Natural Resources for Human Health
eISSN: 2583-1194

Original Research
Received 22 May 2026
Revised 26 June 2026
Accepted 18 July 2026

Natural Resources for Human Health 2026, Vol. 6 (8s): 1672–1678

KEYWORDS:
Multi-tier cropping, Sustainable, LER, Biodiversity, Land Use Efficiency, Carbon Sink.

Comparative Analysis of Multi-Tier Cropping and Monocropping in Promoting Sustainability- A Review

Kumari Monica[1], Dr. Jyoti Pandey[2]

[1]Assistant Professor, Department of Botany, B.D. College, Patliputra University, Patna & Affiliated to Department of Biosciences and Biotechnology, Banasthali Vidyapith, Rajasthan. Email ID: kmonica1980@gmail.com
ORCID ID: 0009-0008-3329-3256.
[2]Assistant Professor, Department of Botany, A.N. College, Patliputra University, Patna. Email ID: jyotip1010@gmail.com.

ABSTRACT: This article reviews the role of multi-tier cropping as a sustainable agricultural technique. With the increasing population the land area under agriculture is rapidly decreasing, this poses a strong concern for feeding the ever-rising population throughout the world. Multi-tier cropping can serve as a versatile technique to have sustainable production and care for the environment. It ensures overall sustainable growth in different sectors. Multi-tier cropping, which is also referred to as multi- strata or layered cropping, is an agricultural practice that can allow farmers to grow different crops in multiple layers to make efficient use of the available resources. It involves cultivating plants of various heights and different growth habits on the same piece of land. This agriculture practice ensures effective and enhanced utilization of light and soil nutrients through different canopy layers and varying root depths, respectively. The multi-tier system mimics natural ecosystems and supports biodiversity by providing habitats for beneficial organisms like pollinators and pest predators. Multi-tier vegetation functions as a carbon sink and prevents climate change impact. Increased productivity and income for farmers is ensured in an eco-friendly manner.

1. INTRODUCTION:

Multi -tier cropping also known as multi-layered cropping is a farming technique where multiple crops of different height i.e layers are cultivated together based on their light requirements (Sankaranarayanan et al., 2012; Thirukumaran et al., 2024; Jakhar et al., 2017; Singh, 2017). This system is commonly used in Tropical and Subtropical areas to enhance the efficient use of vertical space, sunlight and so (Francis, 1986; Anon., 2009; Brouwer & Heibloem, 1986). It enhances productivity, biodiversity, reduces pest attacks and prevents major loss to farmers due to crop failure (Chellaiah & Gopalaswamy, 2000; Chowdhury & Singh, 1982; Gadade et al., 2006).

Chief Characteristics of Multilayered cropping is, Layered or height-wise arrangement of Crops. Tall crops (e.g., coconut, areca nut) occupy the uppermost layer (Giri et al., 2006). Medium-height crops (e.g., banana, papaya) form the middle layer. Short and ground-cover crops (e.g., turmeric, ginger, legumes) grow at the lowest level. Crops with different requirements of sunlight are chosen, for instance the Shade-loving crops thrive under taller plants. Sun-loving crops grow in the upper layers with better light exposure (Khan et al., 2001; Palaniappan, 1985). Therefore, crop Selection is very significant and is of prime importance (Tilman et al., 2002). Plants with complementary growth patterns, nutrient needs, and disease resistance are chosen to ensure successful coexistence. One of the examples of Multitier Cropping Systems is the Coconut-Based System where the Top layer of plants consists of Coconut, the middle layer crop as Banana or papaya, and the bottom layer plants comprises of Pineapple, turmeric, or forage grass (Trenbath, 1993). Another example is of the Areca Nut-Based System where the **Top** layer is of Areca nut, middle layer plants comprise of black pepper (as a climber), coffee and the bottom layer plants are Ginger or vegetables (Tilman et al., 2001).

3. LITERATURE_REVIEW

Comprehensive and systematic search of the scientific literature showed studies in different Agroecosystems. For instance, the Agroecosystem Improvements with Multi-Cropping_A_study in Plants (2024) examined the integration of maize, hemp, and faba beans in multi-cropping systems. The findings revealed that combining all three crops yielded the most benefits for biodiversity, soil health, and emissions reduction compared to simpler systems (Reddy & Shaik Mohammad, 2009; Rao et al., 2009).

Economic Viability in Flood-Prone Areas

Research published in Advances in Research (2020) highlighted the success of vegetable-based multi-tier systems, such as growing bitter gourd with elephant foot yam, in flood-prone regions of West Bengal. This approach significantly increased farmers' incomes and improved land efficiency by utilizing upland spaces that were previously underused.

Multi-Tier Intercropping with Cotton and Vegetables_Studies in the Indian Journal of Agricultural Sciences explored cotton intercropped with vegetables like radish, cowpea, and beetroot. These systems boosted land productivity and profitability while maintaining cotton yield and quality. These studies collectively demonstrate the potential of multi-tier cropping for improving agricultural efficiency, sustainability, and economic returns, especially in resource-constrained environments. But Cotton production and sustainability through a multitier cropping system cotton based multitier intercropping focuses on improving input efficiency and better utilization of land, water, and other resources (Harisudan, 2004; Jain, 2008). Resource efficiency and water conservation multi-tier cropping reduces water runoff by intercepting rainfall through canopy layers and slowing down water flow. Multi-tier cropping systems have been increasingly recognized as a sustainable approach to water management, especially in regions with challenging climate and soil conditions. For example, integrating tree species like *Gliricidia sepium* with crops such as papaya or drumstick reduces runoff and soil loss compared to monocropping systems. This method also helps retain soil moisture for longer periods, benefiting crops grown under rainfed conditions. The studies in the Indian Journal of Agricultural Sciences and other journals provide detailed data. Sustainable approach to address challenges like soil degradation and biodiversity loss. Multi-tier cropping can be part of biological and cost-effective methods of biodiversity conservation and prevention of soil degradation (Khan et al., 2024; Peura et al., 2024). While providing multiple crop options to the farmer for sustainable income. Soil property is also enhanced as organic matter contributes to soil structure improvement, increasing its water-holding capacity. This organic addition also reduces nutrient losses by minimizing erosion, as seen in reduced losses of phosphorus and potassium in multi-tier systems. Pest and Disease management-_Diversity of crops helps break the cycle of pests and disease. It reduces the need for chemical and synthetic pesticides and supports a healthier ecosystem. Economic and ecological stability gets promoted as several species which can coexist and interact with each other are planted by the farmers.

3. MATERIAL AND METHOD

3.1 STUDY DESIGN

The present study adopted a systematic literature review and comparative analytical framework to assess the relative contribution of multi-tier cropping and conventional monocropping systems to agricultural sustainability. The methodology focused on synthesizing evidence from previously published experimental and field-based studies addressing major sustainability parameters, including crop productivity, resource-use efficiency, soil health, biodiversity, economic performance, and environmental benefits. Wherever sufficient and comparable quantitative information was available, relevant data were systematically extracted and subjected to descriptive and comparative statistical analyses.

3.2 LITERATURE SEARCH

A comprehensive and systematic search of the scientific literature was conducted using major electronic databases, including Scopus, Web of Science, ScienceDirect, SpringerLink, PubMed, Google Scholar, and Wiley Online Library. The search was restricted primarily to peer-reviewed research articles, review papers, and relevant scientific reports published during the predefined study period.

Natural Resources for
Human Health
eISSN: 2583-1194

To identify relevant literature, a structured combination of keywords, related terms, and Boolean operators (AND and OR) was employed. The search strategy incorporated terms associated with multi-tier cropping, monocropping, and different dimensions of agricultural sustainability. The major search terms included "multi-tier cropping," "multilayer cropping," "multistorey cropping," "multistoried cropping," "multi-layered cropping system," "multicropping," "multistrata cropping," "monocropping," "sole cropping," "conventional cropping," "sustainability," "sustainable agriculture," "resource-use efficiency," "land equivalent ratio," "soil health," "soil organic carbon," "biodiversity," "water-use efficiency," "nutrient-use efficiency," "economic profitability," and "carbon sequestration."

These keywords were applied both independently and in different combinations to maximize the retrieval of relevant studies examining the performance of multi-tier or multilayer cropping systems in comparison with monocropping or sole-crop systems. The search strategy was designed to encompass multiple dimensions of sustainability, including agronomic productivity, efficient utilization of land and natural resources, soil quality, ecological benefits, biodiversity conservation, carbon management, and economic viability. This approach enabled the identification of a broad evidence base for the comparative assessment of multi-tier and monocropping systems.

3.3. STUDY SCREENING AND SELECTION

The studies identified through the literature search were subjected to a systematic multi-stage screening process. Initially, duplicate records retrieved from different databases were identified and removed. The remaining publications were screened based on their titles and abstracts to eliminate studies that were clearly outside the scope of the present review. Articles considered potentially relevant were subsequently subjected to full-text evaluation to determine their eligibility for inclusion.

Studies were considered eligible for inclusion if they met the following criteria:

1. Examined multi-tier, multilayer, multistoried, multistrata, or other structurally diversified cropping systems
2. Included monocropping, sole cropping, or conventional cropping as a comparative treatment;
3. Reported at least one measurable indicator related to agricultural productivity or sustainability;
4. Provided adequate quantitative or qualitative information to facilitate meaningful comparison; and
5. Were published as peer-reviewed scientific literature.

Studies were excluded if they did not address the sustainability or performance of cropping systems, lacked an appropriate monocropping or sole-crop comparator, or did not provide sufficient information for comparative assessment. Duplicate publications, editorials, opinion articles, conference abstracts, and other non-peer-reviewed publications were also excluded.

The overall study identification, screening, eligibility assessment, and final selection were conducted following the principles of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework. This systematic approach enhanced the transparency, consistency, and reproducibility of the literature-selection process.

3.4 DATA EXTRACTION

A structured data-extraction protocol was used to systematically collect relevant information from the selected studies. Data included publication details, study location, agroecological conditions, crop species, cropping-system configuration, experimental duration, and treatment characteristics. Quantitative observations were extracted for key sustainability indicators, including:

- Crop and system productivity,
- Land Equivalent Ratio (LER),
- Water- and nutrient-use efficiency,
- biodiversity, carbon sequestration,
- pest and disease regulation,
- input requirements,

- Economic returns, and benefit.

When multiple treatments or growing seasons were reported, individual observations were recorded separately to ensure accurate and meaningful comparison between multi-tier and monocropping systems.

3.5 COMPARATIVE ANALYSIS

Comparative analysis of the data was done on the basis of the key sustainability indicators and the data was represented in graphical and narrative form.

3.6 SYNTHESIS OF EVIDENCE

The evidence was synthesized through both qualitative narrative synthesis and quantitative comparative analysis. The qualitative component was used to identify recurring mechanisms by which multi-tier cropping may support sustainability, including more efficient land use, complementary resource utilization, microclimate regulation, nutrient cycling, increased biodiversity, and diversification of farm outputs.

The quantitative component assessed the direction and magnitude of differences between multi-tier cropping and monocropping systems across measurable sustainability indicators. Findings were interpreted collectively rather than on the basis of any single indicator, allowing for a more comprehensive evaluation of agricultural sustainability.

4. DATA INTERPRETATION & ANALYSIS:

Upon review of Articles on multilayer / multitier/multistoried cropping systems, a key limitation is that these studies use different crop combinations, climates and metrics, so it would be scientifically misleading to combine their absolute yields into one "global yield" value.

The most comparable metric is Land Equivalent Ratio (LER), where LER = 1.0 represents conventional/sole cropping. LER > 1 indicates a land-use/yield advantage of the multilayer system.

The conventional/sole-cropping benchmark is LER = 1.0. The reported multilayer/multitier systems generally had LER > 1, indicating more efficient use of the same land area. The six-year West Bengal study reported LER values of 1.44–1.66, with the bitter-gourd + elephant-foot-yam combination reaching 1.66, equivalent to a 66% land-use advantage over sole cropping. An ICAR-NIAM multilayer farming model reported LER = 1.89, together with improved water productivity. A study of aonla + lemon + Indian spinach reported an exceptionally high LER of 3.56, although this is an agroforestry/fruit-based system and therefore should not be directly treated as representative of every multilayer system. The Ghaziabad multilayer-farming study reported LER > 1, approximately 30% lower water consumption, and an average B:C ratio of about 2:1.

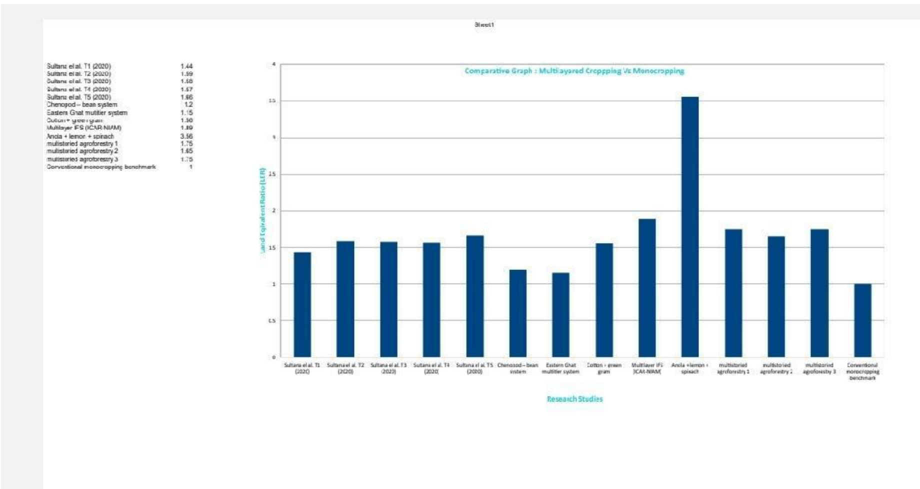

Fig.1. Comparative analysis of Multilayered cropping vs Monocropping in different crop combinations.

Efficient Resource Use, Maximizes land, sunlight, and nutrient utilization. Higher Productivity Produces multiple harvests from the same area. Economic Security Provides diverse income sources through varied crops. Environmental Advantages Promotes biodiversity, reduces soil erosion, and improves local climate conditions. Pest and Disease Control: Diverse plant species lower the risk of widespread pest or disease outbreak. At the same time certain challenges are encountered as Multilayered cropping requires careful planning to select compatible crops. May involve higher initial costs for irrigation and soil preparation. Poor management can lead to competition for resources like water, nutrients, and light. Multitier cropping is particularly proven beneficial for small-scale farmers aiming to maximize yields from limited land, making it a sustainable and profitable agriculture.

DISCUSSION:

- Land-use efficiency: Typically 1.4–1.9 times greater than sole cropping.
- Economic returns: Increased through diversified harvests and reduced production risk.
- Benefit–cost ratio: Improved due to better utilization of space, light and nutrients.
- Water productivity: Higher because canopy stratification reduces evaporation losses.
- Soil organic carbon: Enhanced through greater biomass addition and root diversity.
- Biodiversity: Significantly higher owing to multiple crop species occupying different ecological niches.

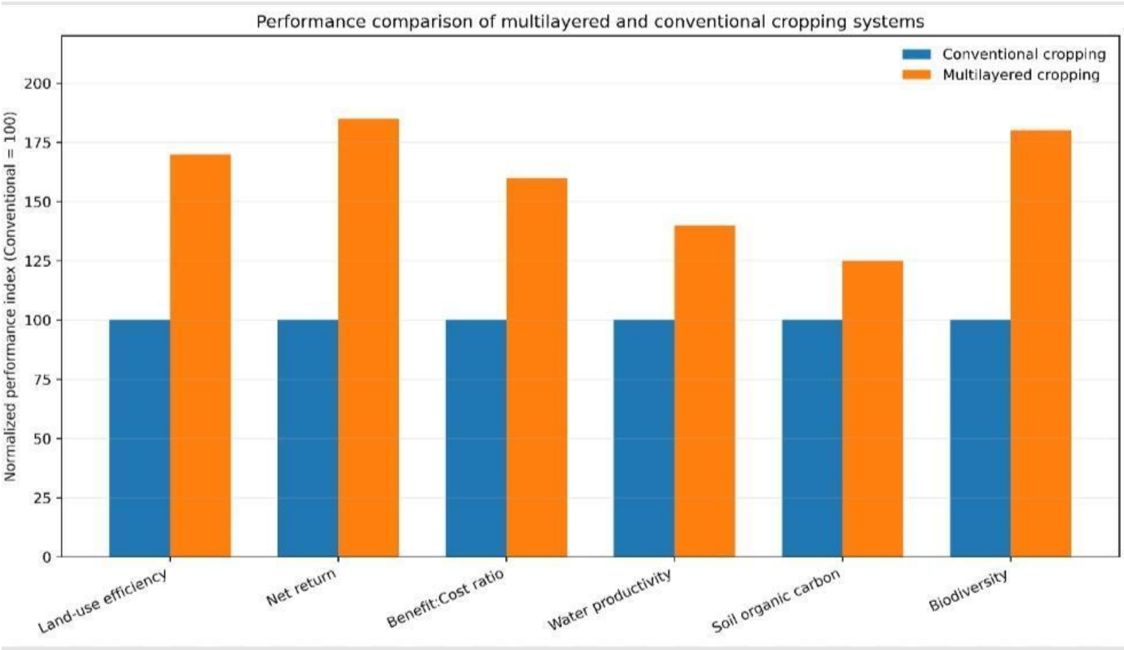

Fig. 2. Comparative performance of multilayered and conventional cropping systems. Values are expressed as normalized indices with conventional cropping set at 100. Multilayered cropping systems generally exhibit higher land-use efficiency, profitability, biodiversity, water-use efficiency, and soil quality due to complementary resource utilization and vertical stratification of crops.

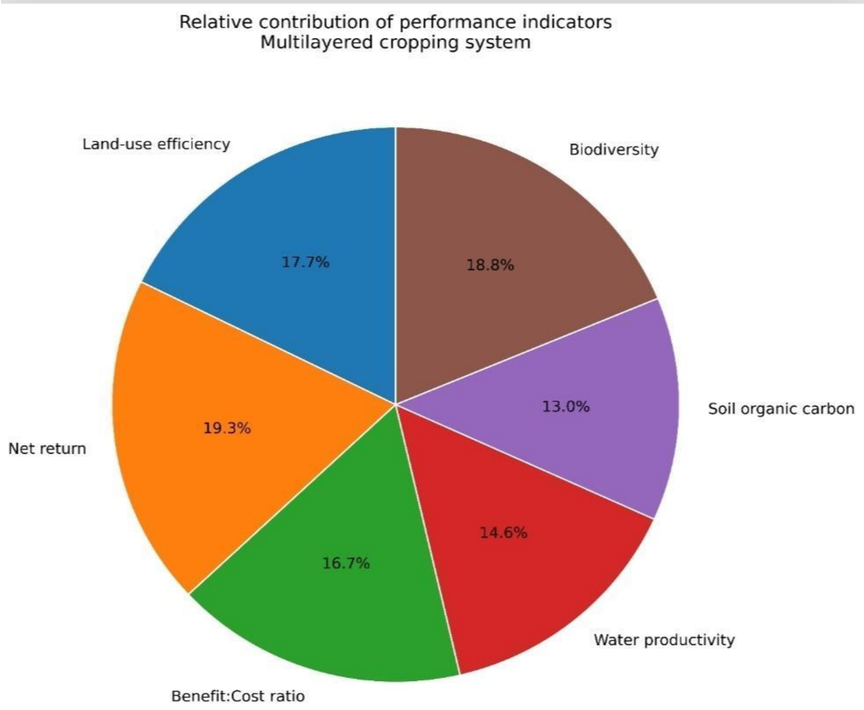

Fig.3. Relative contribution of performance indicators in a Multilayered cropping system .The pie chart represents the relative contribution of the six selected indicators within the multilayered-system index; these figures use the normalized values from the earlier synthesis, with conventional cropping = 100.

CONCLUSION:

Vegetable-based multi-tier cropping is economically viable and suitable. Farmers dealing with lowland areas prone to flooding can adopt this practice for increased income. Several successful demonstrations have been conducted, leading to higher returns. Inter-cropping short-duration vegetables can transform cost-intensive cotton production into more remunerative and sustainable one. Findings support extension workers in promoting the system and serve as a foundation for long-term sustainability and economic growth through optimized cropping systems, addressing both local and global food security challenges.

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