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Cultivation of *Moringa oleifera* in agroforestry for leaf production

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Abstract
Moringa oleifera is a tropical species that thrives in temperatures between 25-35°C, with a tolerance range of up to 48°C. While it can withstand cooler temperatures, frost can cause damage to the plant. The leaves, fruits, flowers, and pods of *M. oleifera* are valued for their high nutritional and medicinal properties. Additionally, Moringa seed extracts have been found effective as a primary coagulant in water treatment, in addition to antimicrobial activity. Notably, the leaves have gained commercial attention in recent years due to their rich nutrient profile, cytokinin-like compounds, and medicinal properties, including hypo-cholesterolemic and thyroid-regulatory effects. There is a need to raise awareness and encourage farmers and decision makers to adopt Moringa on marginal and degraded lands with changing climate risks. Leaves can be harvested when plants reach 1.5-2.0 m in height, typically after a minimum of one year. Harvesting involves plucking leaves and removing branches from the stem. Due to its high content of nutrients, especially proteins and bioactive compounds, it can be used as an alternative to conventional ruminant feed materials.

Keywords: Moringa, cultivation, leaves, nutrients, demand, economics, rural livelihood

Introduction

Moringa oleifera is a small to medium-sized tree, typically growing up to 10-12 meters in height, characterized by a spreading, open crown with drooping, fragile branches, and feathery, tripinnate foliage. Native to the Himalayan foothills of South Asia, *M. oleifera* is commonly found in regions spanning from northeastern Pakistan (33°N, 73°E) to northern West Bengal, India, and northeastern Bangladesh, typically thriving at elevations ranging from sea level to 1,400 m on recent alluvial land or near riverbeds and streams.

The leaves, fruits, flowers, and pods of *M. oleifera* are valued for their high nutritional and medicinal properties (Ramachandran *et al.*, 1980) [7]. The kernel contains 30-42% oil, which is utilized as a lubricating oil and edible vegetable oil (Ferrao and Ferrao, 1970) [3].

Additionally, Moringa seed extracts have been found effective as a primary coagulant in water treatment, in addition to antimicrobial activity (Muyibi and Akif, 2003) [6]. Moringa wood, despite being soft and lightweight, has various practical applications, including fuel-wood, light construction, and pulp for paper production. It can also serve as a source of blue dye (Fig. 1). Although not suitable for high-end furniture, it can be used for crafting simple items like mortars or paneling. Notably, the leaves have gained commercial attention in recent years due to their rich nutrient profile, cytokinin-like compounds, and medicinal properties, including hypo-cholesterolemic and thyroid-regulatory effects (Mishra *et al.*, 2012, 2013; Singh and Singh, 2015) [4, 5, 8]. Due to this, the demand for its leaves is increasing day by day in domestic and industrial sectors.

Fig 1: Plant parts of *Moringa oleifera*

Moringa based agroforestry model incorporating growing of moringa for leaf production is a profitable preposition for farmers. Building on the success of *M. oleifera* intercropping with sunflower and maize, recent studies have demonstrated that integrating vegetable crops such as tomato, radish, brinjal, and pointed gourd can further

enhance income through optimal land utilization. It also promotes growth of the main crop by suppressing weeds and improving soil health, thereby increasing overall productivity. There is a need to raise awareness and encourage farmers and decision makers to adopt Moringa on marginal and degraded lands with changing climate risks (Atreya *et al*. 2023) [1].

Moringa cultivation: Essential components and methods

Climate and soil type

M. oleifera is a tropical species that thrives in temperatures between 25-35°C, with a tolerance range of up to 48°C. While it can withstand cooler temperatures, frost can cause damage to the plant. The species exhibits drought tolerance and can grow in areas with variable rainfall, although optimal growth occurs in regions with an average annual rainfall of 250-1500 mm. In terms of altitude, it grows best up to 600 m above sea level, but can also thrive at elevations up to 1200 m. *M. oleifera* can be cultivated in a wide range of soils, including weak and less fertile land, and can remain green throughout the year without irrigation. While it can tolerate barren and uncultivated conditions, commercial cultivation is best suited for loamy and clay soils. In contrast, red soils may require additional fertilizers and are more susceptible to termite infestations. The ideal soil pH range for Moringa cultivation is 6-7.5, although it can grow in soils with pH values between 5.0 and 9.0. However, waterlogging and extreme drought conditions are detrimental to its growth.

Variety selection

The Moringa variety has internal genetic variation due to its nature like leaves, flowers and better quality of pods. Desirable traits include broad, dark green leaves, long and tender pods, bushy growth habit, and rapid regrowth of new branches after pruning. To optimize cultivation, it is essential to select a variety that is well-suited to local growing conditions, taking into account factors such as climate, soil type, and pest/disease pressure. For leaf production, traditional or specific varieties such as PKM1, PKM2, ODC, and ODC 3 can be used.

Nursery production

M. oleifera seedlings can be grown in various containers, including root trainers, pots, polythene bags, or beds. Seeds are best germinated in partial shade, ideally with 50% shade cover. Polybags with dimensions of 18 cm height and 12 cm width are recommended. A well-draining soil mixture, consisting of a 3:1 ratio of soil to sand, is ideal for optimal growth. Two to three seeds should be sown per bag at a depth of 1-2 cm. The soil should be maintained at a consistently moist level, avoiding waterlogging. Germination typically occurs within 5-12 days, depending on seed age and pre-treatment methods.

After germination, thin the seedlings to one per polybag by removing excess plants. When the seedlings reach a height of 60-90 cm, they are ready for transplanting. Before transplanting, gently tear or cut a hole in the bottom of the polybag to allow the roots to emerge. Ensure that the soil is firmly packed around the roots after transplanting to prevent air pockets. To enhance germination rates, seeds can be pre-treated by soaking them in water overnight, peeling the seed coat, or planting only the kernels. For seed bed cultivation, sow 2-3 seeds per furrow, spaced 10-25 cm apart. Transplant the seedlings after approximately one month or when they reach a height of 20-30 cm. Carefully dig up the seedlings using a trowel to minimize root damage. Immediately place the bare-rooted plants in a bucket of water and transplant them as soon as possible to ensure optimal survival.

Field preparation and planting

Prior to cultivation, ensure that the field is protected from cattle through fencing or other effective measures. For leaf production, dense and direct seeding is the most suitable method. To promote successful cultivation of M. oleifera, incorporate 4-6 tons of well-rotted cow dung or 10-12 quintals of vermin-compost into the soil during field preparation. For organic farming systems, apply 25 kg of organic fertilizer or bio NPK per acre. To manage termite infestations, consider using 2-3 quintals of neem cake or 2 kg of Beauveria bassiana per acre, both of which have been shown to be effective. Rows should be spaced 3 m apart in the prepared field, allowing for easy access to plants and facilitating irrigation through furrows between the rows.

Planting time

The appropriate time for planting drumstick is February – March and July – August. However, with adequate irrigation, planting can be done in other seasons, except during the winter months of December-January.

Method of transplantation

Direct sowing of seeds: M. oleifera can be propagated through direct seeding, where seeds are planted directly into the soil. A seed rate of 500-600 g/ha is typically sufficient. However, it's essential to note that Moringa seeds have a limited viability period, with high germination rates initially, but potentially dropping to zero after approximately two years. Prior to planting, seeds are soaked in water overnight to enhance germination. Seed treatment with *Trichoderma* (7-10 g/kg seed) reduces the risk of fungal infections. Seeds are planted 1 foot apart and 2 cm deep, followed by light irrigation. *M. oleifera* is relatively drought-tolerant and requires minimal watering, but consistent soil moisture is essential. Germination typically occurs within 5-12 days, and seeds that fail to germinate within 15 days should be replanted. In summer months, irrigation at 15-day intervals can promote faster growth.

Use of stem cuttings: *M. oleifera* can be readily propagated using stem cuttings. This method is often preferred over seed propagation, which can result in delayed maturity and lower quality seeds or pods. While cuttings promote faster growth, the resulting trees may develop a shallow root system, rendering them more vulnerable to moisture stress and wind damage. For successful propagation using stem cuttings, select woody branches from mature trees (at least 1 year old) with a length of 1-1.5 m and a circumference of 4-10 cm. In North India, the spring season (February-March) is optimal for rooting branch cuttings, outperforming summer, rainy, and winter seasons. Treatment with the plant growth regulator IBA (50 ppm for 24 h) can enhance root growth percentage. However, larger cuttings have been found to root successfully without hormonal treatment (Sanjay Singh *et al*., 2012) [4]. Before planting, cuttings can be shade-dried for 3 days. They can then be planted directly in the field or in containers such as plastic pots or polybags

in a nursery or screen house. For direct planting, use a well-draining, lightly sandy soil to support optimal root development. Nursery-grown plantlets are typically ready for field transplanting after 2-3 months.

Transplantation: Prior to transplanting, prepare pits of 50x50x50 cm by filling each with 4-5 kg of well-rotted cow dung and 10 g of Furadan mixed into the soil. At transplanting, apply a basal dose of fertilizers, consisting of one-fourth of the recommended nitrogen, full phosphate, and half potash. For leaf production, *M. oleifera* can be planted using two different spacing arrangements, as illustrated (Fig 2.) The choice of spacing depends on the farming system: closer spacing (left method) for intensive farming and wider spacing (right method) for intercropping.

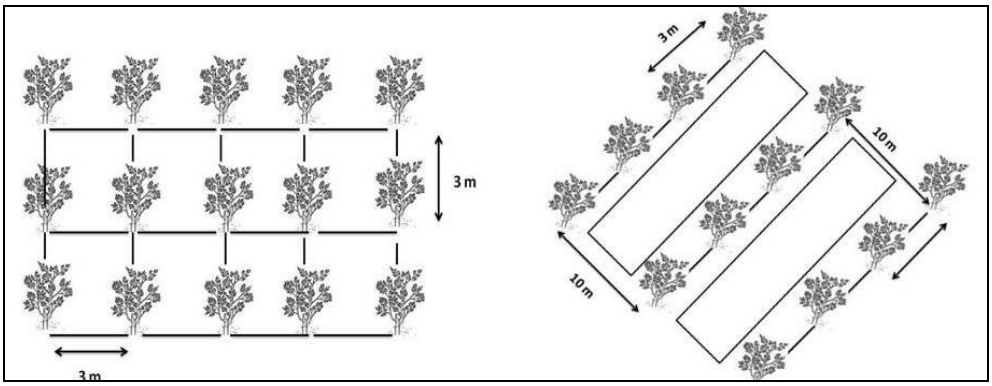

Fig 2: Spacing design for *M. oleifera* cultivation

M. oleifera can thrive in a wide range of soils with minimal fertilization due to its extensive and deep root system, which efficiently absorbs nutrients. For optimal growth and yield, apply fertilizers at planting time. Create a basin around the base of each plant and apply approximately 300 g of a nitrogen-rich fertilizer per tree. Alternatively, use compost or well-rotted cow dung manure at a rate of 1-2 kg per tree if synthetic fertilizers are not available. After three months of planting, apply 100 g of urea, 100 g of superphosphate, and 50 g of potash per pit. Repeat the application of 100 g of urea per pit after another three months. Alternatively, research has shown that organic Moringa farming can achieve comparable yields without synthetic fertilizers by using 15 kg of cow dung manure per pit, along with *Azospirillum* and phosphate-solubilizing bacteria (PSB) at a rate of 5 kg per hectare.

Crop management

Irrigation: Newly transplanted trees should be irrigated immediately after planting to facilitate rapid root establishment. In arid climates, regular watering is essential during the first two months. Once established, *M. oleifera* is highly drought-tolerant and typically does not require supplemental irrigation. However, if prolonged wilting occurs, watering may be necessary to prevent stress.

Weed Control: Prior to planting, thoroughly till the soil to minimize weed pressure. Apply a layer of straw mulch around the base of each young tree to suppress weed growth. Maintain weed-free conditions through regular cultivation of beds and inter-row spaces.

Pruning: Pruning is essential for optimizing Moringa yield, promoting branching, and facilitating leaf harvesting. If the main stem is allowed to grow unchecked, it will produce fewer leaves. To encourage branching, prune the top shoots when the tree reaches 1-2 m in height, using a sharp knife, axe, or saw to make clean cuts. New branches will emerge just below the cut site. Subsequent pruning of branch tips will promote a bushy habit, increasing leaf production and accessibility. An alternative pruning strategy involves cutting each branch back by approximately 50% (to 30 cm) when it reaches 60 cm in length, promoting a multi-branched, bushy habit. For older or unproductive trees that have become too tall, drastic pruning to ground level can stimulate new shoot growth from the base, rejuvenating the plant.

Fig 2: *Moringa oleiera*: famers field for intensive leaf production

Disease and pest control: While *M. oleifera* is generally resilient to pests and diseases, it can be susceptible to certain issues. For example, Diplodia root rot can occur in waterlogged soils, leading to severe wilting and plant mortality. Fungal diseases can be a significant concern in intensive Moringa cultivation, causing brown spots on leaves that can spread, leading to yellowing and defoliation. Key pathogens include *Cercospora*, *Septoria lycopersici*, and *Alternaria solani*, with the latter causing distinctive angular, dark-brown leaf spots and branch lesions. Early detection is challenging, and once symptoms are visible, leaf removal may be necessary. To manage the disease, monitor for periods of symptom occurrence in the first year and take preventative measures in subsequent seasons. Effective and affordable fungicides for treatment include mancozeb and mancozeb-based products.

Common insect pests of Moringa include grasshoppers, crickets, and caterpillars, notably the hairy caterpillar (*Eupterote mollifera*), which can cause significant defoliation. These insects feed on various plant parts, including leaves, buds, flowers, shoots, fruits, and seeds, disrupting sap flow and causing damage. Outbreaks often occur in dry areas during the early dry season, when Moringa's lush foliage becomes a primary food source. A potential management strategy involves pruning trees to remove visible green parts, reducing attractiveness to these pests. Mite infestations are more prevalent in dry and cool weather, causing leaf yellowing, although plants often recover as temperatures rise. Other potential pests include termites, aphids, leaf miners, whiteflies, and caterpillars. For termite management, several organic approaches can be employed, including incorporating neem seed tablets into the soil, applying castor oil around the base of the stem, and using ash piles at the base of the plant. Chemical pest control should be employed judiciously, targeting severe infestations and selecting pesticides that are specific to the pest, minimizing harm to beneficial organisms. Opt for pesticides with short residual activity to reduce environmental impact. If synthetic insecticides are necessary, opt for relatively low-toxicity options like pyrethroids, which maintain efficacy for 20 days or more, even in challenging environmental conditions. Pyrethroids are effective against Lepidoptera eggs. To ensure safety, observe a minimum pre-harvest interval of 7 days after application. Limit pesticide reapplications to 2-3 times per season to minimize environmental impact and prevent resistance development.

Harvesting

Moringa plants can exhibit rapid growth under optimal conditions. Leaves can be harvested when plants reach 1.5-2 m in height, typically after a minimum of one year. Harvesting involves plucking leaves and removing branches from the stem. Pruning young shoot tips and making strategic cuts along main branches encourages lateral branching and promotes new shoot development. Harvest using a sharp tool, such as a sickle, at a height of 25-30 cm above ground level. Best practices include harvesting in the morning, bundling cut plants, and transporting them to a treatment center promptly (Mishra *et al*., 2012) [4]. Following harvest, apply organic fertilizer as needed and irrigate the field to support regrowth. For plants grown at wider spacing and higher densities, harvest by cutting stems 10-20 cm above ground level. To process dried leaves for powder production, separate the leaves from their woody stems, as the stems can be easily removed during sifting, resulting in a higher-quality powder. For fresh market production, bundle cut leaves and store them in a shaded area to preserve freshness. Due to their high moisture loss rate, people harvest Moringa leaves early in the morning and ideally sells them the same day (Fig. 3). In situations where nutrient deficiencies are critical, leaves can be dried in the sun for a few hours and consumed as a nutrient-rich supplement.

Processing

Sort and remove diseased and damaged leaves from the bundles. Then, immerse the leaves and branches in a 1% saline solution (10 g salt/L water) for 5 minutes, followed by two rinses with clean water. After thorough washing, allow the material to drain excess water before drying in a controlled environment, such as a drying room or a mechanical dryer. The dried leaves are ground into a powder using a mill, with the fineness determined by the sieve size. For Moringa leaf powder, recommended sieve sizes range from 0.2 mm to 1.0 mm. After grinding, the powder is heated to 50°C for 30 minutes to eliminate moisture generated during processing. The dried powder is then stored in airtight containers to maintain quality. Storage conditions should be clean, dry, and free from contamination to preserve the powder's integrity.

Assessment of production and sales

One acre of Moringa cultivation can yield 5-6 harvests per year, with the first harvest producing 100-150 kg of leaf powder and subsequent harvests yielding 200-300 kg each. This translates to an average annual production of 1,200-1,500 kg of Moringa leaf powder per acre. With a market price of ₹80-90 per kg, the estimated annual revenue is ₹96,000 to ₹1,35,000. After deducting costs, the net profit can range from ₹64,000 to ₹1,00,000 per annum. The benefit-cost ratio of this model is approximately 3.5, although this may vary depending on the region and choice of intercrops. However, leaf yield is influenced by factors such as seed quality, soil conditions, fertilizer application, irrigation, and environmental conditions. Additionally, market value can fluctuate over time, affecting profitability.

Mixed crop cultivation with Moringa

Moringa can be effectively intercropped in agroforestry systems to enhance crop performance and improve soil health. It’s low-input requirements make it an ideal candidate for intercropping with drought-tolerant crops that share similar soil preferences. Suitable companion crops include maize, sunflower, cassava, pumpkin, tomato, radish, pulses and groundnut, and various shade-tolerant vegetables. Sunflower is particularly beneficial for weed suppression. Ongoing research explores agroforestry models combining Moringa with legumes (beans, peas, peanuts), millets (jowar, bajra, ragi) and cereals. A recommended Agri-Silvi-Horticulture system integrates maize, *Casuarina equisetifolia* and Moringa, showcasing the potential for diversified and sustainable farming practices. Vine crops like bitter gourd, ridge gourd, and beans can be trained on mature Moringa trees, providing additional income streams. However, young trees should be protected from vine growth.

Impetus on Moringa in Uttar Pradesh

India dominates global Moringa production, particularly in the cultivation of Moringa leaves, contributing an estimated 80% to the world's supply. In recent years, rising demand for Moringa-based products has fueled a significant expansion in cultivation, extending beyond its traditional southern strongholds - such as Tamil Nadu, Karnataka, Kerala, and Andhra Pradesh into new regions across the country, particularly Uttar Pradesh, Bihar, Jharkhand. *M. oleifera* cultivation is gaining momentum in Uttar Pradesh, particularly after the state government's initiative to promote large-scale cultivation as part of its strategy for nutrition security and sustainable agriculture. This initiative is being implemented through home garden schemes and targeted support in aspirational districts, focusing on low-income households and beneficiaries of housing missions. Drumstick cultivation requires minimal irrigation and labor, making it manageable for family-run farms. Its low fertilizer needs further reduce operational costs. Given the small landholdings of most farmers (less than 1 ha), transporting produce to local markets is also feasible, adding to the crop's practicality for small-scale farmers. Overall, *M. oleifera* cultivation has significant potential in Uttar Pradesh, and with the right support and initiatives, it can become a valuable crop for farmers and contribute to the state's agricultural development. Due to its high content of nutrients, especially proteins and bioactive compounds, it can be used as an alternative to conventional ruminant feed materials (Dhillon *et al*. 2023) [2].

Economics of cultivation

Moringa is commercially cultivated for its leaves and pods. If the annual profit is solely from the leaves per hectare, 2,500 trees can be planted at a distance of 2 x 2 meters. On an average, approximately 0.3 quintals of fresh leaves per tree yield 75 tons of produce per year from the total area. Similarly, if the production of pods is to be achieved, approximately 280 trees can be planted at a distance of 6 x 6 meters per hectare. Approximately 14 tons of pods and 0.5 quintals of leaves can be obtained per year from the total area. The cost of planting each tree is approximately ₹40 to ₹45. Annual profit of Rs. 1.5-2.0 Lakh from the leaves and ₹1.0 to 1.25 lakh from the pods per hectare may be net gain for the farmers/tree growers.

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