Forest Reproductive Material Quality

Subjects: Forestry

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More than two billion hectares worldwide offer opportunities for restoration. The need to accelerate reforestation programmes is caused by global climate change and human impacts. There is no consensus in the scientific community as to what goals to pursue in the implementation of programs and what methods to use to achieve the goals. Confusing terminology in the field of world reforestation, conflicting research makes it necessary to establish the basic quality criteria. The impact of the quality of forest reproductive material on reforestation cannot be underestimated. Definition of forest reproduction material (FRM) quality should be project specific, because seed and seedling quality attributes targeted and desirable for one site, could be unsuitable for others. Seed size and germinability have the strongest effect on plant performance, both in nursery and on the field. Root collar diameter is the single most useful seedling morphological attribute. The most important quality attributes of seed and seedling can be improved by simple techniques and practices. In a long term, the genetic aspect of FRM quality have a decisive role and any restoration program should be based on proper seed source to site matching, with maintaining the wide genetic diversity. In any restoration program, imperative should be the use of FRM with targeted quality attributes: physical, morphological, physiological, and genetic. Meeting demands for huge quantities of FRM, should not be at the cost of quality.

Adapted for the Encyclopedia from [Ivetić V., Novikov A.I. The role of forest reproductive material quality in forest restoration. Forestry Engineering Journal **2019**, 9, 2, 56-65.]

Setting the Framework

A quick search in Google Scholar for “forest restoration” generates more than 1 million hits and the topic is being strongly and wide discussed from different aspects. One is terminology issue, given the lack of consensus on definition of both terms: Forests and Restoration [1] . The other issue is goal of restoration. What to restore? Should we restore a degraded forest to its original state (e.g. composition and structure) as suggested by (FAO, 2019[2]) or should we try to restore the forest functions as suggested by some authors, like Stanturf et al. (Aerts, Honnay, 2011[3]; DellaSala et al., 2013 [4] ; Dumroese, Palik, Stanturf, 2015[1]; Hanberry et al., 2015 [5] ; Hart, Buchanan, Cox, 2015[6]; Stanturf et al., 2014[7]). Facing the uncertainty of climate change, restoring the “original state” at some historical reference is going to be hard and using a forward thinking approach of restoring of forest functions at the landscape level is more logical. However, in this occasion we will avoid these deep waters of debate and focus on forest reproductive material (FRM), as important part in any restoration program.

The most of ecological restoration in terrestrial systems is basically restoration of forest ecosystems, which rely on silviculture, and therefore it cannot be separated from forestry, and more specifically from afforestation and reforestation. Before we give the overview on role of FRM in forest restoration, just a quick reminder on definition of FRM. For this articles, we will use the definition of FRM given by (OECD, 2018[8]) which includes seeds, any part of the plant and whole plant (e.g. seedling) which can be used for production of plants. However, we will keep our focus on seeds and seedlings, because they are by far the most used reproductive material in forestry.

More than two billion hectares worldwide offer opportunities for restoration – an area larger than South America (Table 1). The final important aspect in our framework is the amount of FRM needed for forest restoration programs. At the Bonn Challenge website there is a map with sites suitable for restoration – more than two billion hectares worldwide — an area larger than South America. Indeed, there is a number of large initiatives, commitments, and ongoing programs for forest restoration, reforestation, and afforestation worldwide, with The Bonn Challenge and its extension in The New York Declaration on Forests as the most important in sense of commitments, but with China's as the most important ongoing programs. In paper published last year, Haase and Davis (Haase, Davis, 2017[9]) calculated that roughly 18,3 billion of seedlings need to be planted each year in next 12-year period. Here we need to notice that this calculation is based on a very conservative target density of only 500 seedlings per hectare, which is much lower compared to more usual planting density in reforestation programs, which is between 2,000 and 3,000 seedlings per hectare. In any case, it is obvious that we need a vast amount of FRM to meet a global restoration goals. And this brings us to the topic of this research – importance of quality of FRM used for restoration programs.

Table 1. Some worldwide opportunities for restoration

Program	Started	Goal	Level	Initiated by	Success
The Plant for the Planet: Billion Tree Campaign	2006	To plant a minimum of one billion trees in 2007	Global	United Nations Environment Programme (UNEP)	YES - The billionth tree was planted in November 2007. Until end of 2017, more than 15 billion trees are already planted.
The Trillion Tree Campaign	2017	n.d.	Global	n.d.	It accounts 15 billion trees planted during The Billion Tree Campaign.
The Bonn Challenge	2011	150 million hectares by 2020	Global	International commitment	By July 2018, 160.2 million hectares pledged in 47 commitments.
The New York Declaration on Forests	2014	350 million hectares by 2030	Global	n.d.	
African Forest Landscape Restoration Initiative (AFR100)	n.d.	100 million ha by 2030	Africa	Regional collaboration platform of The Bonn Challenge	n.d.
Initiative 20×20	n.d.	20 million ha	Latin America and the Caribbean	Regional collaboration platform of The Bonn Challenge	n.d.

Three-north shelterbelt forest program (the Green Great Wall)	1978	35 million ha by 2050	China	Government of China	By 2010, 26,47 million ha.
Grain for Green Program (GGP)	1999	Systematic forestation campaign	China	Government of China	By 2013, total of 27.2 million ha.
Eden Reforestation Projects	2004	To plant a minimum of 100 million trees each year	Global	I-NGO	Over 210 million trees planted by the mid-2018.
Brazil's INDC		Restoring and reforesting 12 million hectares of forests by 2030	Brazil	Government of the Federative Republic of Brazi	n.d.

Seed Quality

As any other product quality, seed quality refers to the value of the seed. Seed quality is one of those familiar terms that we all understand but find difficult to define, and it means different things to different people. For operators in seed center it is a final product, and for nurseryman it is a raw material. To get the final product of high quality, we need to optimize collecting, processing, storing, and treating methodologies. On the other side, initial seed quality can be maximized or ruined by appropriate or unappropriate nursery culture and finally by site matching. For example, inappropriate sowing date can diminish a positive effect of germination potential. At the end, having on mind that the ultimate measure of seed quality is tree growing in the field, poor seed source to site matching will diminish all seed potential and time and effort invested in production of planting material.

Definition of seed quality is usually restricted to physical and physiological condition of the seed used in nursery operations. Indeed, germination and viability percentages combined with purity and seed weight indicate the overall quality of the seed and provide the starting point for calculating sowing densities, and a basis for comparing different seed lots. However, for long-term success, the most important is genetic quality. Herewith do not neglect the use of simple techniques and equipment for seed grading (Drapalyuk, Novikov, 2018[10]), investigating the possible relationship between the physical and genetic parameters of seeds. Seed quality is a function of seed origin (including genetic improvement), seed viability, and nursery performance (Fig. 1).

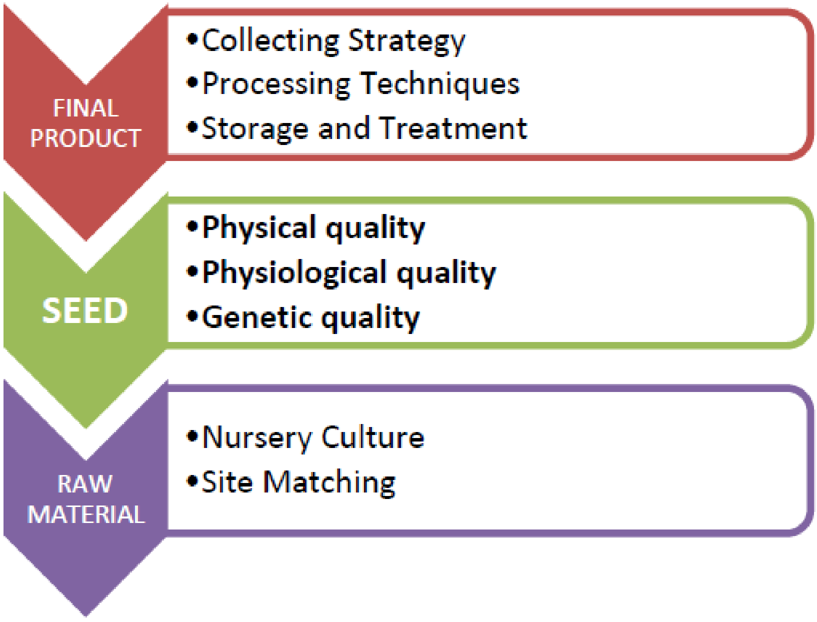

Figure 1. Seed quality is a function of seed origin (including genetic improvement), seed viability, and nursery performance

Seed Size

One of the most important physical attribute of seed quality is size, including mass or weight. Seed size depend on a collecting strategy by selection of the best representatives of tree population as mother trees. Further, with a level of breeding program and genetic improvement, seed size usually increase. But, at operational level, seed size in the particular seed lot can be increased by grading, following the logic that: Average minus poor gives better.

However, we are more interested in outputs of seed quality and we will pay more attention on effect of seed size for restoration success. There is a number of evidences suggesting that germination, seedling establishment, as well as their subsequent growth and survival increases with seed size. This effect can last up to 7 years. It seems that this is true only to a certain threshold, as it is found for some tree species, like *Albizzia lebbek* and *Dalbergia sissoo* (Khera, Saxena, Singh, 2004[11]). A good summarization of seed size effect given by Novikov (2017)[12] that larger seeds produce larger seedlings than smaller ones; that the size of the seed affects seedling growth up to a certain point; that there is an inverse correlation between size and germination; and that there is no dependence between seed size and germination – can be supported by general observations that results are not consistent; that seed size effect is a species specific; and that expression of seed size effect depends on germination and growth environmental conditions.

The seed size effect is important for both nursery production and direct seeding for forest restoration (Novikov, Ivetić, 2018[13]). At the same time, an interesting and debatable question remains the effect of the seed coat color for the growth of seedlings (Novikov, Ivetić, 2019[14]).

Germination rate, and specifically germination speed can have a large impact on nursery production or direct seeding success. From operational aspect, it is important to apply treatments for speeding up the germination and seedlings emergence. Again, we will not speak about seed treatments for dormancy breaking and germination enhancement. We will rather focus on effect of fast and uniform seed germination on seedling success.

Basically, early germination extend the growing season, giving the seedling more time to develop and grow. Early germination can result with larger seedling size and survival rate. For example, seedlings which emerged earliest experienced the lowest mortality, had the largest diameters (Boyer, Duba, South, 1987[15]). Seedlings of *Pinus taeda* and *P. ponderosa* emerging 10 days after emergence began were 35% smaller at the end of a growing season than those emerging first (Mexal, Fisher, 1987[16]). In the same experiment, Loblolly pine mortality ranged from less than 1% for the earliest germinants to as much as 23% for the late germinants. Ponderosa pine mortality ranged from less than 30% for early germinants to over 50% for late.

So, "… to increase seedling uniformity and reduce the number of culls, it is important to have uniform germination" (Mexal, South, 1991, p. 94[17]). Uniformity of germination can be improved by seed grading, stratification for dormancy breaking, and use of improved seed, i.e. sowing seed at a family level.

Seedling Quality

High quality planting material improves the likelihood of reforestation success with the uncertainty of changing environments. Similar to seed quality, it is difficult to define seedling quality. How difficult is shown in an excellent review by Grossnickle and MacDonald (Grossnickle, MacDonald, 2018[18]), with list of references that discuss seedling quality offering a different conceptual ideas. They collected a large number of references from 1916 to 2016 – and these are only references published on English.

Again, similar to the seed quality, seedling quality means different things to different people. For nurserymen, seedling is a final product – the result of seed procurement, nursery culture, and lifting and shipping operations. For silviculturist, it is a raw material which field performance and final success depends on proper site matching, planting technique, and post-planting silviculture. However, the target plant concept is developed in order to build a partnership between the two parties, by providing the right information to the nursery manager on targeted seedling quality attributes.

The overall seedling quality is a function of morphological, physiological, and genetic quality (Figure 2).

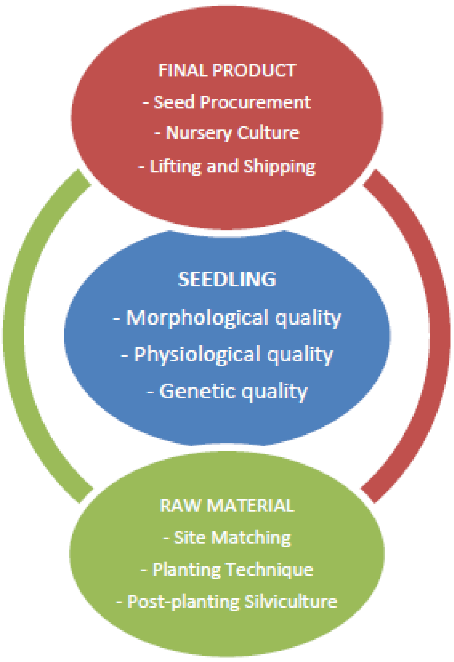

Figure 2. Seedling quality

Although measurement of physiological processes becomes more available in recent times, seedling morphology remains the basis for seedling quality assessment. There are three reasons for this: 1) morphological attributes are cheap and easy to measure; 2) seedling's morphological attributes can be considered a physical manifestation of its physiological activities; and the most important 3) relationship between seedlings morphological attributes at planting time and after planting success.

Morphological attributes can forecast seedling field performance with different reliability and for different numbers of years after planting (Ivetić, Devetaković, Maksimović, 2016[19]). Here we can see the synopsis of morphological seedling quality attributes effect on field performance. Unlike the root collar diameter, which always have a positive relationship with seedling field survival and growth, for some morphological attributes, like seedling height, there are opposite relationships reported with field performance. This relationship can be positive or negative, it is a species specific, but also can depend on site conditions, as we can see on these graphs. On harsh sites, relationship between seedling height and survival is usually negative, and this can be explained by unfavorable shoot to root ratio and water balance.

On the other side, on favorable sites, initial morphological attributes of seedlings have a low forecasting ability for survival, but some of them, including root collar diameter, can forecast plant growth up to 12 years after planting.

Although there is no “silver bullet”, root collar is considered the single most useful morphological attribute to measure. Here we can see just some of simple nursery practices which can increase seedlings root collar diameter.

Genetic quality

On long run, the most important aspect of FRM quality is genetic quality.

“The use of high quality seed is imperative because it increases the early success by improving the establishment rate, and also forest stand performance due to increased genetic gain” (Grossnickle, Ivetić, 2017, p. 108[20]). Use of genetically improved seed is proven to result with a superior seedling field performance. The use of orchard seed of *Pinus sylvestris* instead of stand seed significantly increased the seedling mean height by 25% and the mean height per sown germinable seed by 60% (Wennström, Bergsten, Nilsson, 1999[21]). This superiority is confirmed for four-year survival, as well (Wennström, Bergsten, Nilsson, 2007[22]). Here we can see the genetic gain for the most modern seed orchards of Scots pine and Norway spruce established before 1998 in Sweden. The gain is an estimated percentage production advantage compared to stand seeds assuming only seed orchard progeny in the regeneration. The benefit of using genetically improved seed is well recognized, and we are witnessing the global increase in use of seeds from seed orchards, up to 100% for some species.

However, genetic quality of FRM is not only about genetic gain. Seed origin, i.e. species and/or provenances to planting site matching have a decisive impact on success. Facing the additional challenges connected to the climate change, different provenancing strategies are offered, from traditional use of local provenances, to predictive, composite, admixture, and climate-adjusted provenancing.

As we mentioned before: Forest restoration should be forward thinking, and more active approaches, like assisted migration will become more important in changing climate. These new restoration strategies rely heavily on genetic quality.

Another important aspect of genetic quality is level of genetic diversity. It is often necessary to trade off between genetic diversity and genetic gain expressed with desirable traits like vigor/fast growth, pest tolerance/resistance and quality products/service. On the other side, genetic diversity define the tree population potential of evolutionary flexibility, adaptability, and resistance to biotic and abiotic disturbance.

Every step in production of forest reproductive material, from collection to nursery production, has an effect on genetic diversity mainly by directional selection. However, the review by Ivetić et al. (Ivetić et al., 2016[19]) revealed no consistent decrease of genetic diversity during forest reproductive material production and planting.

The following review on genetic diversity in planted forests (Ivetić, Devetaković, 2017[22]) revealed that in most cases, there are no significant differences in genetic diversity between natural and planted forests, followed by an almost equal number of cases with decreased and increased level of genetic diversity. These results shows that the size of parental population is determinant for the level of genetic diversity in the new forest, with the provenancing and seed collection strategy as the most important management practices in planting projects. In addition, these results shows that, if properly designed, seed orchards can provide genetically superior seedlot with wide genetic diversity.

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Keywords

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