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Transforming guava cultivation through high-density planting and meadow orcharding: A review of recent developments

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Abstract

Guava (*Psidium guajava* L.) is a commercially important fruit crop of the tropical and subtropical regions, appreciated for its nutritional value, adaptability, and year-round market demand. Nevertheless, conventional orchard systems are increasingly constrained by excessive canopy vigour, poor light penetration, delayed orchard productivity, labour intensiveness, and suboptimal resource-use efficiency. In this context, high-density planting and meadow orcharding have emerged as viable production strategies for guava intensification, offering opportunities for improved early bearing, yield regularization, and enhanced profitability. These systems derive their effectiveness from coordinated canopy architecture, strategic pruning, crop regulation, and precision management of water and nutrients. Recent advances in fertigation, deficit irrigation, mechanized canopy manipulation, and digital orchard monitoring have further expanded the technical scope of these systems under evolving climatic and economic conditions. This review critically examines the recent progress in high-density and meadow orcharding in guava, with particular emphasis on production system design, canopy management, crop regulation, precision nutrient and water management, fruit quality, economics, sustainability, and emerging research needs. The available evidence indicates that the successful adoption of these systems depends on cultivar suitability, training intensity, site-specific management, and integration of precision horticultural tools. High-density and meadow orchard systems therefore represent an important pathway for sustainable guava production, combining productivity enhancement with improved resource efficiency and long-term orchard manageability.

Keywords: Guava, high-density planting, meadow orcharding, canopy management, crop regulation; fertigation, precision horticulture, sustainable intensification, productivity enhancement, fruit quality

Introduction

Guava (*Psidium guajava* L.), belonging to the family Myrtaceae, is one of the most important fruit crops of the tropical and subtropical regions because of its wide adaptability, prolific bearing habit, high nutritional value, and economic importance (Patil *et al.*, 2020; Nautiyal *et al.*, 2020)^[27, 12]. The fruit is popularly known as the “Apple of the Tropics” or “Poor Man’s Apple” and is highly valued for its richness in vitamin C, dietary fibre, pectin, antioxidants, and essential minerals (Patil *et al.*, 2020; Nautiyal *et al.*, 2020)^[27, 12]. Guava is consumed both as a fresh fruit and in processed forms such as juice, nectar, jam, jelly, puree, beverages, and dehydrated products, thereby contributing substantially to nutritional security and the agro-processing sector (Patil *et al.*, 2020)^[27].

India is one of the leading producers of guava and the crop occupies an important position among fruit crops because of its adaptability, comparatively high productivity, and suitability under diverse agro-climatic conditions (Patil *et al.*, 2020; NHB, 2019)^[27]. However, despite expansion in area under cultivation, productivity in many orcharding regions remains below realizable potential because a large proportion of orchards continue to be managed under conventional systems characterized by wider spacing, excessive vegetative growth, poor light penetration, delayed bearing, and inefficient utilization of land, water, and nutrients (Lal *et al.*, 2000; Lal *et al.*, 2007; Nautiyal *et al.*, 2020)^[12, 8, 9]. These limitations have become more serious in the face of shrinking landholdings, rising land value, labour scarcity, rapid urbanization, and climate variability, all of which necessitate the adoption of more intensive and efficient orchard systems (Patil *et al.*, 2020; Singh *et al.*, 2023)^[27].

Traditionally, guava orchards have been planted at wider spacings ranging from 5×5 m to 8×8 m, resulting in low plant population and delayed economic returns (Lal *et al.*, 2007; Patial *et al.*, 2020) ^[27, 9]. Under such systems, large canopies create mutual shading, reduce photosynthetic efficiency, impair canopy aeration, hinder cultural operations, and adversely affect fruit quality and productivity (Patial *et al.*, 2020; Pratibha *et al.*, 2013) ^[21]. To overcome these constraints, high-density planting (HDP), ultra-high-density planting (UHDP), and meadow orcharding have emerged as promising approaches for sustainable intensification of guava production (Patial *et al.*, 2020; Nautiyal *et al.*, 2020) ^[27, 12].

High-density planting aims to maximize productivity per unit area through efficient utilization of light, water, nutrients, and canopy space, while maintaining optimum tree architecture by training and pruning (Patial *et al.*, 2020; Singh *et al.*, 2023) ^[27]. Among intensive orchard models, meadow orcharding represents a particularly important innovation in guava. The system was developed and standardized at the Central Institute for Subtropical Horticulture (CISH), Lucknow, and generally accommodates about 5,000 plants ha^{-1} at a spacing of 2.0

$\times 1.0$ m with regular topping, hedging, and canopy regulation to maintain compact tree size and sustain fruiting. This production model facilitates early bearing, easier harvesting, better light distribution, and higher yield efficiency than conventional orchards (Nautiyal *et al.*, 2020) ^[12].

Research on intensive guava systems has consistently shown that canopy management is the central determinant of orchard performance. Pruning severity and timing strongly influence vegetative growth, flowering behaviour, fruit set, fruit retention, seasonal crop distribution, fruit quality, and profitability (Nautiyal *et al.*, 2016; Patial *et al.*, 2020; Nautiyal *et al.*, 2020) ^[15, 27]. In high-density orchards of cv. Pant Prabhat, complete removal of non-fruiting shoots followed by one-leaf-pair pruning during the first week of May improved winter fruiting, total yield, and benefit:cost ratio under 2.0×1.0 m spacing (Nautiyal *et al.*, 2020) ^[12]. Likewise, earlier studies demonstrated that spacing and pruning intensity significantly influence canopy development, leaf nutrient status, fruit quality, and yield performance under high-density systems (Joshi *et al.*, 2014; Joshi *et al.*, 2016; Nautiyal *et al.*, 2016) ^[15].

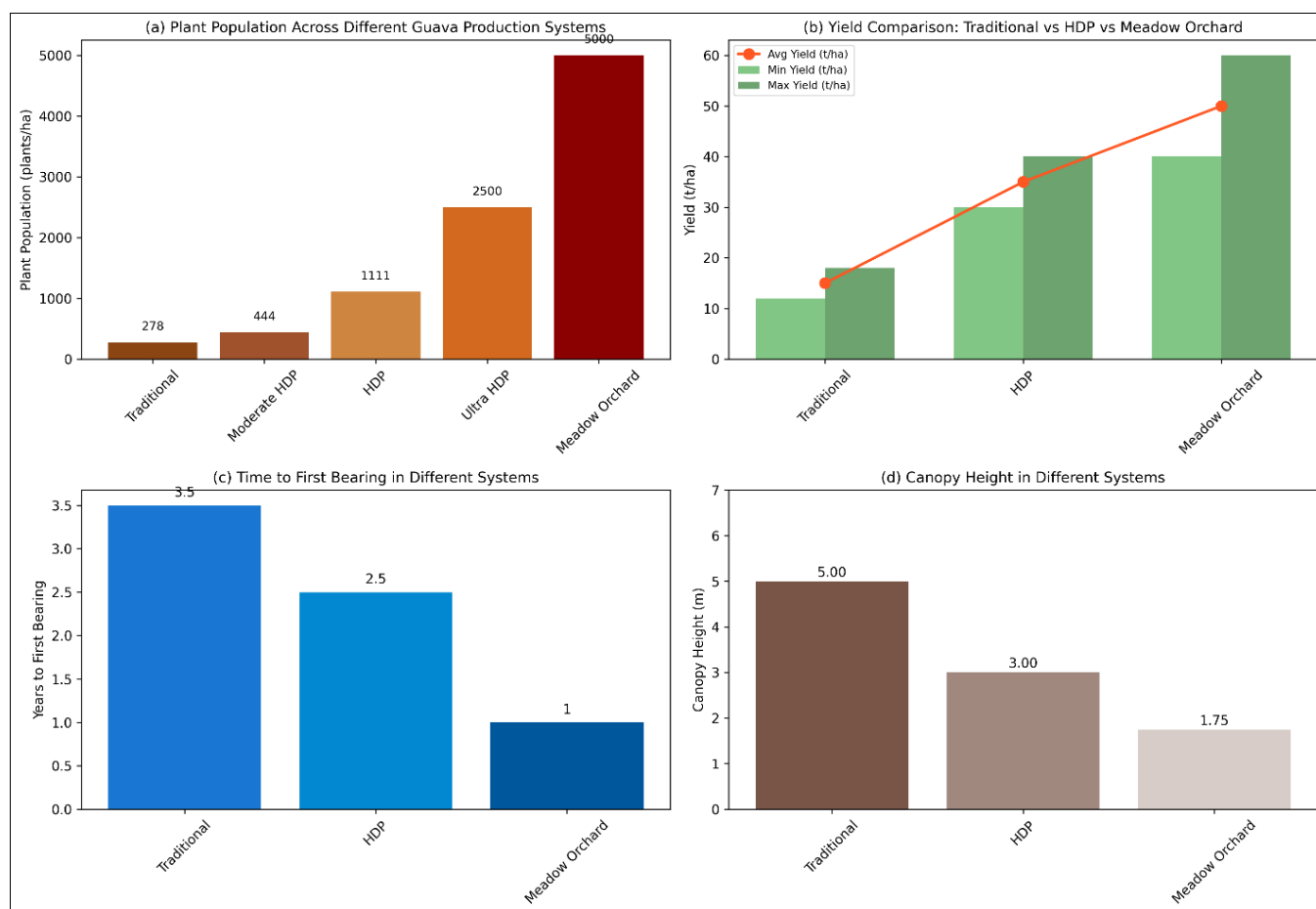


Fig 1: High Density Planting and Meadow Orcharding in Guava: Key Comparisons

In recent years, intensive guava production has been further strengthened by advances in precision horticulture, drip fertigation, integrated nutrient management, crop regulation, sensor-based irrigation, and digital orchard monitoring. These interventions are increasingly important under changing climate and resource constraints because they improve nutrient-use efficiency, water productivity, orchard

uniformity, and management precision. Available evidence suggests that well-managed HDP and meadow orchard systems can substantially enhance yield per unit area, improve fruit quality, and increase profitability relative to traditional systems.

In view of increasing market demand for quality fruits, pressure on land and water resources, and the need for

climate-resilient horticultural systems, high-density planting and meadow orcharding offer a robust pathway for sustainable guava intensification. Therefore, the present review critically examines recent advances in high-density planting and meadow orchard systems in guava, with special emphasis on canopy management, crop regulation, nutrient and water management, productivity enhancement, economic viability, sustainability benefits, and future research priorities.

Review of Literature

Evolution of intensive guava orcharding

The transition from conventional guava orchards to intensive planting systems has been driven largely by the need to increase productivity per unit area and improve orchard manageability (Lal *et al.*, 2007; Singh *et al.*, 2023) ^[9]. Earlier research established that traditional wide-spaced guava orchards suffer from delayed canopy filling, inefficient interception of solar radiation, and lower land-use efficiency, whereas closer planting improves early returns provided canopy size is effectively regulated (Lal *et al.*, 2000; Pratibha *et al.*, 2013) ^[8, 21]. Meadow orcharding subsequently emerged as a more specialized form of intensive planting in which plant size is deliberately restricted through repeated pruning and canopy shaping, allowing extremely high plant densities without permanent loss of orchard functionality.

Canopy management and pruning

Pruning is the most critical cultural operation in high-density guava because the crop bears on current season's growth and therefore responds strongly to canopy manipulation (Patial *et al.*, 2020; Nautiyal *et al.*, 2020) ^[27, 12]. Reviews and experimental studies have shown that pruning time and severity alter shoot emergence, flowering pattern, crop regulation, fruit set, and fruit quality, especially when the objective is to shift production toward the superior winter crop (Patial *et al.*, 2020) ^[27]. Nautiyal *et al.* (2020) ^[12] demonstrated that under high-density conditions, complete removal of non-fruiting shoots followed by one-leaf-pair pruning enhanced winter yield and profitability, while unpruned trees produced higher rainy-season yield but inferior seasonal distribution and lower economic advantage. Similar findings were reported by Thakre *et al.* (2016) ^[25], Sah *et al.* (2017) ^[22], and other workers who observed that systematic pruning improves light penetration, reduces canopy congestion, and increases

productive shoot formation in intensive guava plantations.

Spacing and orchard geometry

Plant spacing directly affects canopy expansion, competition for light, nutrient uptake, and yield per hectare under HDP systems (Joshi *et al.*, 2014; Joshi *et al.*, 2016). Wider spacing generally promotes greater vegetative growth and canopy spread, whereas closer spacing suppresses vigour but increases productivity per unit land area when supported by adequate pruning and nutrient management (Nautiyal *et al.*, 2020) ^[12]. In Pant Prabhat guava, spacing at 2.0×1.0 m resulted in higher winter-season fruit set and markedly greater yield per hectare than 2.0×2.0 m spacing, demonstrating the importance of planting geometry in yield optimization under intensive management. Earlier experiments under different agro-climatic conditions also confirmed that close spacing combined with canopy control improves orchard efficiency, fruit quality, and profitability.

Crop regulation and winter cropping

Crop regulation is a major objective of pruning-based guava management because the winter crop is superior in quality, less affected by pests and diseases, and more remunerative than the rainy-season crop (Patial *et al.*, 2020; Nautiyal *et al.*, 2020) ^[27, 12]. The literature indicates that pruning in May can suppress the undesirable rainy crop and promote higher flowering and fruiting in winter through stimulation of new shoots and redistribution of assimilates (Singh *et al.*, 2001; Tiwari and Lal, 2007; Patial *et al.*, 2020) ^[9, 27]. This principle is especially valuable in high-density plantations where crop load, canopy vigour, and source-sink relationships must be precisely balanced to achieve high-quality winter production.

Fruit quality responses

Fruit quality in guava under intensive systems is strongly influenced by canopy openness, crop load, pruning intensity, and season of harvest (Patial *et al.*, 2020) ^[27]. Several studies have shown that fruits from winter-season crops generally possess higher total soluble solids, better flavour, improved shelf life, and superior market acceptability compared with rainy-season fruits (Patial *et al.*, 2020; Nautiyal *et al.*, 2020. Pal *et al.* (2017) ^[27, 12, 19, 20] further reported that plant spacing in high-density orchards affects physico-chemical quality parameters, indicating that orchard geometry and canopy management jointly determine not only yield but also market quality.

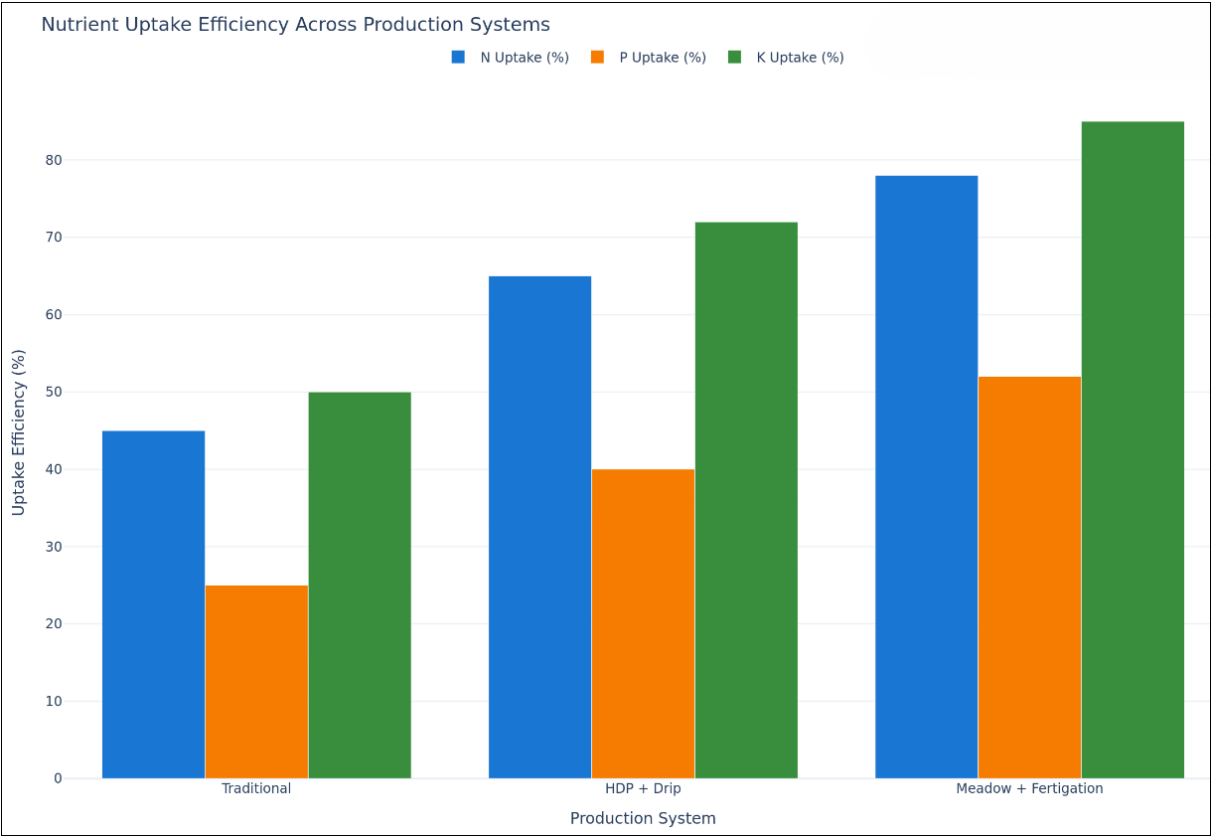


Fig 2: Nutrient Uptake Efficiency across Production Systems

Nutrient and water management

As planting density increases, nutrient and water management become more precise and more critical for sustaining productivity and canopy balance. Drip fertigation has emerged as an efficient tool for nutrient delivery in fruit crops because it improves nutrient-use efficiency, supports targeted application, and can enhance vegetative growth,

yield, and economic returns under well-managed orchard conditions. Integrated nutrient management and precision irrigation are increasingly viewed as necessary components of HDP guava because dense orchards require synchronized supply of nutrients and water to avoid excessive vegetative growth, nutrient depletion, and fruit quality deterioration.



Fig 3: Water Use Efficiency across Different irrigation Systems in Guava

Economics of high-density systems

Economic analysis has consistently favoured intensive guava systems when canopy management is properly executed. In high-density cv. Pant Prabhat planted at 2.0×1.0 m, Nautiyal *et al.* (2020) ^[12] reported the highest net return and benefit:cost ratio with complete removal of non-fruited shoots followed by one-leaf-pair pruning, mainly because this treatment maximized profitable winter yield.

Their study reported an average total yield of 283.07 q ha and a benefit: cost ratio of 2.02 under this treatment at close spacing, compared with lower profitability in unregulated systems. These findings support the broader conclusion that the economics of HDP guava depend not only on plant density but on the successful integration of pruning, crop regulation, and seasonal fruit quality improvement.

Table 1: Comparative Characteristics of Traditional, High-Density Planting (HDP) and Meadow Orchard Systems in Guava

Parameter	Traditional Orchard	High-Density Planting (HDP)	Meadow Orchard System
Plant population (plants ha ⁻¹)	278	1,111-2,500	5,000
Typical spacing (m)	6 × 6	3 × 3 to 2 × 2	2 × 1
First commercial bearing (year)	3-4	2-3	1
Average yield (t ha ⁻¹)	12-18	30-40	40-60
Yield efficiency	Low	High	Very High
Pruning intensity	Low to Moderate	Moderate	High and Regular
Canopy height (m)	4-6	2.5-3.5	1.5-2.0
Canopy architecture	Large, spreading canopy	Compact and managed canopy	Dwarf, highly regulated canopy
Light interception efficiency	Moderate	High	Very High
Light penetration within canopy	Poor	Good	Excellent
Fruit quality	Moderate	Good	Excellent
Harvesting convenience	Difficult	Easy	Very Easy
Spraying efficiency	Moderate	Good	Excellent
Pest and disease management	Difficult	Easier	Easier due to open canopy
Labour requirement	High	Moderate	Moderate to High
Mechanization potential	Low	Moderate	High
Water-use efficiency	Moderate	High (with drip irrigation)	Very High (with drip fertigation)
Nutrient-use efficiency	Moderate	High	Very High
Economic returns	Moderate	High	Very High
Suitability for precision horticulture	Low	Moderate to High	High
Payback period	Longer	Moderate	Shortest

Sources: Compiled from Joshi *et al.* (2016) ^[5], Pal *et al.* (2017) ^[19, 20], Nautiyal *et al.* (2020) ^[12], Nautiyal *et al.* (2023) ^[14], and recent literature on intensive guava production systems.

Sustainability and future direction

Recent literature increasingly interprets HDP and meadow orcharding within the broader framework of sustainable intensification, climate resilience, and precision horticulture (Singh *et al.*, 2023) ^[23]. These systems improve land-use efficiency, facilitate micro-irrigation and mechanized operations, and support more targeted nutrient and canopy management, thereby reducing wasteful input use and improving orchard productivity under resource constraints. Future research priorities include cultivar and rootstock standardization for dense planting, location-specific pruning protocols, sensor-based irrigation, digital orchard monitoring, and climate-smart management models for long-term sustainability in guava production systems.

Conclusion

High-density planting and meadow orcharding represent a paradigm shift in guava cultivation, transforming it from a traditional low-input, low-productivity orchard system into an intensive, scientifically managed production system capable of delivering 40-60 t/ha—three to four times higher than conventional orchards. The accumulated evidence from research conducted at ICAR-CISH Lucknow, GBPUAT Pantnagar, and other institutions clearly demonstrates that meadow orcharding at 2.0×1.0 m spacing (5000 plants/ha) facilitates first-year bearing, compact canopy architecture, and sustained productivity through systematic topping,

hedging, and pruning.

The success of intensive guava systems critically depends on the integration of several key components: (i) optimum planting geometry aligned with cultivar vigour; (ii) precise canopy management through strategic pruning that regulates vegetative growth while promoting profitable winter cropping; (iii) crop regulation through bahar management, water stress, and plant growth regulators; (iv) precision nutrient and water management through drip fertigation, which can save 20-30% fertilizer while improving nutrient-use efficiency; and (v) adoption of emerging digital technologies including sensor-based irrigation, IoT monitoring, and AI-based yield prediction.

Economic analyses consistently show that high-density and meadow orchard systems provide superior returns despite higher initial establishment costs. The benefit: cost ratio of 2.0-2.5, combined with early bearing from the first year and payback periods of 3-4 years, makes these systems particularly attractive for small and medium growers operating under land constraints. The compact orchard architecture also enhances labour efficiency, facilitates mechanization, and improves spray penetration for better pest and disease management.

From a sustainability perspective, intensive guava systems contribute to sustainable intensification by improving land-use efficiency, reducing input wastage through precision delivery, and enhancing climate resilience through

manageable canopy structures. The integration of fertigation, drip irrigation, and integrated nutrient management supports soil health, water conservation, and reduced environmental impact.

However, several challenges remain that require attention: high initial investment for planting material and irrigation infrastructure, the need for skilled labour trained in precision pruning, limited availability of quality planting material suitable for dense planting, mechanization limitations in small orchards, and complexities in nutrient management under high plant density. Future research must prioritize the development of dwarfing rootstocks, cultivar-specific recommendations for dense planting, location-specific pruning protocols, sensor-based decision-support tools, and climate-smart orchard models.

In conclusion, high-density planting and meadow orcharding are not merely alternative planting systems but represent the future of sustainable guava production. Their successful adoption requires a holistic approach that integrates planting geometry, canopy architecture, crop regulation, precision input management, and digital technologies. As the horticultural sector increasingly emphasizes productivity enhancement, resource-use efficiency, and climate resilience, intensive guava orchard systems offer a robust pathway to meet the growing demand for quality fruits while ensuring economic viability for growers and environmental sustainability for the broader agro-ecosystem. Location-specific recommendations, extension support, and capacity building will be essential to realize the full potential of these transformative production systems across India's diverse agro-climatic regions.

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