

VEGETATIVE PROPAGATION OF ANNUAL MORINGA (*MORINGA OLEIFERA* LAM.): A REVIEW OF PROPAGATION METHODS, AUXIN RESPONSE AND NURSERY MANAGEMENT

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ABSTRACT

Moringa oleifera Lam., commonly known as drumstick tree or murungai, is an important multipurpose vegetable and tree crop cultivated extensively in tropical and subtropical regions. In India, annual cultivars such as PKM 1 and PKM 2 are commercially important because of their productivity and suitability for intensive cultivation. Although moringa is commonly propagated through seed, seed-derived plants may exhibit variability in growth and other desirable characteristics. Vegetative propagation provides an alternative approach for multiplying selected mother plants and producing relatively uniform planting material. This review synthesizes recent research on hardwood cuttings, semi-hardwood cuttings, air layering, grafting and other clonal propagation approaches in *M. oleifera*, with particular emphasis on annual cultivars PKM 1 and PKM 2. Recent experimental evidence demonstrates that propagation success is influenced by cultivar, propagule maturity and size, propagation method, auxin concentration, rooting medium and nursery environment. Among the conventional methods evaluated in annual moringa, air layering has shown particularly promising results. PKM 2 air layering treated with 4000 ppm indole-3-butyric acid (IBA) recorded early rooting and sprouting together with greater root and shoot biomass, whereas semi-hardwood cuttings treated with 1500 ppm IBA produced the longest roots in PKM 2. Recent studies have additionally demonstrated the potential of shorter hardwood cuttings, grafting, basal branch cuttings and improved nursery media. The review highlights the need for cultivar-specific propagation protocols, multi-season validation, economic assessment and large-scale nursery testing. An integrated approach combining elite mother-plant selection, standardized propagule characteristics, optimized auxin treatment, suitable rooting media, effective hardening and field validation can contribute to the commercial production of vigorous and uniform annual moringa planting material.

KEYWORDS: *Moringa oleifera*, annual moringa, PKM 1, PKM 2, vegetative propagation, air layering, hardwood cutting, semi-hardwood cutting, IBA, clonal propagation

1. INTRODUCTION

Moringa oleifera Lam. is an important vegetable and multipurpose tree crop belonging to the family Moringaceae. Commonly known as drumstick tree and as “Murungai” in Tamil, the species is native to the Indian subcontinent and is now cultivated widely in tropical and subtropical regions. It is a fast-growing plant valued for its leaves, flowers, tender pods and seeds, which are used as food and for several other purposes (Leone et al., 2015; Saini et al., 2016). The nutritional importance of moringa is associated with the presence of proteins, vitamins, minerals, carotenoids and other bioactive compounds in its edible parts (Gopalakrishnan et al., 2016; Saini et al., 2016). Recent evaluation of moringa genotypes has also demonstrated considerable variation in nutritional composition, indicating the importance of genotype selection for quality-oriented production. Attri and Kumar (2025), for example, reported substantial variation among six *M. oleifera* genotypes in proximate composition, vitamins and mineral nutrients, with PKM 1 and PKM 2 among the evaluated genotypes. Similar studies were carried out by various scientist viz., proximate composition and nutrient variation under different environments (Asante et al. 2014; Moyo et al. 2011; Saini et al. 2011; Fahey, 2005; Stohs and Hartman, 2015) genetic variability, leaf composition, phytochemicals and nutritional properties (Leone et al. 2015), phenolics, flavonoids, vitamins, minerals and other bioactive compounds (Saini et al. 2016), antioxidant and health-related properties (Vergara-Jimenez et al. 2017)

In addition to its vegetable use, moringa has applications as livestock feed, green manure, seed-based water purification material, cosmetic oil and other multipurpose products. India is an important producer of moringa, and Tamil Nadu is one of the major production regions, particularly for annual moringa cultivation. The adoption of annual cultivars such as PKM 1 and PKM 2 has increased the importance of efficient planting-material production. Vegetative propagation provides an opportunity to multiply selected mother plants and maintain desirable characteristics in the resulting planting material. Propagation methods investigated in moringa include hardwood cuttings, semi-hardwood cuttings, air layering, grafting and micropropagation (Marfori, 2011; Saini et al., 2012; Coles and du Toit, 2020; Kutty and Pradeepkumar, 2025). Recent research has substantially expanded the understanding of vegetative propagation in moringa. Balakumbahan et al. (2024) evaluated hardwood cuttings, semi-hardwood cuttings and air layering in PKM 1 and PKM 2 under different IBA concentrations. Their results demonstrated strong interactions among cultivar, propagation method and auxin concentration.

Kutty and Pradeepkumar (2025) subsequently demonstrated that hardwood cuttings of only 55–60 cm could perform comparably to 1.5 m cuttings and that grafting could provide an efficient vegetative propagation approach. Their findings are particularly relevant to nursery multiplication because shorter cuttings can increase the number of propagules obtained from a mother plant. More recently, Muniandi et al. (2025) developed an integrated propagation framework involving superior genotype selection, stem cuttings and air layering. Their results showed that cutting position and diameter affected regeneration, while air layering using Jiffy-7 pellets achieved high rooting and survival. Therefore, efficient vegetative propagation of annual moringa requires consideration of cultivar, propagule characteristics, propagation technique, auxin concentration and nursery environment. The present review summarizes the available evidence and identifies practical propagation approaches and research priorities for commercial production of annual moringa planting material.

2. Importance of Annual Moringa Cultivars

Annual moringa cultivars such as PKM 1 and PKM 2 are important commercial cultivars in Tamil Nadu. Their popularity is associated with their yield potential, suitability for intensive cultivation and adaptation to commercial production systems. Balakumbahan et al. (2024) specifically investigated PKM 1 and PKM 2 to standardize vegetative propagation and improve crop uniformity. The production of high-quality planting material is an important component of successful commercial cultivation. Uniform plants facilitate synchronized crop establishment and simplify irrigation, nutrient management, pruning and harvesting operations. Conversely, variability in plant establishment and early growth may result in uneven crop development. The importance of genotype selection has also been emphasized by recent studies. Muniandi et al. (2024) investigated genotype screening and clonal propagation for superior *M. oleifera* planting material, while Muniandi et al. (2025) subsequently integrated genotype selection with propagation strategies.

For commercial nursery production, an efficient propagation technique should ideally provide:

- high rooting percentage;
- rapid root initiation;
- adequate root length;
- greater root biomass;
- early shoot emergence;
- vigorous shoot development;
- high transplanting survival;
- uniform plant growth; and
- acceptable production cost.

These parameters should be considered together because the treatment that produces the earliest roots may not necessarily produce the longest roots or greatest root biomass. The results reported by Balakumbahan et al. (2024) clearly demonstrate this distinction.

3. Vegetative Propagation and Its Advantages

Seed propagation remains a common method of moringa establishment. However, sexual propagation may result in variation among seedlings. Vegetative propagation can reduce this variation by multiplying selected mother plants and thereby producing relatively uniform planting material.

The principal advantages of vegetative propagation in annual moringa include:

1. Maintenance of desirable plant characteristics: Selected mother plants can be multiplied while retaining important phenotypic characteristics.
2. Production of relatively uniform planting material: Clonal propagation can improve uniformity in nursery growth and subsequent field establishment.
3. Rapid multiplication of selected plants: Superior mother plants can be multiplied without relying exclusively on seed production.
4. Potential for early establishment: Properly rooted vegetative propagules can establish rapidly following transplanting.
5. Improved crop uniformity: Uniform planting material can facilitate synchronized crop-management operations.
6. Efficient multiplication of elite genotypes: Combining superior genotype selection with clonal propagation provides an approach for producing high-quality planting material (Muniandi et al., 2024, 2025).

However, vegetative propagation requires careful management of mother plants, propagule selection, rooting conditions, hardening and nursery management. The success of propagation is therefore determined by a combination of biological and environmental factors.

4. Major Vegetative Propagation Methods

4.1 Hardwood Cuttings

Hardwood cuttings are prepared from mature branches and represent one of the simplest vegetative propagation methods in moringa. Balakumbahan et al. (2024) evaluated hardwood cuttings approximately 25–30 cm long and 2–3 cm thick with at least two to three nodes. The basal portion was treated with different concentrations of IBA before planting in a rooting medium consisting of sand, vermicompost and soil. Hardwood cuttings have the advantage of utilizing mature stem material with considerable stored reserves. In the study of Balakumbahan et al. (2024), hardwood cuttings showed favourable shoot dry matter and dry shoot-to-root responses under selected treatments. However, rooting performance varied according to cultivar and IBA concentration. Similar studies was done various scientists viz., Netam et al.(2018), Makwan et al. (2024), Keerthivasan et al. (2024).

Recent research suggests that hardwood cutting length can also be reduced without necessarily compromising propagation performance. Kutty and Pradeepkumar (2025) reported that 55–60 cm hardwood cuttings produced sprouting and root and shoot growth comparable to 1.5 m cuttings. Shorter cuttings could consequently increase the number of propagules obtained from a mother plant. Santoso and Jayaputra (2026) further demonstrated that cutting length and nursery medium interactively influence seedling establishment and biomass production. Their study found that 60 cm cuttings generally promoted rapid sprouting and higher shoot and root biomass, whereas 40 cm cuttings produced high establishment, and compost-amended media improved establishment compared with topsoil alone.

Thus, hardwood cuttings remain a promising low-cost propagation method, but cutting length and physiological maturity need to be standardized for particular production objectives.



4.2 Semi-Hardwood Cuttings

Semi-hardwood cuttings are obtained from young but sufficiently mature branches and represent an intermediate propagule type between soft and hardwood material. Balakumbahan et al. (2024) evaluated semi-hardwood cuttings of approximately 25–30 cm length and 1–2 cm thickness containing two to three nodes. Among the treatments evaluated, PKM 2 semi-hardwood cuttings treated with 1500 ppm IBA recorded the highest root length of 16.30 cm and the highest shoot dry matter content of 61.99%. These findings demonstrate that semi-hardwood cuttings can be highly responsive to moderate auxin concentrations. However, propagation success depends on the physiological maturity of the branch, cutting size, season and environmental conditions. Similar studies was undergone by Veeraragavathatham et al. (1985), Palai et al. (2024) and Makwana et al. (2024).



4.3 Air Layering

Air layering involves inducing roots on a branch while it remains attached to the mother plant. This technique has an important physiological advantage because the developing propagule continues to receive water and mineral nutrients through the parent plant during root initiation. Coles and du Toit (2020) demonstrated the potential of

open air layering in *M. oleifera*. Balakumbahan et al. (2024) subsequently evaluated IBA-assisted air layering in PKM 1 and PKM 2.

PKM 2 air layering treated with 4000 ppm IBA produced particularly strong results. It recorded:

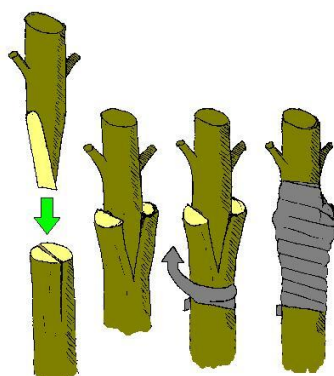
- minimum days to rooting: 17.99 days;
- minimum days to sprouting: 9.85 days;
- highest root fresh weight: 2.70 g;
- highest root dry weight: 1.80 g;
- highest shoot fresh weight: 12.52 g; and
- highest shoot dry weight: 6.90 g.

These results indicate that air layering combined with 4000 ppm IBA was particularly effective for rapid rooting and vigorous early growth in PKM 2. Muniandi et al. (2025) also reported strong performance of air-layered shoots, with Jiffy-7 pellets producing high root number, root length and survival in their integrated propagation study. Air layering therefore appears particularly suitable for multiplying selected elite plants where propagation quality is more important than maximizing the number of propagules per mother plant.



5. Grafting and Other Clonal Propagation Approaches

Although hardwood cuttings, semi-hardwood cuttings and air layering are the major conventional methods considered for annual moringa, recent studies indicate that grafting can also contribute to vegetative propagation. Kutty and Pradeepkumar (2025) evaluated different rootstocks for grafting the high-yielding moringa variety 'Anupama'. The highest graft success was obtained when 'Anupama' itself was used as rootstock, followed by *Moringa stenopetala*. The study reported graft compatibility between *M. oleifera* and *M. stenopetala*, representing an additional opportunity for vegetative propagation and rootstock utilization. Micropropagation also provides an alternative approach where rapid multiplication of selected material is required. Earlier studies have demonstrated regeneration of *M. oleifera* through tissue culture and direct organogenesis (Marfori, 2011; Saini et al., 2012; Zhang et al., 2017). Such approaches may be particularly valuable for conservation and rapid multiplication of elite genotypes, although their cost and technical requirements are generally higher than those of conventional cuttings.



6. Role of IBA in Vegetative Propagation

Indole-3-butyric acid (IBA) is widely used to promote adventitious root formation in vegetative propagation. In annual moringa, Balakumbahan et al. (2024) evaluated IBA at 0, 1500, 2500 and 4000 ppm in combination with three propagation methods and two cultivars. The study used a factorial experimental design involving cultivar, propagation method and IBA concentration. The response to IBA was not uniform across cultivars or propagation methods. Important observations included:

- 1500 ppm IBA was particularly effective for root length in PKM 2 semi-hardwood cuttings.
- 4000 ppm IBA promoted early rooting and greater root biomass in PKM 2 air layers.

- 4000 ppm IBA produced the highest root dry matter content in PKM 1 air layers.
- IBA concentration also affected shoot-growth characteristics.

Therefore, an optimum IBA concentration cannot be recommended independently of cultivar and propagation method. The results suggest that moderate IBA concentration may be sufficient for some cutting types, whereas air layering may respond favourably to higher concentrations. The use of different auxins has also been reported in moringa; therefore, future studies should compare IBA with other rooting stimulants under standardized conditions. Similar studies were done by many scientists *viz.*, Veeraragavathatham et al. (1985), Nagaraja et al. (1991), Singh et al. (2001), Silva (2012), Netam et al. (2018) and Makwana et al. (2024).

7. Rooting Behaviour

Rooting is a critical stage in vegetative propagation because root quality directly affects subsequent hardening and transplanting success.

7.1 Root initiation

PKM 2 air layers treated with 4000 ppm IBA required only 17.99 days for root initiation, indicating rapid rooting under this treatment.

7.2 Root length

PKM 2 semi-hardwood cuttings treated with 1500 ppm IBA produced the maximum root length of 16.30 cm. The treatment producing maximum root length differed from that producing the earliest rooting, demonstrating that these parameters should be evaluated separately.

7.3 Root biomass

PKM 2 air layers treated with 4000 ppm IBA recorded 2.70 g root fresh weight and 1.80 g root dry weight. Greater root biomass is generally desirable because it provides a stronger foundation for plant establishment following transplanting.

7.4 Root dry matter

PKM 1 air layering with 4000 ppm IBA recorded the highest root dry matter content of 70%. This demonstrates that the response of the same auxin concentration can differ between cultivars. Overall, rooting performance should be assessed using a combination of rooting time, root length, root number, fresh weight, dry weight and survival rather than a single parameter.

8. Shoot Growth and Establishment

Root formation alone does not guarantee successful propagation. Vigorous shoot development is essential for hardening and field establishment. PKM 2 air layering with 4000 ppm IBA produced the earliest sprouting at 9.85 days and the highest shoot fresh and dry weights of 12.52 and 6.90 g, respectively. PKM 2 semi-hardwood cuttings treated with 1500 ppm IBA recorded the highest shoot dry matter content of 61.99%. In PKM 1, hardwood cuttings treated with 4000 ppm IBA produced the highest dry shoot-to-root ratio of 9.19. These differences demonstrate that maximum shoot biomass, dry matter accumulation and shoot-to-root ratio are not necessarily associated with the same treatment. Therefore, a comprehensive propagation assessment should integrate root and shoot characteristics.

9. Interaction Between Cultivar, Propagation Method and IBA

The available evidence demonstrates a clear interaction among:

Cultivar × Propagation method × IBA concentration

The responses of PKM 1 and PKM 2 were not identical. Similarly, the most effective IBA concentration varied according to propagation method and the growth parameter evaluated.

Cultivar	Propagation method	IBA concentration	Major response
PKM 1	Air layering	4000 ppm	Highest root dry matter (70%)
PKM 1	Hardwood cutting	4000 ppm	Highest dry shoot-to-root ratio (9.19)
PKM 2	Semi-hardwood cutting	1500 ppm	Maximum root length (16.30 cm)
PKM 2	Air layering	4000 ppm	Early rooting and sprouting; highest root and shoot biomass

These findings indicate that a single IBA recommendation for all annual moringa cultivars and propagation methods would oversimplify the experimental response. Similar studies carried out by various scientists *viz.*, Kumari (2024), Mabrouk (2016), Abdullah et al. (2020), Saini et al. (2012) and Balakumbahan, et al. (2024).

10. Physiological Basis of Root Formation

Adventitious root formation is influenced by endogenous hormones, carbohydrate reserves, tissue maturity and environmental conditions. In air layering, the propagule remains physiologically connected to the mother plant during root initiation. This can help maintain water and nutrient supply and may support the accumulation and transport of metabolites required for root development. The physiological maturity of the propagule is also important. Mature stems may contain greater carbohydrate reserves, while younger tissues may possess greater physiological rooting potential. Consequently, the relationship between stem maturity and rooting ability is not necessarily linear. Auxin plays a central role in adventitious root initiation. Exogenous IBA may enhance the initiation and development of root primordia, but excessive auxin concentrations may not necessarily improve

rooting. The optimum concentration therefore depends on tissue type, genotype, propagation method and environmental conditions.

11. Nursery Management Considerations

Propagation success depends on nursery conditions in addition to propagation technique and auxin treatment.

Important nursery practices include:

1. Selection of healthy and vigorous mother plants.
2. Selection of disease-free branches of suitable physiological maturity.
3. Standardization of cutting length, diameter and node number.
4. Proper preparation of basal and upper cuts.
5. Correct application of IBA.
6. Use of a well-drained and adequately aerated rooting medium.
7. Maintenance of appropriate moisture and humidity.
8. Protection from excessive solar radiation and desiccation.
9. Regular monitoring of rooting and shoot emergence.
10. Proper hardening before field planting.

Balakumbahan et al. (2024) used a sand, vermicompost and soil medium in a 2:1:1 ratio for propagation experiments. Recent work by Santoso and Jayaputra (2026) further demonstrated the value of compost-amended nursery media, with compost addition improving seedling growth and establishment. Muniandi et al. (2025) also demonstrated successful propagation under protected nursery conditions and reported strong performance of air layering using Jiffy-7 pellets.

2. Comparative Evaluation of Propagation Methods

Propagation method	Major advantages	Important considerations
Hardwood cuttings	Simple, inexpensive and suitable for multiplication of mature branches	Cutting length, maturity and IBA concentration require optimization
Semi-hardwood cuttings	Good rooting and root elongation under suitable auxin treatments	Response is strongly influenced by physiological maturity
Air layering	Early rooting, good root biomass and suitable for elite mother plants	Labour-intensive and requires individual branch handling
Grafting	Useful for combining desirable scion and rootstock characteristics	Requires skilled labour and careful graft management
Micropropagation	Potential for rapid multiplication and conservation of elite material	Requires specialized infrastructure and technical expertise

Among the conventional methods evaluated specifically in PKM 1 and PKM 2, air layering with 2500–4000 ppm IBA was identified as the most promising method by Balakumbahan et al. (2024). However, the most appropriate technique depends on the objective. Air layering may be preferred for high-quality multiplication of selected plants, while shorter hardwood cuttings may be more advantageous when maximizing the number of propagules obtained from a mother plant.

13. Practical Propagation Protocol for Annual Moringa

Based on the available evidence, the following general protocol can be considered for nursery-level propagation.

Step 1. Selection of mother plants

Select healthy, vigorous and phenotypically superior PKM 1 or PKM 2 plants free from visible pest and disease symptoms.

Step 2. Selection of propagules

For conventional cuttings, select appropriately mature hardwood or semi-hardwood branches. Cutting length should be selected according to the cultivar and production objective.

Step 3. Preparation of cuttings

Prepare cuttings with an appropriate number of nodes and make a basal cut below the lower node.

Step 4. IBA treatment

Apply an appropriate IBA concentration according to the propagation method and cultivar. The available evidence indicates that 1500 ppm may be suitable for root elongation in PKM 2 semi-hardwood cuttings, whereas 4000 ppm is particularly promising for PKM 2 air layering.

Step 5. Planting

Plant treated cuttings in a well-drained rooting medium such as an appropriate soil, sand and organic-matter mixture.

Step 6. Air layering

Select suitable branches, remove a ring of bark, apply the rooting treatment and cover the wounded portion with moist rooting material before wrapping it securely.

Step 7. Root development

Monitor the propagules regularly for root initiation and shoot emergence.

Step 8. Separation and hardening

Once an air layer develops an adequate root system, detach it from the mother plant and transfer it carefully to a suitable container.

Step 9. Nursery maintenance

Maintain adequate moisture, humidity and protection from environmental stress during the hardening period.

Step 10. Field planting

Select only vigorous and well-hardened plants for field establishment.

14. Research Gaps

14.1 Rooting percentage

Rooting percentage should be reported together with root quality parameters. A high rooting percentage is particularly important for determining nursery efficiency and production cost.

14.2 Economic analysis

Comparative assessment of labour, IBA, rooting media, nursery infrastructure and production time is required to determine the economic feasibility of each propagation method.

14.3 Field validation

Differences observed during nursery propagation should be validated under field conditions to determine whether superior nursery performance results in improved establishment, growth and yield.

14.4 Seasonal variation

Seasonal variation in temperature, humidity, rainfall and physiological condition of mother plants may influence rooting. Multi-season trials are therefore required.

14.5 Large-scale nursery evaluation

Large-scale trials are necessary to assess labour requirements, propagation uniformity, mortality, nursery survival and operational feasibility.

14.6 Cultivar-specific recommendations

PKM 1 and PKM 2 show different responses to propagation method and IBA concentration. Therefore, cultivar-specific propagation protocols should be developed rather than applying a single universal recommendation.

14.7 Long-term field performance

Future studies should determine whether vegetatively propagated plants maintain their expected growth, yield and quality characteristics over multiple cropping seasons.

15. Future Prospects

Future research should focus on developing integrated, cultivar-specific and economically viable propagation systems.

The following areas deserve particular attention:

- Elite mother-plant selection: Identification of superior plants based on yield, growth, pod quality and other desired traits.
- Propagule standardization: Establishment of optimum cutting length, diameter, maturity and node number.
- Auxin optimization: Determination of cultivar- and method-specific IBA concentrations.
- Rooting-media optimization: Evaluation of media combinations that improve aeration, moisture retention and root development.
- Protected propagation: Optimization of humidity, temperature and moisture conditions.
- Hardening protocols: Development of standardized procedures for minimizing transplant shock.
- Nursery quality standards: Establishment of standards based on root development, shoot vigour and plant uniformity.
- Field validation: Assessment of long-term establishment, growth and productivity.
- Economic assessment: Determination of cost-effective propagation systems.
- Integration with clonal selection: Combining elite genotype identification with efficient vegetative propagation.

Recent research supports this integrated approach. Muniandi et al. (2025) demonstrated that superior genotype selection combined with optimized cutting position, cutting size and air layering can improve the production of high-quality planting material.

Santoso and Jayaputra (2026) further demonstrated that propagule length and nursery media influence seedling establishment and subsequent leaf biomass production, indicating that nursery management should be considered together with propagation method.

16. CONCLUSION

Vegetative propagation is an important approach for producing relatively uniform planting material of annual *Moringa oleifera*. Hardwood cuttings, semi-hardwood cuttings and air layering are practical conventional methods, while grafting and micropropagation provide additional opportunities for specialized propagation and clonal multiplication. The available evidence demonstrates that propagation success is strongly influenced by the interaction among cultivar, propagation method, propagule characteristics and auxin concentration. In PKM 1 and PKM 2, air layering was identified as the most promising conventional method, particularly when combined with

2500–4000 ppm IBA. PKM 2 air layering treated with 4000 ppm IBA showed particularly strong performance, with early rooting and sprouting and high root and shoot biomass. PKM 2 semi-hardwood cuttings treated with 1500 ppm IBA were particularly effective for root elongation. Recent studies have expanded these findings by demonstrating the potential of shorter hardwood cuttings, grafting, basal branch cuttings, air layering and improved nursery media. Nevertheless, further multi-season, large-scale and field-based research is required before a single commercial propagation package can be universally recommended. Economic analysis, rooting percentage, nursery survival, transplanting success and long-term field performance should be incorporated into future studies. An integrated propagation strategy combining elite mother-plant selection, standardized propagule characteristics, cultivar-specific IBA concentration, suitable rooting media, controlled nursery conditions, effective hardening and field validation offers the greatest potential for large-scale production of vigorous, uniform and high-quality annual moringa planting material.

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