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Evaluation of attributes and quality indices in nursery plants for successful reforestation in Pinar del Río, Cuba: Systematic review

Evaluación de atributos e índices de calidad en plantas de vivero para la reforestación exitosa en Pinar del Río, Cuba: Revisión sistemática

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Abstract

The reforestation process is one of the most complex tasks for foresters since there are several factors that limit success, one of them has to do with the quality of the material to be planted. Hence, every day it is more important to guide studies that facilitate understanding the adaptation of plants to the site and the establishment of highly productive plantations, based on the production of quality plants in nurseries. The objective of this work was to evaluate the attributes and quality indices of the most appropriate plants in forest nurseries, through a systematic review, as a contribution to reforestation programs in the province of Pinar del Río, Cuba. The methodology sought relevant data from the review of reliable sources related to the issue of plants quality in the nursery. The results reported the need to diagnose the quality of the plants in the nursery through the combination of morphological and physiological parameters that allow us to better understand the functioning of the plants and guarantee its response to the planting site. It was found that more than 90% of the studies expressed a positive relationship between the diameter of the plant in the nursery and the growth after planting, making these parameters a high priority for decision making regarding the quality of the forest plants, which would facilitate greater growth, survival and development in plantation conditions.

Keywords: documentary review; reforestation; morphological attributes; physiological attributes, quality plants in the nursery.

Resumen

El proceso de repoblación forestal resulta una de las tareas más complejas para los silvicultores ya que existen varios factores que limitan el éxito, uno de ellos tiene que ver con la calidad del material a plantar. De allí, que cada día es más importante orientar estudios que faciliten entender la adaptación de plantas al sitio definitivo y el establecimiento de plantaciones altamente productoras, considerando como base la producción de plantas de calidad en viveros. El objetivo de este trabajo fue evaluar los atributos e índices de calidad de las plantas más adecuados en los viveros forestales, mediante revisión sistemática, como contribución a los programas de reforestación en la provincia de Pinar del Río, Cuba. La metodología buscó datos relevantes a partir de la revisión de fuentes confiables relacionadas con el tema de calidad de planta en vivero. Los resultados reportaron la necesidad de diagnosticar la calidad de las plantas en vivero, mediante la combinación de parámetros morfológicos y fisiológicos que permitieron entender mejor el funcionamiento de la planta y garantizar su respuesta al sitio de plantación. Se encontró que más del 90% de los estudios expresaron una relación positiva entre el diámetro de las plantas en vivero y el crecimiento después de la plantación, resultando de alta prioridad estos parámetros para la toma de decisiones en cuanto a la calidad de las plantas forestales, lo que facilita un mayor crecimiento, supervivencia y desarrollo en las condiciones de plantación.

Palabras clave: revisión documental; reforestación; atributos morfológicos; atributos fisiológicos; plantas de calidad en vivero.

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Introduction

The grow for forest plants in nurseries is a priority for reforestation programs in the province of Pinar del Río, which is recognized for its strong compromise for sustainable forest development. There is more and more effort put into achieving these goals in the country.

Reforestation requires high-quaility plants to increase survival and field development (Wightman y Cruz, 2003; Paz et al., 2023). The quality of nursery-produced plants is proved by their response on natural soil, which depends mainly on their genetic and other attributes obtained during their time in the nurseries (Duryea, 1985; Alcalá et al., 2002; Sequía et al., 2002; Serrada, 2005).

Nursery plant productin consists of providing the necessary care and treatment to the seeds so they germinate successfully, grow adequately, achieve high rates survial, and facilitate their implementation on natural soil (Muñoz et al., 2015). The management practices in nurseries are shown in the quality of plants, which must posses morphological and physiological attributes that allow them to adapt and develop in the climate and edaphic conditions of the plantation site (Oliet, 2001; Salvador, 2016; Leones et al., 2018; Senilliani et al., 2021).

The quaility of plants can be defined as the ability of individuals to adapt and grow in the climate and edaphic conditions of the place they are planted in. This ability depends on the genetic characteristics of the germoplasm and the reproductive techniques. (Rodríguez, 2008; Bernaola et al., 2016; Escobar y Rodríguez, 2019). The quality of plants considers the following criteria: genetic origin, sanitary status, and the morphological and physiological attributes fo plants growing in the nursery. These factors, along with soil prepartion and subsequent care in the plantation, are most important elements for plant restoration (Montenegro, 2007; Salvador, 2016). In this context, there are many plantation projects that fail because they do not consider neither the quality criteria in the nurseries, nor the conditions of the forestal site.

Reforestation programs in the Pinar del Río province are not exempt from this reality. Plants produced in nurseries are of low quality, and this hampers the reforestation process. Hence, the objective of this study was to evaluate, through a systematic review, the most accurate quality attributes and rates of plants grown in forestal nurseries, to contribute to the reforestation programs in the province of Pinar del Río, Cuba.

Materials and Methods

The study involved a theoretical research through a systematic review (Arencibia et al., 2008). The review was carried out by selecting and gathering data through a critical review of documents and bibliography in the data bases (Ruano et al., 2003). The goal was to obtain the previous knowledge for a deeper understanding of the theory and contributions about quality attributes in forest plant cultivation in nurseries.

The literature review about plant quality in nurseries included searching for relevant scientific papers of the aforementioned subject. The study is a summary of information from 50 relevant sources, including indexed papers books; of which, 10 sources were rejected because they were not relevant to plant quality in the context of this research.

Then, the scientific information pertinent to plant quality was searched through a critical review of scientific papers in databases such as: Scopus, Dialnet, SciELO, Science Direct, PubMed y Springer Link. The search engine used was Google Scholar (Codina, 2007), which arranges the information according to the number of website clicks, and provided subscriptions and direct access for many journals. The strategy for searching information consisted of identifying keywords, such as: forest nurseries, forest plant quality and morpho-physiological attributes. Moreover, boolean operators were used, such as: AND (to look for two words with different meanings), OR (for words with similar meanings), AND NOT (to exclude certain words). To search for specific words, the word was placed in quotation marks ("…"), and in the case that the intention was to give importance to a word in a group of words, the plus and minus

signs were used depending on the search (..+, ..-) (Oller, 2003).

Literature Review

The literature review provided information regarding the plant quality attributes that were used in forest nurseries to assess forest quality, which in itself is determined by a group of morphological attributes (table 1) such as: diameter, seedling height, biomass (fresh, dry aerial and root), and the root system. The following paragraph is a systematic review and summary carried out by various authors regarding plant quality that is commonly carried out in forest nurseries for morphological assessment (Davis y Jacobs, 2005; Grossnickle y South, 2017; Davis y González, 2021).

The systematic review showed a correlation between morphological attributes with seedling growth after placing them in the plantations, because they retained most of the characteristics

Table 1. Morphological attributes for the quality of forest plants

Attribute	Measurement criteria	Interpretation
Height	This was the simplest attribute to measure. On most of the studies, a ruler or a tape measure was used, measuring from the base of the stem up to the apex of the terminal bud of the seedling.	The height of the plant in nursery was an indicatar of the level of development of the aerial part, which helped predict its height on the field becuse the seedlings with the greatest heights held their height advantage over time; nonetheless, heigh alone did not ensure survival.
Root Collar Diameter(DCR)	This attribute was one of the most used in the characterization of plant quality, due to the low cost of its measurement, in addition to the predictive capacity for response in the field. It was determined with the help of a mechanical Vernier caliper and measured at the base of the stem of all plants. A STANLEY digital caliper was also used, expressed in mm.	This attribute describes the robustness of the seedlings. It was considered the most reliable indicator of the survival and development of plants in the field, since it is related to the size of the roots and the cross section of water transport, nutrient absorption, mechanical resistance, the degree of lignification of the stem and the relative ability to tolerate high soil surface temperatures..
Fresh aerial and root biomass	To determine the fresh aerial and root biomass, samples of seedlings were taken, the biomass of the sample was separated into aerial and root components (stem, leaves and root) and then an analytical balance was used to weigh the samples and obtain more exact values.	The biomass of the plants was an indicator of their volume and leaf area. It was strongly related to physiological aspects, whether transport and photosynthetic activity; Therefore, this was an indicator of how productive the species can be in future plantation conditions.
Dry aerial and root biomass	The dry biomass was obtained from the measurements obtained from the aerial and radical values, exposed to the oven at a constant temperature equal to or greater than 60 °C for 48 hours, subsequently each fraction of the seedlings were weighed on an analytical balance to obtain dry aerial and root biomass.	This attribute was an indicator of the structural balance of the different parts of the plant, it also indicated the proportion and existence of a root system to provide energy to the aerial part of the plant.
Root system	For the root system, samples of seedling roots were used with which the length was measured with a ruler and the dimensions were taken from the collar root to the distal end of the seedling. The growth potential was obtained by counting new secondary roots greater than 1 cm. A 100 mL test tube was used with a common water volume of 60 mL, the samples were immersed inside and the root volume was determined.	Seedlings with a larger size of root systems with high morphological and physiological standards offered the ability to overcome the stress of planting and thus achieve establishment in the planting conditions, in addition to having a greater capacity to develop roots quickly after planting.

for prolonged time periods.In particular, the morphological attributes limited the susceptibility of stress in plantations, and they also improved growth. In addition, they were important for predicting the development and growth after the seedlings were placed; that is why the studies that evaluated the morphological attributes commonly reported a positive response between the measured attributed and subsequent seedling growth.

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Table 2 shows a summary of the physiological attributes that were employed for measuirng the quality of forest plants that were studied by various authors (Birchler et al., 1998; Rueda et al., 2013; Sáenz et al., 2014; Ureta et al., 2018; Escobar y Rodríguez, 2019). Among these, the following were found: resistance to drought, nutritional status, root growth potential, and water potential. The critical analysis and review allowed to recommend that, to dtermine the forest plant quality, it was necessary to combine the morphological and the physiological attributes.

Tabla 2. Physiological attributes of forest plant quality.

Attribute	Measurement criteria	Interpretation
Resistance to drought	During the development and growth of the plant, they have to be subjected to different levels of humidity, that is, risk and stress caused by drought, on a weekly basis, ti quantify the gravimetric humidity content, and hereafter determine the volumetric humidity content using bulk desnity measurements.	The water potential of seedling was considered because it better reflected their immediate water status, because it integrated the seedling response in relation to its resistance to drought, and its environment.
Nutritional status	The analytic measurement of the nutritional status in plants was carried out for nitrogen, using the micro-Khjeldahl. With regard to phosphorus, La determinación analítica para el estado nutricional de las plantas se realizó para el nitrógeno, mediante el método estándar micro-Kjeldahl. In the case of phosphorus, the molybdenum blue colorimetric method was used and for potassium the flame photometry method was used.	This attribute improved the morphological criteria of plants, because it was related to the following: internal nutritional concentrations, stimulation of the development of the root system. production of new roots, number of leaves and root hair length. These factors resulted in positive growth caused by nutrient reserves.
Root Growth Potential (RGP)	To calculate the root growth potential, a seedling sample was taken and placed in containers, which were filled with a substrate with similar properties to the one used to cultivate the pnat in a nursery. Fetilizers qere also added. The initial diameter and height of the plant were measured, and after a while they were taken out of the containers and the final height and diameter were measured. Lastly, the roots were carefully removed and dried on a stove to measure the dry biomass.	The potential growth of the roots was related to the improvement in the planting and growing of plants after planting them in the field. That means that all the physiological ystems worked correctly.
Water potential of leaves	It was measured using a Scholander pressure bomb. A sample was taken from the leavs, first at dawn and at noon. They were placed in the chamber until the MPa pressure values were obtained.	It allowed to measure the water potential in plants. This determined if the plants had a good soil performance, under stress conditions, and lack of water.

Table 3 shows the indexes that were used to calculate the quality of forest plants. The authors mentioned in the literature review employed the most common indexes: shoot/root relation; Dickson Quality Index; Slenderness index; Lignification Index; aerial and root parts relations; chlorophyll fluorescence, stomatal conductance (Sánchez y Carrión, 1997; Birchler et al., 1998; Pérez et al., 2010; Sáenz et al., 2014; Ureta et al., 2018). The majority of indexes combined morphological and physiological attributes and provided technical and silvicolous knowledge about growth potential, development level of plants, soil survival, mechanical resistance, as well as gas exchange in plants, that facilitated decision-taking for the success in placing the plants in forest plantations. Table 4 shows a comparative analysis of the potential of the

attribute that influence the performance of seedlings, and determine the plant quality. The authors reported positive, negarive and non-acceptable criterions.

Table 3. Morphological and physiological indexes to determine the quality of plants.

Index	Process	Interpretation
Shoot/root relation (S:R)	It was obtained from dividing the shoot dry biomass by the root dry biomass.	It helped to estimate the growth of seedling in dry and regular sites.
Dickson Quality Index	It was calculated by dividing the full dry biomass of the plant, by the slenderness, and then adding the aerial dry biomass:root dry biomass ratio.	It expressed the potential of the plant in relation to its survival and growth. This allowed to compare the quality of plants of different sizes.
Slenderness Index.	It resulted from the height/diameter ration of the root collar.	It showed the level of mechanical resistance of plants to heavy rain, drought, grazing, among others.
Lignification Index	The ratio between total dry biomass and total wet biomass in the plant.	The index shows the lignification percentage.
Aerial and root parts ratio.	It was measured by dividing the aerial biomass by the root biomass.	This index shows the plant survival.
Chlorophyll fluorescence	The chlorophyll fluorescence (ChlF) was measured at room temperature, in controlled obscurity for 30 min using a fluorometer.	It was used as an indicator of photosynthetic energy conversion in plants. In Addition it provided informaton about the photosystem state, and identified how the chlorophyll used the absorbed energy and how much it was damaged due to excessive light.
Stomatal conductance	A porometer was used to measure this index, which measured stomatal conductance through the vapor flow from the leave to the stomal of the plant.	It allowed to determine the degree of opening of the stoma, and it was able to reduce water vapor loss and CO2 intake, this, it reduced or regulated transpiration to maximize photosynthesis.
Photosynthesis rate	An IRGA infrared gas analyser was used.	It allowed to determine the CO2 assimilation in the plant. It was directly related to the active photosynthetic radiation (light composition) and gas exchange.

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Table 4. Comparative analysis of results on the quality attributes of the plants.

Author(s)	Morphological attributes				Physiological attributes		
	Height	Root collar diameter	Root system	Shoot/root relation	Resistance to drought	Root Growth Potential	Nutritional state
Muñoz et al., (2011)	+	+	+	+	+	+	+
Johnson and Cline (1991)	↔	+	+	-	+	+	X
Grossnickle and Folk (1993)	+	+	+	+	+	+	+
Mattsson (1997)	X	+	+	+	X	+	X
Grossnickle (2000)	+	+	+	+	+	+	+
Wilson and Jacobs (2006)	↔	+	+	+	+	**X**	**X**
Prieto et al., (2018)	↔	+	↔	↔	+	+	+

Legend: The symbols represent the opinion and results of the authors about the attribute's potential to influence the performance of seedlings and to determine quality (+ means positive; - was negative; ↔ acceptable attribute; X means the author did not the attribute as positive or negative).

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According the literature about morphological and physiological attributes of plant quality, 70% informed informed that there was a positive relation between height as a growth indicatior, and the further development of seedlings in the soil; 20% mentioned that there was not relation of height as an attribute; and only 10% showed a negative relation, that is, that height was not a significant attribute to determine plant quality, because plants with greater height in harsh environments were subjected to greater water stress.

It was also shown that 91% of the reviewed literature yieled a positive relation between initial diameter and growth after plantation. This was due to the root collar diameter being an attribute of great importance, becuase it was related with nutrient reserve and assimilation. On the other hand, 9% of studies did not mentioned a relation between diameter and plant quality.

The seedlings with root systems with high morphological and physiological standards had a positive relation with plant quality. This was demonstrated on 78% of the reviewed studies, with a higher capability to develop roots after planting; nonetheless, 22% of studies did not mentioned any relation; therefore, even when it was a good attribute, it did not always predict seedling growth on the soil.

The analysis indicated that the Root Growth Potential (RGP) managed to predict seedling survival between 70 and 80%, which produced a positive morphological equilibrium, which in turn reduced plantation stressed and assured good development on the soil after plantation.

Among the attributes of plant quality, root collar diameter was deemed as trustworthy, because it facilitated higher survival, lignification and plant development under the extreme ecological conditions of the site; furthermore, the Dickson Quality Index can also be considered as a trustworthy predictor of development potential of the plant, becuase it is necessary to have plants with high potential that can adapt to the edafoclimatic conditions of the plantation site.

Conclusions

The systematic review shows that the majority of studies used morphological criteria as indexes of plant quality; nonetheless, combining morphological and physiological criteria provides better understanding of the plant's performance, both in nurseries and in the plantations.

The analyis reported that more than 90% of studies mentioned a positive relation between root collar diameter and plant growth after plantation. It can be concluded that this morphological attribute can be considered a priority when determining plant quality, which is related to growth and development potential, nutrient reserve and assimilation, and provides useful information to evaluate plant quality in the nurseries.

Conflict of interests

The authors declare that they have no conflicts of interest in this publication in any of its phases.

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Authors contributions

Authors	Contribution
Samantha García-Decoro	Research design; literature review, analysis and interpretation of data, preparation and editing of the manuscript..
Sting Brayan Luna-Fox	Participated in the preparation and editing of the manuscript, literature review, interpretation of results.
Sonia Vega-Rosete	Participated in the preparation and editing of the manuscript, literature review, interpretation of results.
Gretel Geada-López	Participated in the preparation and editing of the manuscript, literature review, interpretation of results.
Yudel García-Quintana	Participated in the preparation and editing of the manuscript, literature review, interpretation of results.