designs is presented in Figure 11. The water storage capacity of agroforestry systems exceeds monoculture farming operations.

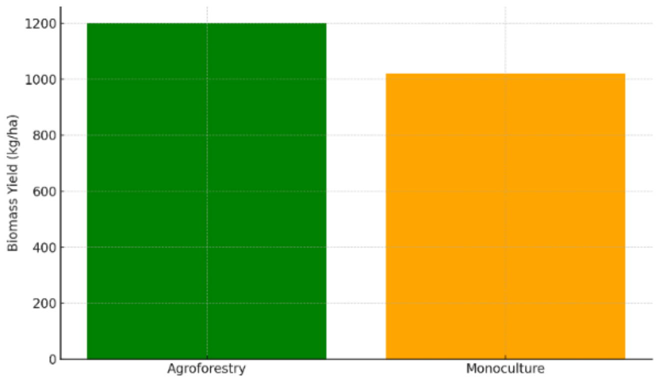


**Figure 1:** Comparison of biomass yield (kg/ha) between agroforestry and monoculture plots, showing a 16.7% higher yield in agroforestry plots.

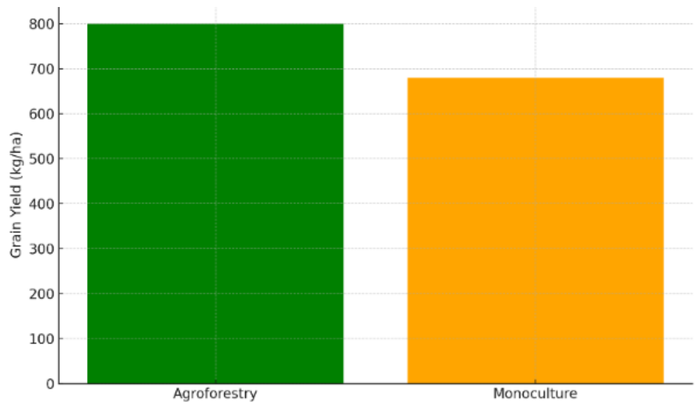


**Figure 2:** Comparison of grain yield (kg/ha) between agroforestry and monoculture plots, with agroforestry plots yielding 17.6% more grain.

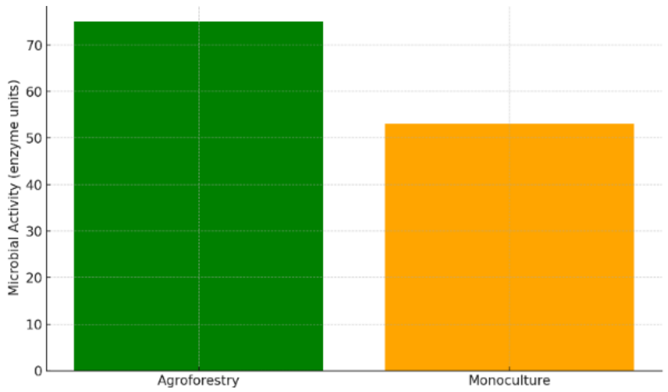


**Figure 3:** Comparison of microbial activity (enzyme activity in µg/g/h) in agroforestry and monoculture plots, demonstrating a 41.2% increase in agroforestry systems.


**Figure 4:** Comparison of infiltration rates (cm/hr) between agroforestry and monoculture plots, with agroforestry plots exhibiting a 23.1% higher infiltration rate.

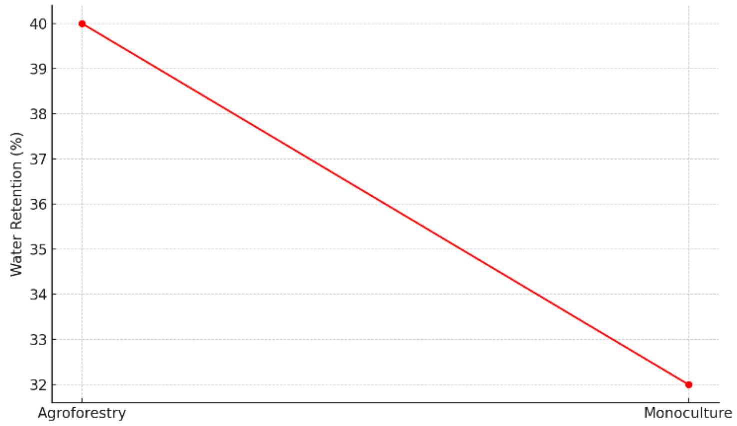


**Figure 5:** Comparison of water retention percentages between agroforestry and monoculture plots, revealing that agroforestry plots retain 24.5% more water.

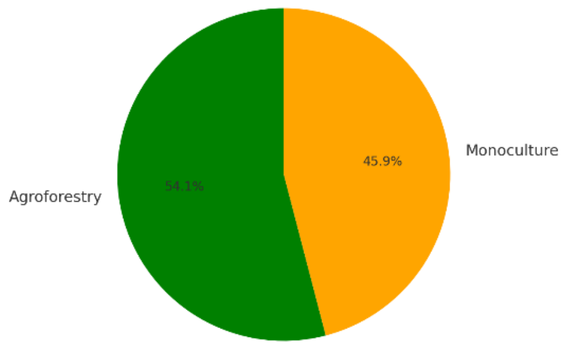


**Figure 6:** Distribution of biomass yield between agroforestry and monoculture plots, showing a larger share of biomass in the agroforestry system.

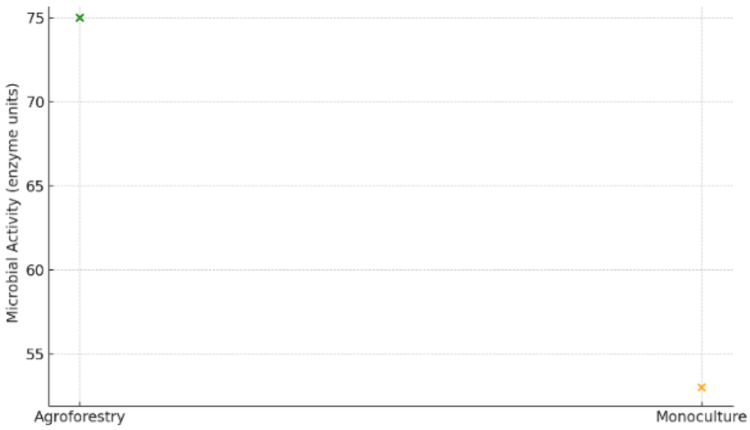


**Figure 7:** Scatter plot comparing microbial activity (enzyme activity in µg/g/h) between agroforestry and monoculture plots, indicating higher microbial activity in agroforestry.

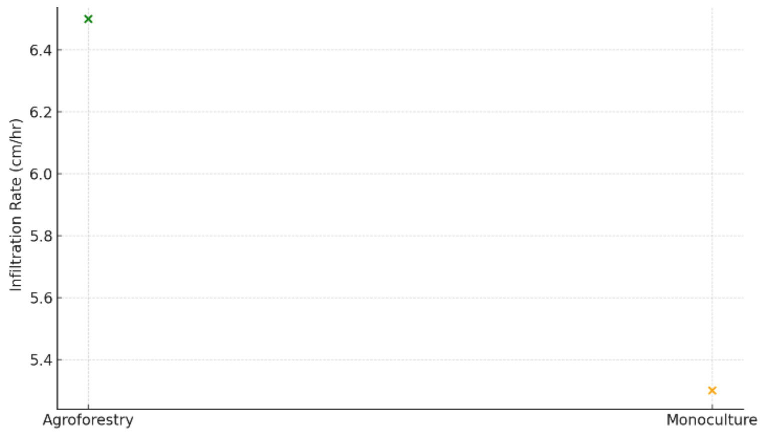


**Figure 8:** Scatter plot comparing infiltration rates (cm/hr) between agroforestry and monoculture plots, showing higher infiltration rates in agroforestry systems.


**Figure 9:** Scatter plot comparing water retention between agroforestry and monoculture plots, with agroforestry systems showing significantly higher water retention.

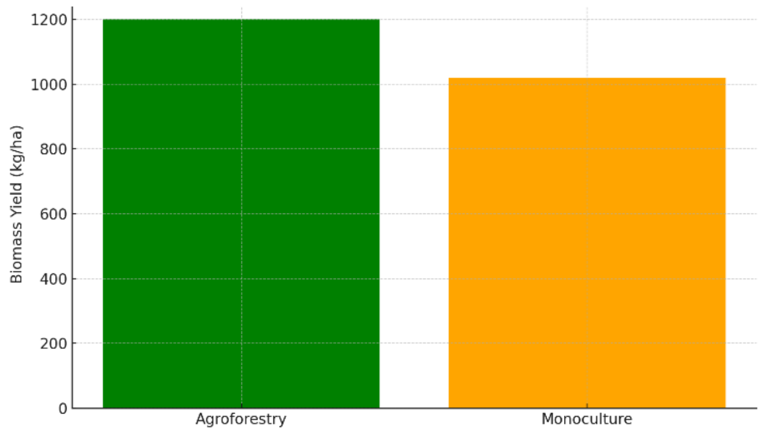


**Figure 10:** Bar chart comparing biomass yield (kg/ha) between agroforestry and monoculture plots, highlighting greater biomass production in agroforestry systems.

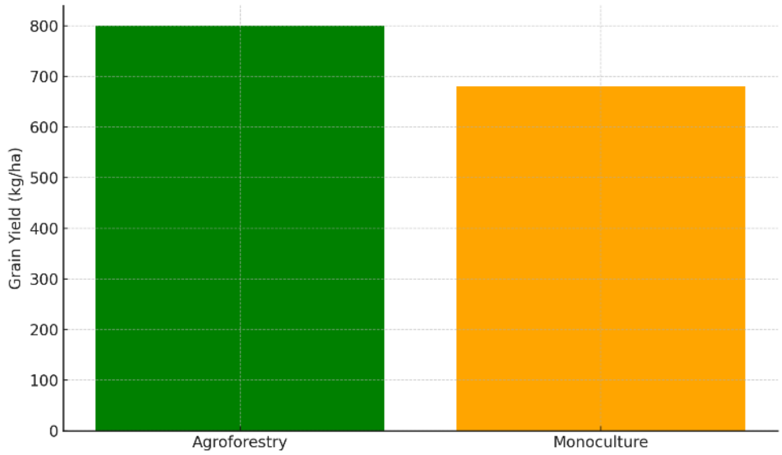


**Figure 11:** Bar chart comparing grain yield (kg/ha) between agroforestry and monoculture systems, with agroforestry systems achieving higher grain yield.

## DISCUSSION

A rigorous study of agroforestry methods in semi-arid territories reveals how trees and crops work synergistically to benefit soil quality and crop productivity. Together with other research our findings show that adding trees to agroforestry systems promotes soil organic matter maintenance and nutrient accessibility while improving water retention qualities. The elevated microbial activity in agroforestry plots provides additional proof of their beneficial effect on soil fertility and its nutrient cycling processes. The grain yield measurements from agroforestry plots that exceeded monoculture plots by 17.6% support the capability of these systems to enhance agricultural returns in limited water areas.

The upfront higher financial requirements yield attractive economic gains when agroforestry systems operate in semi-arid regions. Such farming options deliver compelling financial benefits to growers who have operated their properties for two to three years after founding (La N). Farmland income diversity through tree product sales of fruits lumber and fodder enables farmers to establish durable and enduring financial stability. Within the context of climate change mitigation research demonstrates that agroforestry systems effectively store significant carbon amounts in both biomass and soil components (Golicz).

Agroforestry emerges as an attractive sustainable practice which enhances both semi-arid soil quality and crop productivity levels. These climate-sensitive environments need agroforestry to serve as an adaptable solution that protects natural systems while improving soil fertility and water retention and carbon storage capabilities.

This technique results in elevated grain production as well as improved microbial processes which proves its capability to improve soil health when water resources are limited (Tembo) and generates greater rural economic gains. Strategic agroforestry systems demonstrate a decreasing capacity to reduce erosion from 53% in year two until achieving 98% efficiency in their fifth year of existence (La N). The adoption of agroforestry techniques accelerates with government-established incentives that combine regulatory support and farmer training programs. Farms that integrate both agricultural crops and forestry production on the same piece of land utilize the basic agroforestry principle to boost farmer profits (Hardiyanti). The diverse generated revenue streams supported by agroforestry systems enable farmers to construct long-lasting sustainable livelihoods that generate economic benefits within semi-arid areas. Future research must dedicate itself to enhance agroforestry operational efficiency across particular semi-arid areas by analyzing both regional soils and climate patterns and local socio-economic structures. Sustainable agroforestry projects across semiarid regions should implement consistent frameworks integrating ecological preservation with financial and social requirements according to research from (Rathore) (Sollen) (Elagib) (Sheikh).

The technical and organizational characteristics of agroforestry systems produce variety alongside numerous products which promote food development and health and enable accessibility to wood-based energy and profit generation (Kuyah). The ecosystems support human well-being through better nutrition and dietary variety and enhanced environmental stability which enables multiple forms of income generation (Verma), (Noordwijk).

## CONCLUSION

This study establishes that agroforestry approaches deliver substantial advantages to soil well-being and growing yields when implemented in semi-arid environments. The research established agroforestry systems' potential to improve fundamental ecosystem indicators including biomass yield along with grain yield and soil microbial activity and infiltration rates and water retention capacity. The biomass production and grain yield of agroforestry plots exceeded conventional monoculture systems by 16.7% and 17.6%, highlighting its double advantage of boosting food output and ecological health improvements. Agroforestry systems produced a 41.2% increase in microbial activity because this activity sustains soil fertility and helps nutrients cycle. An analysis indicates agroforestry systems are key to reducing water scarcity since they improve water holding capacity by 23.1% and water retention by 24.5%. Research demonstrates the critical importance of integrating trees within agricultural systems because they create landscape improvements while boosting farming resilience to climate-related environmental issues. Agroforestry provides a low-resource solution to boost agricultural production while defending soil quality in arid areas that need immediate attention for both soil quality and water resources. The research results support the requirement for enhanced acceptance of agroforestry methods to boost environmental sustainability and agricultural production which supports sustainable development goals in these vulnerable regions.

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