AGRI MAGAZINE
(International E-Magazine for Agricultural Articles)
Volume: 03, Issue: 05 (May, 2026)
Available online at http://www.agrimagazine.in

Multi-Storied Cropping Systems: Maximising Vertical Space in Tropical Farming

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Multi-storied cropping systems represent advanced land-use strategies in tropical agriculture, integrating crops of varying heights, canopy structures, and rooting patterns to optimise vertical space and photosynthetically active radiation use. This review synthesises ecological principles, economic benefits, and phytopathological aspects of such systems. Evidence from India, Southeast Asia, and Central America shows income gains up to 4–5 times over monoculture, alongside improvements in soil health, biodiversity, and carbon sequestration. Crop diversity reduces pathogen pressure through host dilution, microclimate modification, and beneficial microbiota, though labour demand and crop management complexity remain key constraints. This article discusses the concepts and principles of multi-storied cropping system simultaneously compares agronomic performance and productivity under various systems. Furthermore, emphasises the ecological implications and challenges faced in adapting a multi-storied cropping system.

Keywords: Multi-storied cropping, Agroforestry, Crop diversity, Disease suppression, Tropical agriculture

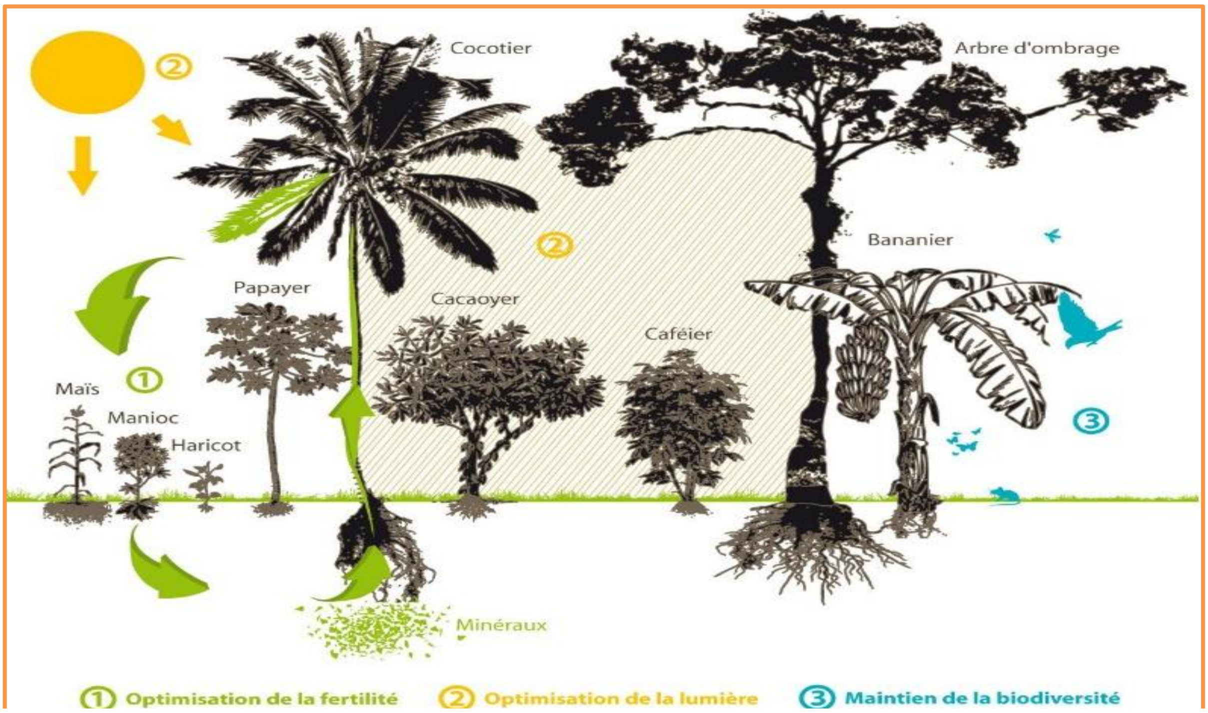
Introduction

The tropics and sub-tropics of the world contain some of the most biodiverse and agriculturally productive ecosystems. However, the continued challenges of population increase, urbanization, land degradation, and climatic variation make them vulnerable to food and nutrition insecurity, especially among small-scale farmers, who form the bulk of the agricultural labor force in the region. For instance, projections suggest that more than 95% of farms in India will be small and marginal farms by 2050 (Nimbolkar et al., 2016a). In light of this situation, multi-story crop production is a promising and proven approach to generate more food and economic returns through increasingly limited land areas.

Multi-story crop production, sometimes called multi-level or multi-canopy agriculture, is an agricultural method whereby plants are grown at different heights, different canopy architecture, different maturity levels, different light requirements, and different root zones either simultaneously or in sequence on the same agricultural field (*Multi-Storey Cropping – Greener.Land*, n.d.). Unlike monoculture, which generally exploits only a small fraction of sunlight and available soil area, multi-story crop production involves multiple layers of canopies, normally ranging from two to five, to exploit the entire vertical agricultural ecosystem. This farming practice thrives well under tropical conditions because of the abundance of sunlight and heat, and consistent allows growth of multiple plant species. With respect to plant pathology, multi-layered cultivation systems become highly significant due to their ability to effectively suppress the development of diseases and insect pests.

This paper aims to review the scientific literature on multi-layered cropping systems within tropical agriculture. The following areas will be addressed:

(i) Theoretical and ecological background of multi-layered cultivation systems;
(ii) Crop layer composition and species compatibility; agronomic and economic benefits;
(iii)Biodiversity and ecosystem services; and
(iv)Plant pathological consequences, specifically pest and disease suppression.



Concept and Principles

Definition and Historical Background

The concept of multiple storey cropping is well embedded within the traditional agricultural wisdom of tropical societies. Farmers in South and Southeast Asian, Central American, and West African societies have been practicing varieties of multi-canopy farming that The concept of multi-storied cropping is rooted in traditional agricultural practices of tropical regions. The concept of multi-storied cropping is rooted in traditional agricultural practices of tropical regions. They described the basic idea of the compatibility between crops due to their different height and rooting system. They studied coconut-based cropping systems in India. From the theoretical point of view, the concept of multi-storey cropping is based upon plant ecology principles as well as agro-ecology and resource utilization efficiency ideas. Relative Yield Total (RYT) – an indicator to evaluate whether the crop combination makes better utilization of resources compared to sole crops growing separately – represents the main idea behind multi-story cropping. If the value of RYT is larger than 1.0, this means that the components make different requests on resources and do not compete biologically (Nimbolkar et al., 2016a).

Vertical Space Management and Solar Radiation Harvesting

Among the main inefficiencies in the monocultural cultivation system is the low utilization of vertical space. Studies have shown that the planting of a single adult coconut palm at intervals of 7.5 m × 7.5 m makes only 22.3% use of the area in question; its canopy covers about 30% of the air and traps only 45-50% of the sun rays (Maheswarappa et al., 2010; Samitha et al., 2024). There are still considerable amounts of unused light, air space, and soil volumes that can be used for extra layers of agricultural crops. The crops in multi-storey farming are chosen and arranged to maximize their complementary properties regarding light capturing efficiency. Light-loving tall plants, like coconuts (15-20 m), areca nut, or oil palms serve as the first-layer canopy. Plants growing on medium heights, for instance, bananas, papayas, coffee, and black pepper take up the second layer. Ground-layer plants are light-shade-loving species such as pineapple, turmeric, ginger, sweet potatoes, and roots

(Nimbolkar et al., 2016b; Sharma et al., 2020). This arrangement imitates the canopy layering of natural rainforests, where each type of plants occupies its own niche.

Complementary Root Systems and Nutrient Usage in Soil

Apart from the horizontal arrangement, the vertical stratification also takes place within multi-layer cultivation. In this regard, crops employ their respective soil zones for taking up nutrients and water. As an instance, the maximum root length of the coconut tree may vary from 2 meters below the ground level. This clearly shows that about 80.4 percent to 87.4 percent of the area between the coconut trees is used by other crops that have varying depths of their root system

Common Multi Storied Cropping configurations in the tropics

Multi-Storied Systems Utilizing Coconuts

Coconut (Cocos nucifera L.) is widely used in multistoried agroforestry across tropical coastal regions, covering about 11.58 million hectares globally. Its single trunk, wide spacing, and moderate canopy support diverse understory crops. Typical systems include coconut, banana, cocoa or coffee, and root crops. Studies from India show higher economic returns and efficient resource use, while "Lakhi baug" systems generate over ₹1 lakh per hectare annually with productivity and profitability gains.

Areca Nut and Coffee-Based Systems

In India, areca nut (*Areca catechu*) and coffee (*Coffea arabica*, *Coffea canephora*) form the base for the cultivation of multistoried farms. Areca nut is cultivated in close planting at a density of 2.7 × 2.7 m; its average height is 15-20 m, and the trunk is narrow. Its plantation involves cultivation of black pepper as a climbing crop along the areca trunk, cocoa, banana, turmeric, ginger, and several other root crops (Sharma et al., 2020). Such farming is most common in Karnataka, Kerala, and some parts of West Bengal. Multi-storeyed systems based on coffee also comprise trees, spices, and annual crops. According to scientific findings, the productivity levels of coffee plantations can be improved substantially with the help of intercropping with the right kinds of crops (Nimbolkar et al., 2016a). Various studies by Sharma et al. (2020) evaluated the diversity of tree species in multi-storied systems.based on coffee, which exhibit substantial structural and species diversity.

Banana and Fruit Trees Multi-Storeyed Systems

In situations where coconut or areca nut trees are not grown as the dominant perennial crops, it is often seen that trees like mango, sapota, guava, or citrus become the key components of the storey. In this case, the multi-layer system follows the Horticulture Agriculture (Horti Agri) pattern, wherein fruits from tree crops are combined in the top storey, with seasonal vegetables or spices or tubers in lower storeys. Examples of such systems were extensively found in India, like ber + clusterbean + mustard, as noted by (Nimbolkar et al., 2016a).

Agronomic performance and Productivity

Land Equivalent Ratio and Yield Benefits

Land Equivalent Ratio (LER) measures productivity advantages of intercropping; values above 1.0 indicate higher yields than monocultures. Multi-layered systems often exceed this, showing efficient resource use. Experiments at OUAT reported high coconut yield (33,407 nuts/ha), income, and benefit-cost ratio (3.21) under multi-layered cropping with soil-based fertilization. Coconut-based integrated farming models also showed up to tenfold productivity increase and four to five times higher profitability with added employment benefits.

Ecological and Environmental Benefits

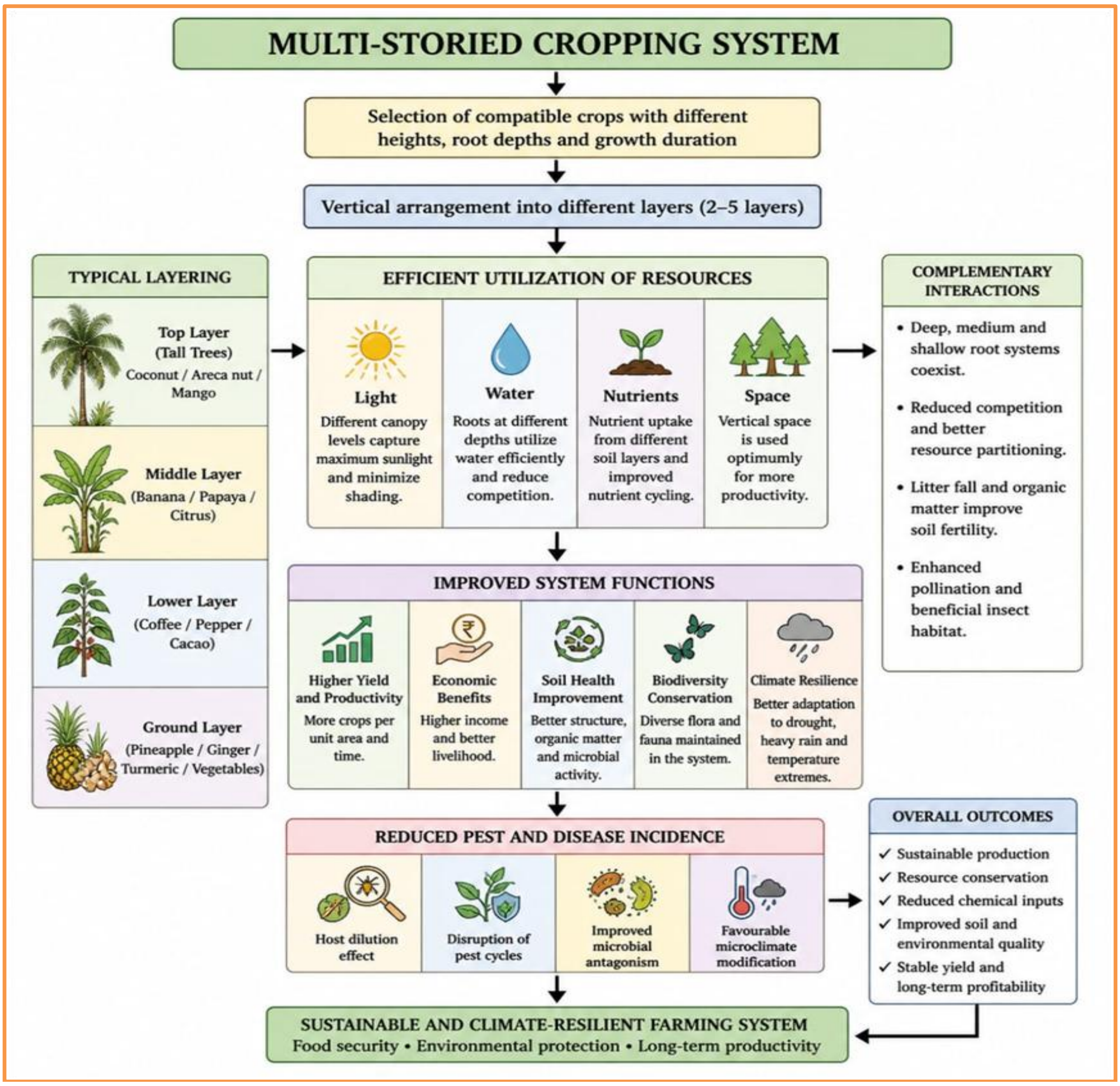
Biodiversity Increase

Multilayered agricultural systems are widely recognized because of their highly diversified nature in terms of Agro-ecology, which gives these practices an ability to support much higher levels of biodiversity when compared to any other type of conventional agriculture. It has been observed in a meta-analysis conducted among various research studies analyzing the comparison of 3,075 paired ecosystems in agroforestry and conventional agriculture that there are 23% more services and biodiversity supported by agroforestry than conventional agriculture practices (Mathieu et al., 2025). A systematic study revealed that the inclusion of trees in combination with crops and livestock within an agroforestry system, like the multi-layered agricultural practices, increased biodiversity on-farm by 25% - 40%.

Soil Health and Nutrient Cycling

Multi-storied cropping systems improve soil health by increasing organic matter through diverse plant residues and enhancing microbial activity. Deep-rooted perennial crops recycle nutrients from deeper layers to the surface via litterfall, making nutrient use more efficient than in monoculture systems. These systems also improve soil nutrient status and increase carbon and nitrogen content in the topsoil. (Sistla et al., 2016)

Several studies concluded that inter-cropping significantly reduced both fungal and insect pest occurrence, suggesting their potential role in cultural practice of integrated pest management. There have been extensive research studies carried out on the coconut and areca nut based multi-storeyed agriculture in India. Despite this, comprehensive research on crop combinations, proper nutrient management, pest monitoring techniques, and profitability under varying tropical conditions has not yet been conducted. For information to be transferred from research centers to actual field settings, effective extension programs should exist in tropical developing countries, but they are still inadequate. Another aspect where research needs to be conducted further pertains to the phytopathology of multi-layered cropping systems undervarying climate conditions.



Challenges and Constraints

Complications of Labor and Management in Multi-story Cropping Systems

While multi-story cropping systems have many advantages, there are complications that come with them. First and foremost among these is the need for more labor. Multistory systems involve more management input, more labor, and more inputs than other agricultural systems. Managing several crops with varying growing periods, nutrient needs, and disease/pest susceptibility requires greater attention from the farmers.

The timing and management of rotations are additional problems associated with multilayer farming systems. Competition between plants of different crops during the different layers may negatively impact the yields when proper management is not undertaken.

Costs Involved in Establishment and Risk of Resource Limitation

Establishing multi-storey farming involves an elaborate procedure of cultivation, which must be done gradually by first planting the lower levels. The cost involved in growing the multi-storeyed plantations includes high costs of seedlings, nutrients, and labor before the system becomes fully productive. In case there is deficiency of one resource, such as water, nutrients, or sunlight, then crops in all layers may end up competing, resulting in poor productivity of all layers of cropping.

Conclusion

Multi-layered cropping is a scientifically supported, culturally relevant, and economically viable strategy for sustainable intensification in tropical agriculture. It enhances yield, nutrition, biodiversity, carbon storage, and natural pest and disease regulation through ecological mechanisms. Amid climate change and land scarcity, it enables efficient land use. Future research should address pathogen dynamics, crop compatibility, phytobiomes, economic transitions, and policy support. For plant pathologists, it offers a shift toward ecological, knowledge-based plant protection and resilient farming systems.

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