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Hortisilvipasture as a multifunctional land-use system: Implications for farmer livelihoods, resource use efficiency and ecosystem service

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ABSTRACT

Abstract: Hortisilvipasture combines horticultural crops, multipurpose trees and pasture species on a single piece of land, raising farm productivity, resource-use efficiency and livelihood security. The approach matters most for small and marginal farmers dealing with shrinking landholdings, fodder shortages, erratic weather and unstable farm income. This review sets out ten conceptual one-hectare models built around major fruit crops — mango, guava, pomegranate, ber, aonla, custard apple, jamun, bael, lemon and papaya — each paired with suitable multipurpose trees and pasture species. Together these components supply fruit, fodder, timber, fuelwood, biomass and livestock produce from the same land, making fuller use of available space, water, light and nutrients across different heights and seasons. Adding trees and pasture also supports nutrient cycling, soil conservation, carbon storage, biodiversity and local climate moderation. For farmers, short-, medium- and long-term returns arriving together spread income across time and reduce reliance on a single crop. How well these systems perform, though, depends on local conditions — species compatibility, spacing, pruning, soil, water availability and market access. The ten models here are starting points for research and field testing, not fixed blueprints, and need validation across different agro-climatic regions before wider use. Overall, hortisilvipasture offers a practical route to more diversified, climate-resilient and sustainable farming

Keywords: Climate-smart agriculture, Nature-based solutions, Integrated farming systems, Biodiversity conservation, Carbon sequestration

1. Introduction

Indian agriculture is facing increasing pressure from land degradation, water scarcity, climate variability, rising input costs and uncertain farm returns. These challenges are particularly important for small and marginal farmers who depend on limited land and a few agricultural enterprises for their livelihood. Diversified production systems that combine crops, trees, pasture and livestock can help spread production risk while improving the productive and ecological functions of farmland (Dhyani, 2020; Datta *et al.*, 2024) [2, 1].

Hortisilvipasture is a multifunctional land-use system that integrates horticultural crops, multipurpose trees and pasture or fodder species on the same land unit. Fruit crops provide high-value produce and income, while silvi-trees contribute timber, fodder, fuelwood, biomass and ecosystem services. Pasture grasses provide livestock feed and protect the soil surface. When compatible species are appropriately arranged, the system can improve the use of land, light, water and nutrients and promote nutrient recycling (Rai *et al.*, 2020; Kumar *et al.*, 2020).

The integration of fruit trees with pasture and multipurpose trees also creates opportunities for livelihood diversification. Farmers can obtain income from fruits, livestock, fodder, timber and other biomass products at different times of the year. Such diversification can reduce dependence on a single crop and improve resilience to climatic and market-related risks (Datta *et al.*, 2024) [1]. In addition, tree and pasture components can contribute to soil conservation, carbon sequestration, biodiversity enhancement and microclimate regulation (Kiran Kumara *et al.*, 2023; Chavan *et al.*, 2024) [3].

However, the success of hortisilvipasture depends on species compatibility, planting density, canopy management, soil and water availability and local market conditions. Therefore, location-specific models are required. This review presents **ten conceptual one-hectare hortisilvipasture models** based on different fruit crops, multipurpose silvi-trees and pasture grasses and discusses their potential contribution to farmer livelihoods, resource-use efficiency and ecosystem services.

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2. Proposed hortisilvipasture models for one-hectare land units

2.1 Mango-based hortisilvipasture model

Mango (*Mangifera indica*) forms the principal horticultural component of this model, planted at a spacing of 10×10 m to accommodate approximately 100 trees ha^{-1} . Multipurpose silvi-trees — neem, shisham, subabul, gliricidia and khejri — are established along the farm boundary and in selected strips at a density of 80–100 trees ha^{-1} . The inter-row space is utilized for buffel grass, Rhodes grass and Napier grass, ensuring continuous fodder supply and ground cover. The resulting system yields mango fruit, fodder, livestock produce, biomass and timber, supporting income diversification across the farm cycle.

2.2 Guava-based hortisilvipasture model

Guava (*Psidium guajava*) is planted at 6×6 m spacing, giving a density of approximately 278 plants ha^{-1} . Neem, siris, subabul, gliricidia and shisham occupy boundary rows and designated tree strips at 100–120 trees ha^{-1} , while buffel, Napier and Rhodes grasses are grown in the inter-row areas. This configuration provides fruit, fodder and biomass, and creates scope for livestock integration and enterprise diversification.

2.3 Pomegranate-based hortisilvipasture model

Pomegranate (*Punica granatum*) is planted at 5×4 m spacing (approximately 500 plants ha^{-1}), with neem, karanja, babul, subabul and gliricidia introduced along the boundary and selected strips at 80–100 trees ha^{-1} . Buffel, Rhodes and Napier grasses are maintained in suitable inter-row areas. This model combines high-value fruit production with fodder and livestock components and is suited to regions where pomegranate cultivation is commercially viable.

2.4 Ber-based hortisilvipasture model

Ber (*Ziziphus mauritiana*) is planted at a comparatively wider spacing of 8×8 m, accommodating approximately 156 trees ha^{-1} . Khejri, babul, anjan, neem and siris are established along boundaries and contour strips at 100–150 trees ha^{-1} , with buffel, Rhodes and Napier grasses occupying the remaining inter-row area. Given the drought tolerance of ber and its associated tree species, this model is particularly suited to dryland conditions and yields fruit, fodder and fuelwood.

2.5 Aonla-based hortisilvipasture model

Aonla (*Phyllanthus emblica*) is planted at 8×8 m spacing (approximately 156 plants ha^{-1}), with neem, siris, shisham, gliricidia and karanja established along boundaries and internal strips at 100–120

trees ha^{-1} . Buffel, Rhodes and Napier grasses occupy the inter-row space. In addition to fresh fruit, this system supports processing-based income streams alongside fodder and biomass production.

2.6 Custard-apple-based hortisilvipasture model

Custard apple (*Annona squamosa*) is planted at 5×5 m spacing, giving approximately 400 plants ha^{-1} . Anjan, babul, khejri, neem and subabul are established along boundaries or designated strips at 80–120 trees ha^{-1} , with buffel, Rhodes and Napier grasses maintained in the available pasture area. This model is particularly relevant to dryland and semi-arid environments, providing fruit, fodder and biomass for livestock support.

2.7 Jamun-based hortisilvipasture model

Jamun (*Syzygium cumini*) is maintained at 10×10 m spacing, giving a density of approximately 100 trees ha^{-1} . Shisham, siris, neem, subabul and karanja are introduced along boundaries and selected strips at 80–100 trees ha^{-1} , with buffel, Napier and Rhodes grasses occupying the inter-row space. This model integrates fruit production with timber, fodder and livestock-related outputs.

2.8 Bael-based hortisilvipasture model

Bael (*Aegle marmelos*) is planted at 8×8 m spacing, accommodating approximately 156 plants ha^{-1} . Khejri, neem, babul, anjan and siris are established along boundaries or contour strips at 100–150 trees ha^{-1} , with buffel, Rhodes and Napier grasses maintained in the available pasture area. Beyond fruit production, this system supports fruit processing, biomass generation, soil protection and associated ecosystem services.

2.9 Lemon-based hortisilvipasture model

Lemon (*Citrus limon*) is planted at 6×6 m spacing, giving a density of approximately 278 plants ha^{-1} . Gliricidia, subabul, karanja, neem and shisham are established along boundaries and selected strips at 80–100 trees ha^{-1} , with Napier, buffel and Rhodes grasses grown in suitable inter-row spaces. This model provides regular fruit-based income while supporting fodder availability and livestock production.

2.10 Papaya-based hortisilvipasture model

Papaya (*Carica papaya*) is planted at close spacing of 2×2 m under intensive cultivation, accommodating nearly 2,500 plants ha^{-1} . Malabar neem, gliricidia, subabul, neem and karanja are planted mainly along boundaries and wider strips at 80–100 trees ha^{-1} , with Napier, buffel and Rhodes grasses maintained in peripheral or inter-row areas. The principal advantage of this model lies in early fruit income during the establishment phase, complemented by fodder, biomass and longer-term tree products.

Table 1. Component-wise plant configuration of the proposed hortisilvipasture systems

Model	Horticultural component	Silvicultural component	Pasture component	Major livelihood outputs
Model 1	Mango	Neem + Shisham + Subabul + <i>Gliricidia</i> + Khejri	Buffel + Rhodes + Napier	Fruit + timber + fodder + livestock
Model 2	Guava	Neem + Siris + Subabul + <i>Gliricidia</i> + Shisham	Buffel + Napier + Rhodes	Fruit + fodder + biomass
Model 3	Pomegranate	Neem + Karanja + Babul + Subabul + <i>Gliricidia</i>	Buffel + Rhodes + Napier	High-value fruit + fodder + livestock
Model 4	Ber	Khejri + Babul + Anjan + Neem + Siris	Buffel + Rhodes + Napier	Dryland fruit + fodder + fuelwood
Model 5	Aonla	Neem + Siris + Shisham + <i>Gliricidia</i> + Karanja	Buffel + Rhodes + Napier	Fruit + processing + fodder
Model 6	Custard apple	Anjan + Babul + Khejri + Neem + Subabul	Buffel + Rhodes + Napier	Fruit + fodder + livestock
Model 7	Jamun	Shisham + Siris + Neem + Subabul + Karanja	Buffel + Napier + Rhodes	Fruit + timber + fodder
Model 8	Bael	Khejri + Neem + Babul + Anjan + Siris	Buffel + Rhodes + Napier	Fruit + processing + ecosystem services
Model 9	Lemon	<i>Gliricidia</i> + Subabul + Karanja + Neem + Shisham	Napier + Buffel + Rhodes	Fruit + fodder + livestock
Model 10	Papaya	Malabar neem + <i>Gliricidia</i> + Subabul + Neem + Karanja	Napier + Buffel + Rhodes	Early fruit income + biomass + timber

3. Estimated productivity and income potential

The economic potential of the proposed hortisilvipasture models depends primarily on fruit yield, pasture production and the additional value generated through fodder, livestock and tree biomass. Since the models are conceptual, the following productivity values should be interpreted as indicative yield potential under suitable management, rather than as experimentally established yields of the complete systems.

3.1 Mango-based model

Mango can provide approximately 8–15 t fruit ha⁻¹ under suitable mature-orchard conditions. Considerable variation occurs among cultivars; ICAR reports yields of 80–90 kg tree⁻¹ for CISH *Ambika*, 60–70 kg tree⁻¹ for CISH Arunika and 35–40 kg tree⁻¹ for Arka Suprabhath. At the proposed 100 trees ha⁻¹ density, actual system yield would depend strongly on cultivar, canopy management and the space allocated to silvi-pasture components (ICAR, 2026).

3.2 Guava-based model

Guava can provide approximately 10–20 t fruit ha⁻¹ in a well-managed system. ICAR reports 85–90 kg tree⁻¹ for CISH Shweta and 100 kg tree⁻¹ for CISH Lalit, while Arka Kiran has reported average yields of about 20 t acre⁻¹ at 4 × 3 m spacing under suitable conditions. In an integrated system, the actual yield would be expected to decline if substantial land is allocated to silvi-trees and pasture (ICAR, 2026).

3.3 Pomegranate-based model

Pomegranate has strong potential as a high-value horticultural component. ICAR reports 23–27 t ha⁻¹ for Solapur Lal under suitable conditions, while Solapur Lal has also been reported with a fruit yield of 36.72 kg tree⁻¹. However, the proposed hortisilvipasture model uses considerably wider tree spacing than a conventional high-density pomegranate orchard, and therefore the actual fruit yield would depend on the proportion of land occupied by associated components (ICAR, 2022; ICAR, 2026).

3.4 Ber-based model

Ber is particularly relevant to dryland-oriented systems. ICAR-CIAH reports an average yield of 34 kg tree⁻¹ at six years for the variety Thar Sevika. With approximately 156 ber trees ha⁻¹ in the proposed

model, this provides a useful reference point for estimating fruit production, although actual yield will vary with cultivar, tree age, rainfall and management (ICAR-CIAH, 2026).

3.5 Aonla-based model

Aonla offers both fresh-fruit and processing opportunities. ICAR-CIAH reports an average yield potential of 102.9 kg tree⁻¹ for Goma Aishwary, an early and drought-tolerant selection suitable for processing and export. ICAR advisory information also indicates that mature aonla trees may produce 1–3 q fruit tree⁻¹, with reported yields of approximately 15–20 t ha⁻¹ under suitable conditions (ICAR-CIAH, 2026; ICAR, 2021).

3.6 Custard-apple-based model

Custard apple can contribute substantially to fruit production under suitable dryland and semi-arid conditions. ICAR lists Arka Sahan with a reported yield of approximately 12 t ha⁻¹. This provides a useful benchmark for the proposed custard-apple-based model, although the actual yield in an integrated system would depend on the space occupied by silvi-trees and pasture (ICAR, 2026).

3.7 Jamun-based model

Jamun is suitable as a longer-term fruit component in diversified systems. Yield varies considerably with genotype and tree age, and therefore a single generalized yield value would be misleading. For the review, the model can be described using a mature-tree yield range of approximately 4–8 t ha⁻¹ as an indicative planning value, with the caveat that this figure requires location-specific validation. ICAR-CIAH's varietal and agroforestry research provides evidence that fruit yield can vary substantially under different production systems (ICAR-CIAH, 2019).

3.8 Bael-based model

Bael has considerable potential for both fresh consumption and processing. ICAR reports 115.75 kg fruit tree⁻¹ at the 12th year for Thar Prakriti. Because bael trees are relatively large, the actual hectare-level yield in a hortisilvipasture system will depend on tree density and the area reserved for associated trees and pasture (ICAR, 2026).

3.9 Lemon-based model

Lemon can provide repeated harvests and therefore has potential for relatively regular cash flow. For the review model, an indicative mature-system yield of approximately 8–15 t fruit ha⁻¹ year⁻¹ may be

used, but this should be explicitly identified as a conceptual estimate requiring validation. ICAR's horticultural research programme recognizes citrus as an important fruit group and has developed improved cultivars and production technologies for different agro-climatic regions (ICAR, 2026).

3.10 Papaya-based model

Papaya has an important advantage because it can generate returns relatively early compared with many perennial fruit trees. ICAR reports that Arka Prabhat can produce a cumulative yield of 90–100 kg plant⁻¹ over two years. ICAR advisory information also identifies conventional spacing around 1.8 × 1.8 m and high-density systems at 1.5 × 1.5 m, with *Pusa Nanha* accommodating approximately 6,400 plants ha⁻¹. In the proposed hortisilvipasture model, however, the actual papaya population and yield would need to be reduced to accommodate silvi-trees and pasture (ICAR, 2023; ICAR, 2021).

3.11 Pasture productivity

The pasture component provides an important additional source of farm output. ICAR specifically reports that its horti-silvi-pasture technology can produce approximately 6–12 t forage dry matter ha⁻¹ year⁻¹ in fruit-orchard-based systems. This provides a more defensible benchmark for the proposed models than assigning an arbitrary fodder yield to each individual combination (ICAR, 2026).

3.12 Economic interpretation

Thus, the income from each model should be calculated from the combined value of fruit + fodder + livestock products + tree biomass, rather than from fruit yield alone. The actual gross and net returns will depend on fruit price, yield, fodder utilization, livestock productivity, labour costs, irrigation expenditure and the age of the plantation. Therefore, for a review article, it is scientifically safer to describe these values as “indicative productivity and income potential” rather than presenting them as experimentally established economic returns.

4. Resource-use efficiency in hortisilvipasture systems

Hortisilvipasture systems improve resource utilization by combining fruit crops, multipurpose trees and pasture within the same land unit. The proposed models can utilize different soil layers, canopy levels and production periods, thereby generating several outputs from a single hectare. Such diversification can improve overall farm productivity compared with a single-component system (Dhyani and Handa, 2015; Rai *et al.*, 2020).

4.1 Land-use efficiency

Land-use efficiency is enhanced by utilizing the inter-row spaces of fruit trees for pasture production. The mango, jamun and bael models, with wider fruit-tree spacing, provide greater opportunity for buffel, Rhodes and Napier grasses. In the guava, pomegranate and lemon models, silvi-trees can mainly be maintained along boundaries and selected strips. Such vertical and horizontal integration allows fruit, fodder, biomass and livestock products to be obtained from the same hectare (Rai *et al.*, 2020; Dhyani *et al.*, 2020).

4.2 Water-use efficiency

Water-use efficiency depends on selecting compatible species and reducing competition between tree, fruit and pasture components. Deep-rooted species such as khejri, neem, babul and shisham can utilize deeper soil moisture, while grasses and fruit crops mainly exploit

upper soil layers. The ber–khejri–babul model therefore has potential for relatively dry environments. Appropriate spacing, mulching and moisture-conservation practices can further improve water availability. Research in silvipastoral systems has demonstrated that moisture-conservation practices influence soil-water availability and water-use efficiency (Kumar and Yadav, 2020).

4.3 Nutrient-use efficiency

Nutrient-use efficiency can be improved through recycling of leaf litter, root residues, pasture biomass and livestock manure. Subabul and gliricidia, included in several proposed models, can contribute nitrogen-rich biomass and improve nutrient cycling. Regular pruning and incorporation of tree biomass can return nutrients to the soil. Agroforestry research indicates that integration of woody perennials with crops and grasses can improve soil fertility and nutrient availability when systems are appropriately managed (Das, 2024; Prasad *et al.*, 2020) [4].

4.4 Light interception and canopy complementarity

The different vertical layers of hortisilvipasture allow more effective use of solar radiation. Fruit trees form the main canopy, silvi-trees occupy boundaries or selected strips, and pasture grasses utilize the lower layer. In mango, jamun and bael models, wider spacing can allow sufficient light penetration to the pasture component. In denser pomegranate and papaya systems, pruning and canopy management are important to reduce excessive shading. Agroforestry trees can also modify microclimate through changes in radiation, temperature and humidity (Alam *et al.*, 2020).

4.5 Biomass and fodder productivity

Buffel, Rhodes and Napier grasses provide fodder and ground cover, while subabul, gliricidia, siris and babul can provide additional tree fodder and biomass. The combination of pasture and fodder trees can increase total biomass production per unit area and support livestock production. Silviculture research in India has reported improvements in forage availability, biomass production and livestock productivity compared with degraded grazing systems (Rai *et al.*, 2020).

4.6 Nutrient recycling through livestock integration

Livestock provide an important link between pasture production and soil fertility. Grasses and tree fodder are converted into animal products, while manure can be returned to the horticultural and pasture components. In the mango, guava, pomegranate, custard apple and lemon models, livestock integration can therefore create a more circular production system. Such integration can improve biomass utilization, nutrient recycling and farm diversification (Rai *et al.*, 2020; Das, 2024) [4].

5. Contribution to farmer livelihoods

Hortisilvipasture can strengthen farmer livelihoods by combining fruit, fodder, livestock, timber and biomass production on the same hectare. The mango, guava, pomegranate and lemon models provide important cash income from fruits, while ber, aonla, custard apple and bael are particularly useful for dryland and processing-based diversification. Pasture grasses provide feed for livestock and can reduce expenditure on purchased fodder. Tree components such as subabul, gliricidia and neem provide additional biomass and farm products. Horti-pasture research has demonstrated its potential to improve food and fodder availability, employment and farm profitability in rainfed regions (Kumar *et al.*, 2012; Meena *et al.*, 2017) [5, 6].

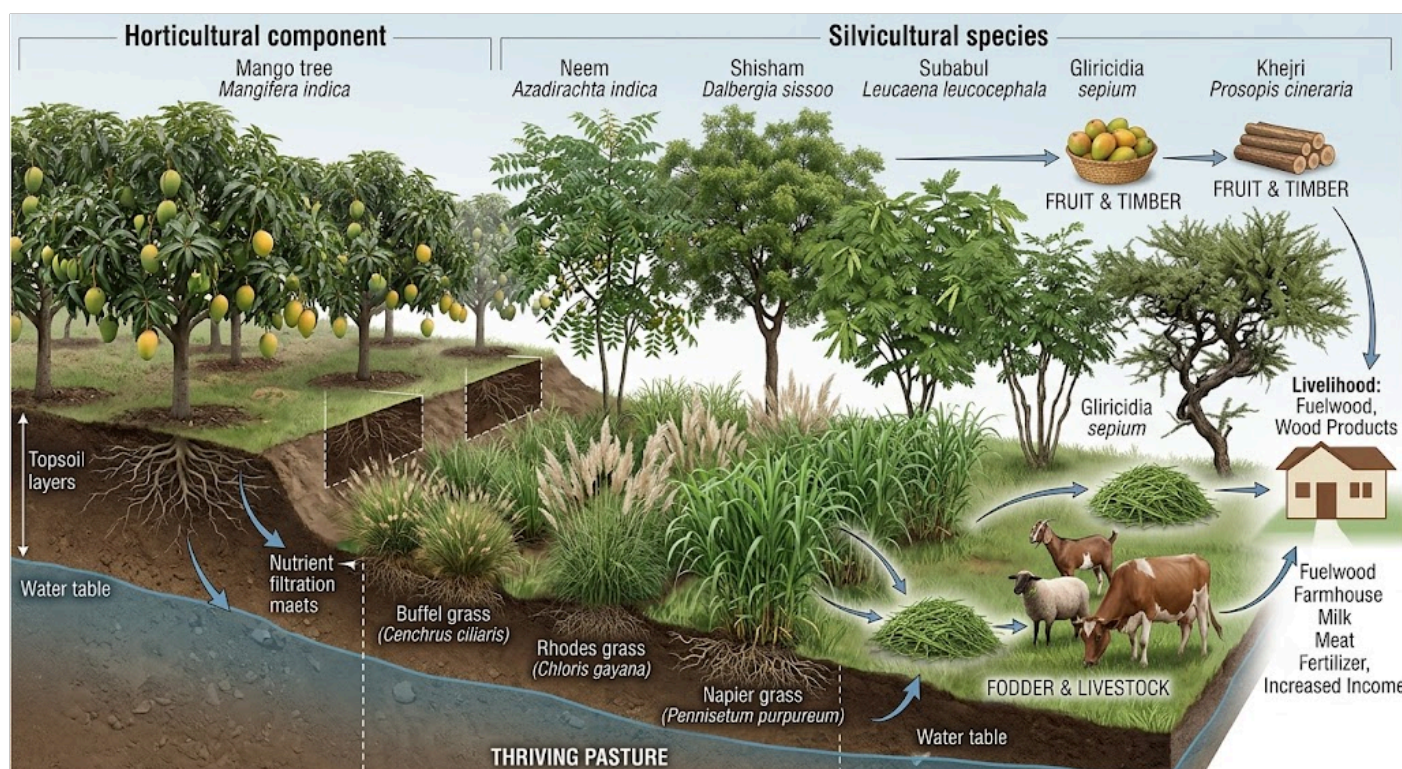


Figure 1. Mango-based hortisilvopasture model contribute to farmers livelihood

6. Ecosystem services and environmental benefits

The proposed models can provide several ecosystem services in addition to direct farm products. Fruit trees, silvi-trees and pasture grasses contribute to soil protection, organic matter addition, carbon storage, biodiversity and microclimate regulation. Tree litter and pasture residues can improve soil physical and biological properties, while tree roots help stabilize soil and reduce erosion. Carbon sequestration is an important benefit because agroforestry stores carbon in both above-ground biomass and soil. The magnitude of carbon storage varies with tree species, system design, site quality and previous land use (Dhyani *et al.*, 2016; Das, 2024) [7, 4].

7. Constraints and management challenges

Despite its potential, hortisilvopasture requires careful management because the different components may compete for water, nutrients, sunlight and physical space. Excessive silvi-tree density can reduce fruit production and pasture growth through shading and below-ground competition. In the pomegranate, lemon and papaya models, maintaining adequate light and moisture is particularly important. Labour requirements for pruning, fruit harvesting, pasture cutting and livestock management may also increase. Farmers may face difficulties in obtaining quality planting material and accessing suitable markets for diverse products. Location-specific planning and institutional support are therefore essential for successful adoption (Dhyani and Handa, 2015; Dhyani and Handa, 2014).

8. Research gaps and future perspectives

Further research is required to validate the proposed models under different agro-climatic conditions. Long-term experiments should determine optimum fruit-tree density, silvi-tree arrangement, pasture composition and irrigation requirements. More information is also needed on competition and complementarity for water, nutrients and light among the three components. Economic studies should assess production costs, labour requirements, market returns and benefit-cost ratios over the complete production cycle. Research should also quantify carbon sequestration, biodiversity and soil-health benefits. Site-specific and farmer-oriented models, supported by participatory

research, can improve adoption and long-term sustainability (Newaj *et al.*, Chaturvedi and Handa, 2008; Das, 2024) [4].

9. Conclusion

Hortisilvopasture offers a promising approach for diversified and sustainable land management, particularly where farmers need simultaneous production of food, fodder and other farm resources. The ten proposed models demonstrate how fruit crops can be combined with multipurpose trees and pasture grasses to generate multiple outputs from one hectare. Their potential benefits include improved resource utilization, diversified income, livestock support, soil improvement and carbon sequestration. However, the proposed combinations should be regarded as conceptual models requiring field validation rather than universal recommendations. Successful adoption will depend on appropriate species selection, planting geometry, water management, market access and farmer-oriented technologies (Rai *et al.*, 1999; Dhyani, 2020) [8, 2].

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