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*Editorial*

# The Production Chain of Tree Seedlings, from Seeds to Sustainable Plantations: An Essential Link for the Success of Reforestation and Restoration Programs in the Context of Climate Change

**Mohammed S. Lamhamedi [1,*], Steeve Pepin [2] and Damase Khasa [3]**

1 Ministère des Ressources Naturelles et des Forêts du Québec, Direction de la Recherche Forestière, 2700 Rue Einstein, Québec, QC G1P 3W8, Canada
2 Centre de Recherche et d'Innovation sur les Végétaux, Département des Sols et de Génie Agroalimentaire, Pavillon de l'Envirotron, Université Laval, 2480 boul. Hochelaga, Québec, QC G1V 0A6, Canada; steeve.pepin@fsaa.ulaval.ca
3 Centre for Forest Research and Institute for Integrative Systems Biology, Université Laval, Quebec, QC G1V 0A6, Canada; damase.khasa@ibis.ulaval.ca
* Correspondence: mohammed.lamhamedi@mffp.gouv.qc.ca

**Abstract:** Although the evolution of principles, procedures, and predictive abilities related to seedling quality throughout the plant production chain (i.e., from seeds to sustainable plantations) has been reviewed over the past decades in various technical and scientific publications, there is still a need to develop and integrate new and efficient practices in forest nurseries and at planting sites, in order to improve the morphophysiological quality of seedlings and saplings, and their survival and growth under different site and environmental conditions in the context of climate change. We have grouped together different scientific articles in this Special Issue of *Forests*, entitled "Production in Forest Nurseries and Field Performance of Seedlings". They cover different topics relating to the seedling production chain in different countries and continents, from growing media to planting performance related to reforestation, restoration, and agroforestry programs.

**Keywords:** forest nursery; cultural practices; microbial inoculation; planting performance; environmental stress

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## 1. Introduction

Across the globe, the successes of various reforestation programs constitute a major challenge for the forest managers and practitioners responsible for these programs. This success is based on the use and production of seeds and seedlings of high morphophysiological quality in forest nurseries, and the monitoring and maintenance of this quality throughout the plant production chain, i.e., from seeds to sustainable plantations (Figure 1). However, across continent and country, the constraints, issues, and technological innovations concerning different components of the seedling production chain are dissimilar. The efforts made by each country to improve the components of the reforestation sector are closely linked to the objectives and priorities of their programs (reforestation, restoration, conservation of genetic diversity, sustainability of ecosystems, increases in forest productivity and wood quality, clonal forestry, mitigation of climate change, integration of innovations and forest biotechnologies, fighting against erosion and desertification, improvement of the incomes of local populations, agroforestry, etc.), and the availability of financial resources expertise (scientific, professional, practical, and technical) in the different areas of the plant production chain.

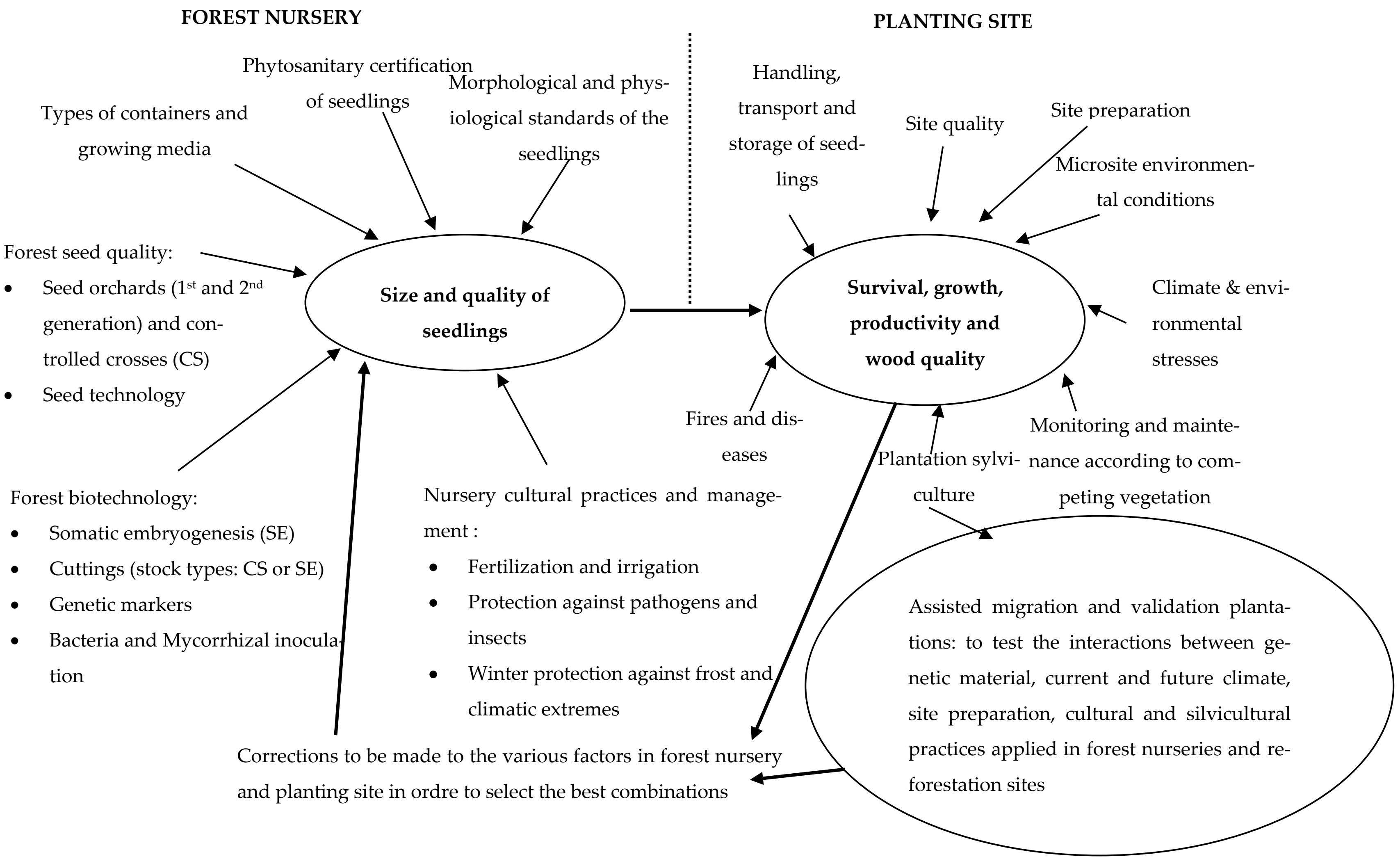


**Figure 1.** The main factors and components affecting the morphophysiological qualities of seeds and seedlings in forest nurseries, and the processes for monitoring and maintenance of these qualities throughout the plant production chain, i.e., from seeds to sustainable plantations (figure adapted from Lamhamedi and Fortin [1]).

## 2. Perpetual Readjustment of the Plant Production Chain of Tree Seedlings in the Face of the Diversified Challenges of Tomorrow

Resorting to the use of seedlings of high morpho-physiological quality allows forest managers to easily achieve the objectives of their reforestation and restoration programs, in terms of survival, growth, and sustainability, while facing the combination of an increased frequency of extreme droughts, heat waves, severe winter frosts, pests and diseases, invasive alien species, etc. Otherwise, replanting with additional seedlings will increase the cost of plantations, which increases the time to reach maturity and harvesting of tree plantations. The evolution of principles, procedures, and predictive abilities related to seedling quality throughout the plant production chain has been reviewed over the past decades in various technical and scientific publications [2–12].

Despite the many scientific and technical publications related to the plant production chain, we are aware that several facets of the state of the art in this field continue to advance and readjust rapidly in the contexts of climate change and the supply of substitute substrates for peat. For example, efforts are being made at the international scale to develop (*i*) a sound scientific basis for the assisted migration of tree species; (*ii*) genetically diverse seed sources with ecophysiological mechanisms to adapt to future climate conditions; (*iii*) substitute substrates for peat due to political and environmental pressures, increasing transportation costs, and the decreasing availability of imported peat in many countries; and (*iv*) new cultural practices in seed technology, the growing of seedlings in forest nurseries, seedling ecophysiology, and handling and planting techniques to improve survival and growth under multiple stress site conditions.

To this end, we have grouped together an Editorial and 12 scientific articles in this Special Issue of *Forests*, entitled “Production in Forest Nurseries and Field Performance of Seedlings”. These 12 articles were peer reviewed confidentially and anonymously, and subsequently published. They cover different topics related to the seedling production chain in different countries and continents from growing media to planting performance.

Boudreault et al. [13] compared the hydraulic and aeration properties of peat substrates used to produce containerized white spruce seedlings (1 + 0) in eight forest nurseries. Their results suggest that the air-filled porosity at the container capacity of forest nursery substrates should be between 0.03 and 0.10 $cm^3\ cm^{-3}$, in order to improve the root and shoot growth of white spruce seedlings (1 + 0). Moreover, a substrate bulk density between 0.07 and 0.115 $g\ cm^{-3}$ had a positive effect on root biomass. However, the extraction of peat and its decomposition when used as growing media in forest and horticulture nurseries constitutes a source of greenhouse gas emissions [14]. Because of the depletion of peat resources, their impacts on climate change and certain countries’ prohibition on importing peat, several countries have developed national strategies to reduce peat and to find renewable alternatives for peat substitution [14–18]. The challenge is to find alternatives to peat whose physico-chemical properties remain relatively stable, both throughout the growing season and from year to year under the cultural practices applied under forest nursery conditions. Du et al. [19] tested the effects of compost tea applications on tree growth and root mycorrhizal colonization for five common urban tree species (*Acer negundo*, *Corymbia maculata*, *Ficus platypoda*, *Hymenosporum flavum*, *Jacaranda mimosifolia*) over six months. In another study, Asmara et al. [20] examined a mixture of woody and herbaceous plant species with the introduction of microsymbionts through inoculation, and the application of biochar amendments for accelerating the post-mining restoration. Their results suggest that the restoration processes are improved with combined factors, including microbial inoculation, biochar amendment, crop mixture, plant density, and their direct effects on microclimate improvements.

Trujillo-Elisea et al. [21] evaluated the effect of 10 rhizobacteria strains, commonly named plant growth promoting rhizobacteria (PGPR), during the early stages of production of *Swietenia macrophylla* King [Meliaceae]) under forest nursery conditions. Their results support the advantages of using PGPRs in commercial tropical tree production, because they significantly increase the growth of seedlings. This timber species is of significant ecological and economic importance in the Neotropics.

Speetjens and Jacobs [22] investigated the effects of controlled-release fertilizer (CRF), chelated Fe treatments, and two pot host species (*Acacia koa* and *Dodonaea viscosa*) on the seedling development of Hawaiian sandalwood (*Santalum paniculatum*). They showed that high-quality *S. paniculatum* seedlings can be grown in containers by providing adequate nutrition, and that *S. paniculatum* may benefit from chelated iron fertilizers in a nutrient-limiting growing environment.

With climate change becoming a reality, Lamhamedi et al. [23] simulated different periods of warm weather at the beginning and end of winter, and evaluated their effects on the dehardening and growth of boreal forest seedlings (*Picea mariana* and *Picea glauca)* in response to different freezing temperatures in northern forest nurseries. In winter, regardless of the warming treatment, the seedlings of the two species tolerated the different freezing temperatures without any apparent damage. However, at the end of winter, and in the absence of snow cover, the seedlings did not show frost tolerance at −20 °C. On the other hand, the seedlings showed normal growth after undergoing frosts at −4 °C and −12 °C, comparable to that observed for control seedlings. Different cultural practices and protection strategies are proposed to improve frost tolerance and reduce the winter loss of seedlings.

Landhäusser et al. [24] investigated how initial differences in size, biomass allocation, and non-structural carbohydrate (NSC) storage affect the subsequent partitioning of new biomass, growth potential, and drought response in seedlings of a broad-leaved deciduous tree species (*Populus tremuloides* Michx.) and an evergreen coniferous species (*Pinus banksiana* Lamb).

The results of this study highlight (1) the complexity of how differences in biomass allocation and changes in seedling size may alter storage and the response of species to droughts, and (2) the importance of accounting for initial seedling characteristics (both morphological and physiological) when predicting seedling growth and the impacts of environmental stressors.

Harayama et al. [25] evaluated the effects of seedling size, seven stock types, and mechanical site preparation methods on the initial survival and growth of Japanese Larch (*Larix kaempferi*) seedlings during four consecutive growing seasons. Seedling type (bare-root versus container) had no effect on seedling height during the four growing seasons after planting. Their findings suggest that seedlings with a sufficiently large root-collar diameter and a young age, regardless of seedling type, can grow taller than the surrounding vegetation more quickly. In a literature review, South et al. [26] reviewed and discussed the various factors that govern the successes and failures of reforestation and restoration programs with healthy pine seedlings after leaving the nursery. With a focus on pine seedlings planted in the southern United States, the authors also listed non-nursery factors that have killed pine seedlings in North America, Africa, and Europe.

With an increase in the population, the quantity of wastewater and the scarcity of water resources due to a significant drop in rainfall and long periods of severe drought, especially in semi-arid areas, several countries are beginning to move towards recycling and decontaminating wastewater, using tree seedlings as a biological means. In this Special Issue, Bousbih et al. [27] investigated the potential use of two forest species (*Salix alba* and *Casuarina glauca*) in the rhizofiltration of heavy-metal-contaminated industrial wastewater. *S. alba* exhibited a greater removal capacity for heavy metal ions, and it could be effective as a phytoremediation species for toxic-metal-polluted industrial effluent water.

To ensure the sustainability of arid ecosystems, improve people's incomes, and fight their rural exodus, rural development approaches have focused on optimizing the management of high value-added agroforestry species. In this Special Issue, there are articles focused on assessing the quality of argan oil extracted from natural stands and urban plantations [28], and the evaluation of arbuscular mycorrhizal fungi (AMF) in different argan stands representative of the distribution and genetic diversity of this species [29], with the aim of selecting AMF isolates and inoculating seedlings in the forest nursery, in order to confer them increased tolerance to drought in different plantation sites.

The ecosystems of the Moroccan argan forest constitute an original socio-agrisylvopastoral system which is unique in the world, and a bulwark against the advancement of desertification. It is estimated that nearly 1.3 million people derive their incomes from the valorization of various products of high added value from argan trees; in particular, the extraction of argan oil and the synthesis of cosmetic and medicinal products, whose demand continues to increase on national and international markets. This oil has become one of the most expensive oils in the world. With multiple uses for argan trees, the growing needs, and the severity of the climate, the areas covered by argan trees regress by 2000 ha/year on average. To ensure its sustainability, in 2014, the United Nations Educational, Scientific and Cultural Organization (UNESCO) granted the Moroccan argan grove a biosphere reserve status (intangible cultural heritage of humanity). The Arganeraie Biosphere Reserve was recently created on "International Day of the Argan Tree", by a declaration by the United Nations General Assembly on 10 May 2022.

Sabiri et al. [28] showed that the chemical characteristics of argan oil extracted from the plantations are similar to the oil from the two natural stands of argan trees. These results suggest that it is possible to implement an assisted migration of this tree species outside its natural area into sites exposed to sea spray, without affecting the quality of its edible argan oil. Because of its great resistance to drought, the enhancement and added value of each constituent of the tree (foliage, fruit, wood, etc.), and because of the severity of the droughts that have raged in recent decades across the globe, the argan tree has become a species of first choice for reforestation outside of its natural range; for example, in several countries in Europe (France, Portugal, Spain), in Latin and North America (Chile, Argentina and USA), in Africa (Tunisia, Algeria, Egypt, Sudan, South Africa, etc.), in the Middle East (Syria, Israel, etc.), and in Australia [30–32].

## 3. Conclusions

With an unprecedented increase in the frequency of fires, and the millions of hectares of forests burnt on a planetary scale in recent years, several programs of reforestation, restoration, and fighting against desertification are underway in different countries. After being planted in several regions of the world, the seedlings are subjected to severe droughts and extremely high temperatures. Faced with these major constraints and challenges, it is not enough to simply plant millions of seedlings, but also to ensure the selection of suitable genetic sources, the morphophysiological quality of the seedlings, and the optimization of cultural practices (e.g., from seed to planting) and silvicultural techniques, in order to achieve the objectives of the various programs (reforestation and wood production, restoration, prevention of desertification, agroforestry, etc.) in terms of survival and growth.

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