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PRODUCTION TECHNOLOGY OF QUALITY PLANTING STOCK: AN OVERVIEW

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The QPS refers to the extent to which this stock effectively fulfils the objectives of forest management, whether it be sustaining through the entire rotation period or realizing specific desired benefits, all while minimizing costs. Essentially, quality equates to the fitness of the planting stock for its intended purpose. In a broader context, when a batch of planting stock successfully serves its intended purpose, it can be considered to have a quality rating of 100%. Conversely, the degree to which a batch of planting stock falls short of achieving the management objectives, regardless of how they are defined, represents the deficiency in the quality of that stock. Importantly, if planting stock with specific attributes can meet these management objectives, it is most advantageous to produce such stock as cost-effectively as possible (Mattsson et al., 2010). Optimizing the cost of production while maintaining quality is pivotal in the realm of forestry and afforestation, as it ensures efficient resource allocation and maximizes the benefits derived from the planted stock.

A Measure of Quality

The primary objective in cultivating superior seedlings is to maximize growth potential and optimize the yield of desired products. These products can encompass a wide array, from timber, food, fuel, and fodder to applications like site enhancement. Assessing seedling quality hinges on a dual appraisal system: the genetic constitution inherited from the parent stock and the physical development influenced by the immediate nursery environment. The selection of desirable genetic traits is a field operation that takes place at seed collection sites. When executed effectively, this process yields the highest quality seeds, preserving the desired inherent characteristics found in the parent stock. Diligent care in seed selection and collection also minimizes the production of subpar stock originating from physically compromised or damaged seeds. Apart from genetic traits, seedlings manifest a range of physical attributes, including robustness, proper form, health, and vigor, many of which can be influenced by nursery practices under the forester's purview.

The pivotal role played by management objectives in determining quality cannot be overstated. These objectives must be realistic and consider site-specific factors, cultural practices, such as site preparation and planting methods, and the inherent traits of the species in question. Introducing new techniques into existing large-scale planting systems should ideally commence with a comprehensive problem analysis, followed by a series of interrelated steps, with each step feeding back information to its predecessors. These steps, often requiring varying timeframes, represent a transition from high to low control over environmental variables. Early steps may comprise components that ultimately culminate in an integrated system considered in later stages. Attempting to circumvent this process by omitting steps is, in most cases, a recipe for unfavorable outcomes. Seeking a deep understanding is imperative for the widespread application of results.

Post-planting stock evaluation serves two distinct yet interconnected purposes. Firstly, it allows scientists to gauge plantation performance and determine the relative significance of controlling factors to guide improvement efforts. Secondly, forest managers employ it to determine the necessity of further operational adjustments. The timing of evaluations should be such that the essential information is both obtainable and timely, considering that species and site characteristics significantly influence the evaluation schedules.

Strategic Planning: An Essential Component

Achieving success in nursery establishment and operations hinges on the seamless flow of well-coordinated steps, each of which directly caters to the specific needs of the plants to ensure optimal growth upon out planting. Central to this endeavour is the essential role of careful planning and vigilant plant monitoring. In the absence of a well-defined plan, foresters can find themselves struggling to keep pace with unforeseen challenges that demand immediate attention. The upcoming sections delineate a comprehensive three-part planning guide dedicated to the cultivation of top-quality seedling stock. These sections delve into the intricacies of container selection, the strategic planning of the nursery, and the effective organization of its day-to-day operations.

Nursery site selection, preparation: Tree nurseries come in two main types, each catering to specific project needs. Temporary nurseries are ideal for short-term projects like erosion control or windbreaks. They often employ basic materials like cut thorn bushes for protection. Regardless of nursery size, plant care remains paramount. Permanent nurseries, on the other hand, support long-term endeavors such as reforestation, commercial plantations, or agroforestry. When choosing a nursery site, central location, easy access to project areas, road access, reliable water sources, and proximity to settled areas are crucial considerations. Topography should be level or gently sloping to aid water drainage and prevent water accumulation, which can attract pests and diseases.

Soil quality is pivotal for bare-root nurseries, with preference for loose, deep sandy clay loam soils and a drainage system to prevent water stagnation. In case of poor soils, manual or mechanical soil improvement methods and compost materials can enhance soil quality. In contrast, containerized nurseries offer more flexibility in location, as potting mediums can be sourced from various places and mixed on-site or off-site with the necessary ingredients.

Assessing Soil Texture by Hand: To differentiate soil types, a simple test involves gently compressing a small soil sample between the thumb and forefinger. Sandy loam soil has a high sand content but contains enough silt and clay for some cohesiveness. Individual sand grains are visible and, when dry, the sample easily crumbles. In its moist state, it forms a stable cast. Loam soil has a balanced mix of sand, silt, and clay, offering a slightly gritty yet smooth texture. When dry, it forms a manageable cast. In contrast, clay soils, when moist, can be molded into pliable ribbons. It's advisable to avoid such soils, as they hinder proper root development and moisture absorption.

The Case for Root Trainers in Tree Nurseries: Root trainer systems represent a revolutionary approach to tree nursery management. These systems utilize rigid or semi-rigid containers with internal vertical ribs designed to guide root growth in a straight downward direction, preventing spiralling. Additionally, containerized plants are elevated on frames above the ground, promoting air-pruning of roots as they emerge from the containers. These containers are engineered to stimulate lateral root development, and these lateral roots can be managed through air or chemical pruning. Research demonstrates that seedlings grown in root trainers exhibit more robust and rapid root growth compared to those in poly-bags. This not only results in improved survival rates upon transplanting but also ensures the long-term health of the trees.

Root trainer systems offer numerous advantages that simplify nursery operations and improve overall outcomes. These advantages include:

1. Disease and Insect Control: Root trainers provide better protection against diseases and pests, as the controlled environment helps reduce the risk of infestations.

2. Transportation and Handling: The design of root trainers makes it easier to transport and handle seedlings, reducing the risk of root damage during transit.

3. Monitoring and Sampling: Root trainer systems facilitate better monitoring and sampling of plant growth and health, allowing for timely adjustments in care.

4. Reusability: While root trainers may have higher initial costs than poly-bags, their reusability offsets this expense over time, making them a cost-effective choice in the long run.

Effective Nursery Design: The nursery layout comprises essential elements, including a water storage facility with provisions for siltation if necessary, shaded areas for young seedlings and staff, ample space for nursery beds and pathways, well-planned driveways and turnaround zones, storage areas for tools and equipment, stockpiles for soil mix ingredients, sturdy fencing and gates, fire buffers, and clear zones. In any nursery planning, having a "materials-flow-chart" or comprehensive plan outlining the entry, movement, and exit of essential materials is vital. These materials typically encompass water, tools, seeds, containers, potting mix ingredients, and more. Additionally, extra areas should be allocated for potential expansion and cutting orchards, especially when propagating planting stock vegetatively.

For containerized nurseries, it's advisable to arrange pots on raised beds with side supports for the plants. However, if ground-level beds are chosen, they should be constructed using gravel or a similarly free-draining material. Pots can be organized in rows of 12 to 15 pots, depending on pot diameter or ease of access to the center of the bed for weeding and other operations. The use of plastic pots or poly-bags is discouraged due to potential severe issues that can jeopardize projects at the nursery stage or later. For optimal results, employing root trainers is the preferred method. Root trainers encompass more than just a container;

they constitute an entire system that fosters proper root development and growth. When using root trainers, raising beds well above ground level facilitates aerial root pruning and simplifies growth monitoring.

Carbon Enrichment Techniques in QPS

In recent years, the use of an enriched CO_2 atmosphere has gained prominence as a nursery technique for manipulating seedling quality in response to environmental stresses. This approach is becoming increasingly popular because an elevated CO_2 atmosphere not only enhances nursery productivity by reducing seedling growth time but also offers the potential for seedlings to exhibit a preferential allocation to root development, thus increasing their root-to-shoot ratio. As the concentration of CO_2 in the atmosphere rapidly approaches 450 ppm, it is poised to have a significant impact on forest conditions, affecting their area, composition, and overall health. This phenomenon has the potential to boost growth rates in some areas while posing a threat to the survival of certain species and forest communities in others. The CO_2 fertilization hypothesis suggests that the rising atmospheric CO_2 levels positively influence tree growth by providing increased carbon availability.CO_2 plays a pivotal role in connecting the atmosphere with the biosphere, serving as an essential substrate for photosynthesis. Elevated CO_2 levels stimulate photosynthesis, leading to increased carbon uptake and assimilation, resulting in enhanced plant growth.

However, the response to elevated CO_2 varies depending on the photosynthetic pathway of the plant. C3 plants tend to exhibit a more significant growth response compared to C4 plants due to competitive inhibition of photorespiration by CO_2. The effects of CO_2 can also be influenced by the leaf habit of the species, where differences in leaf lifespan can result in varying responses to environmental cues like CO_2. Evergreen species typically show lower responsiveness to environmental changes, such as elevated CO_2, due to trade-offs between traits that reduce nutrient loss and those that promote high rates of dry matter production. On the other hand, deciduous species, with their lower specific leaf weight, tend to exhibit a more substantial response to CO_2 enrichment. Some studies have indicated that under elevated CO_2 conditions and with adequate nutrient supplementation, seedling diameter growth can increase by up to threefold (Salimath *et al*., 2023). Total height growth also shows a significant increase under elevated CO_2 conditions. Moreover, the application of nutrients in combination with elevated CO_2 positively influences the volume index and biomass increment of seedlings. This implies that, in the context of climate change, where atmospheric CO_2 concentration is doubled, species can adapt to the available nutrients, leading to enhanced seedling growth.

Integrated Nutrient Management in Nursery (INM)

Integrated Nutrient Management (INM), combining chemical fertilizers, microbial inoculation, and organic manures, outperforms other fertilization methods in citrus cultivation. INM requires fewer applications, typically once or twice, to modify the physico-chemical and microbial environment, unlike conventional fertilization, which necessitates 3-4 applications synchronized with growth stages or even up to 15-20 times using fertigation. Dual-function microbes like *Trichoderma harzianum/viride*, *Pseudomonas fluorescens, Bacillus polymyxa*, and *Arbuscular mycorrhizae*, when coupled with 75% of recommended fertilizer doses, effectively address multiple nutrient deficiencies on diverse soils, cultivars, and climates (Srivastava, 2009). The recent years have witnessed a growing recognition of the effectiveness of bio manures and biofertilizers in producing high-quality planting stock in forest nurseries. These bioresources have proven highly valuable in afforestation efforts and the reclamation of degraded lands, including mined overburdens and challenging terrains. Biofertilizers, encompassing biologically active products and microbial inoculants, play a vital role in promoting biological nitrogen fixation, phosphate solubilization, and nutrient mobilization.

INM is a relatively recent agricultural practice that emphasizes optimizing soil performance by enhancing both chemical and biological soil properties. In forestry, the adoption of INM holds substantial potential for increasing biomass productivity per unit area and unit time. Effective utilization of bioinoculants not only provides economic benefits but also sustains soil fertility and ecological balance within the natural soil ecosystem. The efficient use of these bioresources depends on the specific forest ecological environment and local availability, offering a cost-effective alternative to expensive chemical fertilizers. Different tree species favour specific combinations of beneficial microbes in their rhizosphere, which can improve seed germination and reduce seed dormancy through the production of growth-promoting substances. Mycorrhizal fungi, nitrogen-fixing bacteria, and phosphobacteria are examples of bioinoculants (biofertilizers) that play a crucial role in forestry programs by enhancing tree species' survival and growth. Inoculating nursery seedlings with selective bioinoculants holds promise for improving seedling quality, reducing transplanting periods, enhancing out planting performance, increasing resistance to diseases, parasitic nematodes, and climatic stress. The application of bioinoculants also reduces the reliance on costly chemical fertilizers in plantation programs.

Currently, various biofertilizers are being used in forestry to enhance the growth of tree seedlings in nurseries (Kar et al., 2020). While biofertilizer benefits have been extensively studied in annual crops, information regarding their applicability in perennial crops or trees is limited in India. Nonetheless, some research reports in forestry demonstrate that biofertilizers stimulate growth, biomass, and nutrient uptake, leading to increased seedling survival rates. The application of both macro and micronutrients can significantly improve tree growth and productivity. The application of highly efficient biofertilizers not only ensures high-quality seedlings but also enhances outplanting performance, contributing to soil health and the sustainability of eco-friendly forestry practices.

Plant Quality Assessment Tool

The ever-growing demand for larger, superior, and faster-growing seedlings has driven ongoing advancements in forest seedling production technology for reforestation. Evaluating seedling quality is of paramount importance as it provides insights into seedling development in the nursery and their subsequent growth and survival in the field. However, the assessment of stock quality is inconsistent and often limited. While some nurseries and reforestation managers conduct comprehensive stock assessments annually, others only do so when issues arise. Despite the nurturing environment in nurseries, seedlings face various challenges during their journey from the sheltered nursery to their designated planting sites. From lifting and grading to storage, handling, and planting, seedlings encounter multiple opportunities for moisture stress, temperature stress, and physical stress. These stresses accumulate and can significantly impact field performance.

In cases of poor growth or survival post-planting, disputes may arise between the nursery and the landowner regarding the cause. Seedling quality data plays a crucial role in determining whether performance issues stem from nursery conditions, improper planting practices, or environmental factors post-planting. Seedling quality evaluation serves as a tool to establish benchmarks at specific stages, such as lifting or delivery, providing both the nursery and the customer with a quantitative assessment of a particular seedling lot. Furthermore, seedling quality data aids seedling producers and users in gaining a deeper understanding of seasonal patterns across various factors, including species, stocktypes, seed lots, and cultural treatments.

Seedling Quality Assessment*:* Seedling quality assessment encompasses two key categories: morphological and physiological evaluation, with both aspects contributing to a comprehensive understanding of seedling condition. Morphological quality assessment predominantly relies on physical attributes, with height and stem diameter being the primary parameters examined in forest seedling evaluation. Growing contracts often specify target values for these attributes, including acceptable minimum and maximum ranges. Height and stem diameter are quick and straightforward to measure, providing valuable insights into seedling quality and expected field performance. Nevertheless, relying solely on these measures falls short in fully assessing seedling condition. Root development, closely correlated with stem diameter, is seldom directly evaluated beyond casual observation during grading. Root quality assessments, while essential for assessing seedling health, are more time-consuming and necessitate a separate subsample evaluation. Additionally, seedling balance is crucial – even when height and stem diameter meet targets, an unbalanced seedling can hinder survival and growth after planting.

Physiological assessment of seedlings goes beyond their physical attributes and is vital for identifying stress-induced damage that may compromise seedling quality. Freeze damage, often hard to detect in dormant shoots during fall, can be assessed by potting a sample of seedlings, observing cambium and bud tissue for signs of browning after exposure to warmth and moisture. Cold hardiness testing is a valuable physiological assessment that gauges stress resistance. This test exposes seedlings to gradual freezing temperatures and evaluates the damage to foliage, cambium, and buds. Root growth potential (RGP) is another physiological test, though its predictiveness for field performance is debated. Additional physiological tests include Plant Moisture Stress (PMS), which measures xylem water potential and aids in irrigation scheduling and water stress monitoring, bud Development, which indicates dormancy and future shoot growth potential, chlorophyll fluorescence, reflecting photosynthetic activity, and nutrient status, which influences various metabolic processes within the seedling. Collectively, these assessments provide a holistic understanding of seedling quality, facilitating informed decisions for forest planting operations.

Indices for Seedling Quality Assessment: The evaluation of seedling quality in our country involves several key indicators. These measures play a vital role in determining the viability and performance of seedlings. Some of the significant indicators include:

1. *Collar Diameter:* Collar diameter serves as a valuable gauge of seedling growth. Seedlings with a collar diameter of approximately 2.50 - 3.00 cm (comparable to the thickness of a pencil) exhibit superior establishment potential in the field compared to taller, lankier seedlings.

2. *Root-to-Shoot Ratio*: The root-to-shoot ratio is another reliable indicator of seedling quality. Typically, a seedling with a root-to-shoot ratio falling within the range of 1.0 to 2.0 demonstrates better survival prospects in the field. A ratio greater than 1.00 signifies a robust root system capable of supporting shoot growth, while a ratio less than 1.00 suggests an insufficient root system, negatively impacting seedling survival, growth, and development.

$$\text{R: S ratio} = \frac{\text{Rootdryweight(g)}}{\text{Shootdryweight (g)}}$$

3. *Sturdiness Quotient:* The sturdiness quotient, as defined by Ritchie (1984), is a valuable measure of a seedling's strength, particularly regarding its ability to withstand wind. Young seedlings are often vulnerable to strong winds, which can lead to uprooting or bending. Bending can adversely affect the quality of timber produced by the tree. Seedlings with a sturdiness quotient falling in the range of 10 to 15 are considered ideal for ensuring better survival, growth, and development in the field. The sturdiness quotient is calculated using the formula:

$$\text{Sturdiness Quotient} = \frac{\text{Shoot length (cm)}}{\text{Collar diameter (cm)}}$$

4. *Seedling Quality Index*: Developed by Dickson in 1960, the Seedling Quality Index is a comprehensive measure that takes into account various morphological traits and seedling biomass. This index offers a holistic assessment of seedling quality. A seedling lot with a higher index value is more likely to perform well in the field. The formula for calculating the Seedling Quality Index is as follows:

$$\text{Seedling quality Index} = \frac{\text{Total seedling dry weight (g)}}{\frac{\text{Plant height (cm)}}{\text{Collar diameter (cm)}} + \frac{\text{shoot dry weight (g)}}{\text{Root dry weight (g)}}}$$

These indicators collectively provide valuable insights into the quality and potential of seedlings for successful field performance.

Conclusion

The production of high- QPS in forestry plays a crucial role in achieving reforestation and afforestation goals. It involves a complex interplay of genetic traits, nursery practices, and environmental factors. Key elements in this process include careful seed selection, the use of root trainers to promote proper root development, integrated nutrient management, and the assessment of both morphological and physiological seedling quality. Moreover, the adoption of modern techniques such as carbon enrichment to enhance growth and the use of biofertilizers have the potential to further improve seedling quality and subsequent field performance. Effective planning, site selection, and ongoing evaluation are essential for successful QPS production, contributing to sustainable and eco-friendly forestry practices.

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