Policy Brief
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Quality seed for tree planting: Supporting more effective agroforestry and forest landscape restoration by learning from crop Integrated Seed System Development

Key recommendations

- Government and donor initiatives wishing to support tree planting, including through forest landscape restoration, are recommended to support the creation of an enabling environment for sustainable tree seed and seedling systems that are capable of producing and distributing quality planting material to all tree planters.
- Formal national government tree seed actors, such as ministries of forestry and of agriculture, and national tree seed centres, should support integration of formal and informal tree seed and seedling systems through a multi-stakeholder process of integrated seed systems development.
- Formal national government tree seed actors should also spearhead the identification and documentation of tree seed sources for agroforestry, forest restoration and other tree planting. Mobilizing and building national capacity; and mobilizing, conserving and domesticating a wealth of native species and their genetic resources for the future, are urgent tasks.
- Research on agroforestry and tropical forest restoration should prioritize operational aspects of scaling up tree seed and seedling systems, taking into account constraints in the creation of an enabling environment as presented in this policy brief.

Summary

Tree planting in agroforestry and wider restoration work often relies on poor quality tree seed. However, the high demand for tree seed from large global restoration commitments and a new focus on accountability provide the opportunity for change. The goal should be to release or realize the potential of rural organizations, small-scale private nurseries and local communities to effectively participate in tree seed supply systems. This can be done through a process of integrating formal and informal approaches, and by supporting the development of informal suppliers into a well-functioning commercial sector. In this brief we outline the current status of tree seed supply in the tropics and compare it with the crop sector, to understand what can be learnt from the latter, and where tree seed supply provides unique challenges. We discuss areas where policy to support tree seed supply can be improved.

Introduction

The purpose of this policy brief is to outline how best to source good quality tree planting material, especially in the tropics, to ensure ‘the right tree is planted in the right place for the right purpose’. Unless best practice is followed, tree planting often fails to meet its objectives. This publication has been written primarily for leaders of non-governmental

organizations (NGOs) and other institutions that coordinate tree planting, tree planting practitioners themselves, relevant staff in national ministries of agriculture and forestry, and policy makers in government.

In the rest of this brief, we have used the term 'seed' to include tree seed and other propagation materials, which may include vegetatively-propagated planting stock. We have applied the term 'seed system' to describe any means by which these materials are produced, exchanged and delivered to growers.

Tree seed for forest landscape restoration, agroforestry and wider tree planting

Forest landscape restoration has become an increasingly important concern in recent years, with ambitious commitments made in the last two decades. An example is the current Bonn Challenge which aims to restore 350 million hectares of degraded and deforested landscapes by the year 2030. Of this, it has been estimated that just over a third will be achieved by restoring natural forests and woodlands through natural regeneration and planting. On top of this, it is anticipated that plantations will occupy about 45% of the 'restored' area. Finally, but importantly, it is expected that agroforestry will account for the remaining fifth, with much of this tree planting on smallholder farms.

There are clearly a range of approaches for restoring tree cover when planting, and each relies on a tailored tree seed system. Sometimes this system is relatively simple, as is generally the case in temperate regions with well-developed infrastructure and where the number of tree species to be planted is fairly limited. Large-scale tree plantation establishment in tropical regions where only a few well-known industrial tree species are grown also has a relatively simple seed system. However, the seed system for smaller scale but cumulatively very important tree plantings in the tropics involving smallholder growers is much more complex. These growers apply agroecological practices such as agroforestry and rely on high levels of agrobiodiversity in their farming. They therefore plant a diversity of tree species in their farms, and when they are involved in natural forest restoration. Here, there is a lack of access to, limited knowledge about, and few incentives for establishing, suitable tree seed sources. It is therefore a huge challenge to provide good quality tree seed to these growers.

A fundamental problem with forest landscape restoration planting in particular has been the focus on 'hectares restored' rather than the quality of the planting undertaken. Recently, though, quality issues have arisen in the agendas of various societies as some restoration initiatives have notably failed to address people's ecological and social concerns. Although this is a welcome development, the discussion so far has still not paid much attention to the foundational need to access

This breeding seedling orchard (BSO) of Cordia africana *at ILRI/ICRAF in Addis Ababa was established in August 2018. The photo was taken in May 2019, 11 months after planting (Photo: ILRI/Apollo)*

tree seed of higher quality for better planting. Only limited attention, for example, has been given to the enormous task of producing tree seed that is matched both environmentally to restoration sites and functionally to growers' planting purposes.

Even putting aside quality issues, the number of trees needed for planting to support restoration commitments can at first seem daunting. If we assume on average that 1000 tree seedlings are required for planting for every hectare of land to be restored under the current Bonn Challenge commitment, then this equates to 350 billion seedlings. Taking into account typical seed germination rates and mortalities in the tree nurseries that produce these seedlings, as well as seedling mortalities after establishment that mean replanting is required, this could equate to a need for around 1.4 trillion tree seed initially. Then we must take the next step and consider quality: globally, the needed seed must come from many different tree species, perhaps in their thousands, if concerns to maintain biodiversity are to be effectively addressed during planting. Furthermore, for each tree planting site, consideration needs to be given to match the tree seed used to the specific environment and planting purpose at that site. These environments and planting purposes can vary enormously.

We illustrate the importance of quality in tree seed sourcing in Figure 1. This figure shows the losses (or gains) that could occur when genetically inferior (or superior) planting material is used. In this illustration, we have explored the concept of quality in terms of production gains and losses. But quality could alternatively be measured in terms of how good different germplasm sources are in providing environmental services. The figure illustrates that seed quality, defined further in Box 1, is not an 'all-or-nothing' measure, but should be viewed on a sliding scale. The intention of upgrading quality is not necessarily to reach an 'optimal' quality, which pragmatically may be unattainable, but to move as far as we can along an axis of improved quality (i.e., as far as possible to the right in Figure 1). The level of effort taken to bring about this movement should be commensurate with the value of the end product or service intended by tree planting. Thus, a tree potentially providing a very valuable product (or service) may merit more attention to genetically improve its productivity (or service provision) than one that is of lesser potential.

In the case of environmental service provision, the most important quality-determining feature may be the level of improvement in matching the tree to the planting environment. In this case, 'high quality' would mean that seed is well adapted to the planting site. This could entail considering the

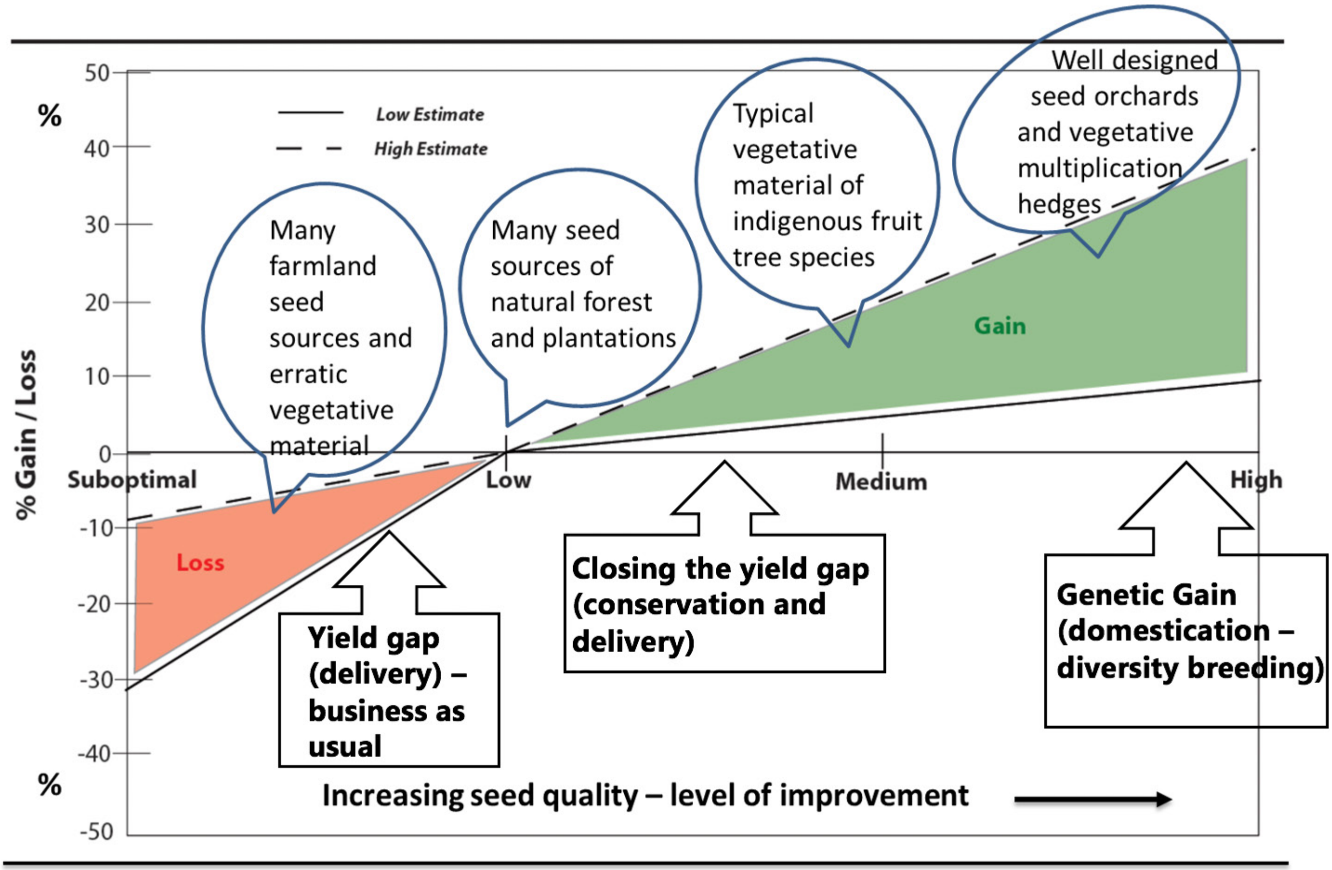

Figure 1: Loss and gain based on choice of tree seed source and level of genetic improvement. Many sources used in agroforestry and natural forest restoration are sub-optimal (at left of the figure), with only a few examples of medium- and high-quality sources (moving to the right of the figure). See also Box 1, which explains quality criteria, and Box 2, which provides costed estimates of the benefits of investing in quality. Our figure focuses on quality in terms of productivity, but equally quality could be considered in terms of environmental service provision.

'natural' conditions of the site, as well as how these conditions have been altered through landscape degradation, including any ongoing anthropogenic climate change that could alter site conditions within the lifespan of the tree.

Although it may seem tempting to put off tree seed quality considerations on the basis of the effort involved, neglect of this aspect could have huge negative consequences. It may amount to billions of tonnes of lost sequestered carbon, translating into a loss to the global community as a whole. It could also involve billions of dollars in lost revenue, which is a loss to the growers, specifically. This does not even begin to consider the broad impacts of lost biodiversity for reduced environmental sustainability. We describe further some of the costed benefits of investing in tree seed quality in Box 2.

In the following sections, we will elaborate on quality issues. In doing so, we will focus on how seed 'input supply chains' could be improved to support successful tree planting.

The starting point for improvement: understanding tree seed system history

Smallholder farmers, indigenous people and other local community members are key participants in both agricultural development and forest landscape restoration. Their access to high quality tree planting material is important for improving their livelihoods and for strengthening the recovery of damaged ecosystems. However, the tree seed systems that currently support them do not work well. Understanding these people's constraints to accessing good quality tree planting material is therefore of crucial importance to ensuring positive change.

A good place to start is to look at annual crop seed systems and compare these with tree seed systems. The literature reveals somewhat parallel histories of both in the tropics. Over 50 years ago, governments and donors established parastatals for 'formal' (top-down) delivery of seed inputs of

Box 1. Defining seed quality

The quality of seed can be separated into three aspects: genetic, physiological and physical. This policy brief focuses on the genetic quality. Measures of genetic quality tell us about the suitability of seed for a particular growing site, and predict the health and growth of future plantings.

Genetic quality

Adaptation of seed sources: a single tree species is often distributed naturally across wide environmental variation. This means that different populations of the same tree are often adapted to different environments. This needs to be taken into consideration as a quality criterion in seed sourcing, with matching of seed source to planting environment. Seed sources from different tree populations (also known as 'provenances', sometimes also referred to here as 'varieties' for purposes of comparison) can be regarded in the same way as varieties for crop seed, with their own unique features.

Outcrossing and inbreeding: most tree species are outcrossing and suffer from inbreeding if individuals that are too related mate. This means that deploying genetic diversity in tree planting is a crucial issue and seed collections must also sample this diversity. A good standard for seed collection is that it should sample seed from at least 30 'mother' trees. A planted seed production stand would also contain at least this many different trees (normally more).

Vegetative material: sometimes, vegetatively-propagated material is used in tree planting. One reason for this is that it allows the 'true-to-type' propagation of selected genotypes. This is important for well-known tree crops such as mango, cocoa, coffee, tea, rubber, cashew and oil palm, as well as lesser-known indigenous fruits, and some timber trees. Here, genetic quality is determined by clone identity, as well as the number of different clones distributed in a landscape (to ensure adequate genetic diversity). Although specific varieties of such crops are often well defined and in principle in high demand, smallholders' access to fruits/commodity crops is still severely constrained, details of which are not covered in this brief.

Physiological quality

Seed used for planting must be collected in the right state from 'mother' trees. This means that it is mature and has completed all necessary physiological processes, to later germinate and produce a healthy plant. Seed must also have been treated appropriately during collection and storage, such that its capacity for germination and growth has not been damaged. The physiological quality of tree seedlings also depends on good nursery practices.

Physical quality and purity

The seed used for planting should not be physically damaged, including by insects and diseases. A seed lot should also be free of impurities such as fruits, twigs and soil.

both annual crops and trees. In the case of trees, the focus was on plantings to establish large-scale industrial plantations. However, later, more attention was paid to delivery of tree seed through these formal means to smallholder farmers (they have always been the focus for annual crop seed delivery).

About 40 years ago, a number of important changes in seed system design began. Among these was the privatization of parastatals to create initial commercial incentives in crop and tree seed supply. Subsequently, and largely due to the limited success of privatization in reaching smallholders, NGOs became increasingly engaged in supplying planting material of both crops and trees, thereby absorbing the large transaction costs involved in reaching smallholders in rural areas.

More recently, there has been a change in emphasis with crop seed systems to more demand-oriented (market-driven) supply. Rich discussions and experimentation have informed the implementation of such new approaches for annual crops. However, there has not been a commensurate effort in the case of tree seed systems. It thus remains the case, to the current day, that a key constraint in formal supply systems is the inability to effectively provide smallholders with a wide diversity of tree species. Furthermore, efforts to enhance quality in 'informal' tree seed supply systems still remain largely unsupported, due to lack of appropriate policies and funding.

Building on the crop-based approach for tree seed systems

We can learn much from crop seed systems that is relevant for tree seed. However, there are also some unique aspects of trees that have to be taken into account for more optimal seed delivery.

First, whereas for annual crops the germplasm that is planted on the farm is generally seed itself, for trees it is normally seedlings. The entity that is at the final node in tree seed supply to growers is therefore a tree nursery rather than an agro-vet shop as is often the case for annual crops.

Box 2. Cost benefit considerations for investing in quality tree seed

Plantation forestry is a good starting point for illustrating the value of paying proper attention to the quality of tree planting material. Here, annual internal rates of return of 10% and higher from tree genetic improvement are common. Seed source selection can provide physical gains of 10% to 30% in production. Selection within a seed source may add a further 10% to 25% in gain, and an additional 15% to 25% gain can typically be added by formal breeding. Through fairly simple processes that do not require large investments, it is thus possible to achieve 35% to 80% gain. This investment in seed quality typically translates into only a small fraction of the total costs of establishment of a tree stand.

Conversely, when the matching of planting material to planting site is not considered or only done inadequately, huge losses in productivity opportunities are common. The loss may be complete, if seedlings once planted simply die, or may be in the form of severely reduced productivity, if the seedlings are mal-adapted but still manage to survive. Adding up the loss from careless choice and the additional opportunities of gain from well planned genetic improvement can easily provide for manifold benefits. For example, widely planted species of acacia illustrate the importance of utilizing the right material, where the careful choice of an improved variety developed from superior natural provenances versus using an (inbred) 'landrace' (local variety) can provide up to four times higher volume growth.

As another example, consider the total restoration commitment of the African Forest Landscape Restoration initiative (AFR100), which now exceeds 100 million hectares. The cost of the planting material based on current practices in tree seed sourcing, which do not insure against the huge potential losses described above, is already high. At an additional cost of investment in germplasm quality, it will be possible to avoid this risk and guarantee much higher benefits. For example, assuming 20% of the restoration target area of AFR100 is reached with adapted, diverse and higher yielding planting material (at an extra cost per seedling of less than 5%), according to our own estimates the tangible extra values that could be derived are:

- An increase in the Net Present Value (NPV) of tree products of USD 5.7 billion.
- An extra 4 million tonnes of soil conserved per year.
- An extra 19 million tonnes of sequestered CO_2 in additional biomass in target systems, with an increase of NPV of almost USD 310 million additional to the figure above.
- An increase in employment of over 80,000 jobs in harvesting additional tree product volumes.

Extra income benefits after processing of tree products, as well as extra benefits for biodiversity and human health (fruit consumption, etc.), have not been included in the above calculations and are likely to increase total value substantially.

Second, demand and supply operate on a different scale for tree seed. This is because of the much larger number of seed produced by a single tree than by an annual crop plant. Whereas, for example, a single maize plant may produce a few hundred seed in a growing season, a single tree may produce tens of thousands of seed in a year, and not only for one year but for its whole lifespan once it matures. In addition, to ensure genetic quality, the trees that are used to produce seed for planting should be more than one or a few individuals (see Box 1). Taking these facts into account, it is evident that a tree seed production stand may provide sufficient planting material for a very large number of growers, each of whom might only want to plant a few trees of any particular species.

It stands to reason then that any tree seed production stand will be able to service a relatively large geographic area. Thus, individual custodians of tree seed sources must connect to many tree seedling nurseries within that area, while nurseries must network with many different seed source custodians to capture the wide variety of species that their clients may want to plant. Hence, networks operating on a landscape scale to support germplasm exchange have a particularly important role to play in tree seed supply.

Countering this, however, is that an individual tree seed source is not suitable for planting everywhere, but rather every seed source must be described with respect to its recommendation domain based on environmental characteristics. A single tree species will typically have different seed sources that are suited to different environments (see Box 1), and using the wrong seed source at any given location may lead to large losses (see Figure 1, red area). Thus, there are two opposing forces at work here that must be balanced: the scale of the tree seed supply enterprise needed to make it profitable versus the scale of the recommendation domain.

Third, institutional arrangements around seed supply are different for trees and annual crops due to the time span for seed production. In the case of annual crops that produce seed after a single growing season, the functions of varietal seed supply can be separated along the value chain into breeder, foundation and commercial seed. Initial crop variety development through to production of foundation seed is typically handled by public institutions, while the up-scaling of varieties through to production of commercial seed from foundation seed is carried out by a number of different actors.

On the other hand, with trees that take several years to mature, it is not practical to separate the categories of breeder, foundation and commercial seed. In most countries, all formal tree seed sources are thus registered and managed by a single entity, most often a publicly-supported national tree seed centre (NTSC). In addition, most tree seeds are collected and distributed from informal sources that are neither described nor registered. Furthermore, in the tropics, only for commercial forestry species and a few other examples are 'varieties' (meaning populations adapted to specific environments) documented, with only a few initiatives working to identify and document seed sources as commercial.

The lengthy time span of seed production for most trees also has an additional effect. This is related to the flexibility or speed of response that is possible in seed sourcing. Whereas with annual crops foundation seed can be quickly dispersed to the locations where it is needed for scaling through commercial seed production, this is simply not possible for trees that take several years to mature.

These features related to time span all lead in the same direction to result in a large untapped resource of tree varieties that have not yet been documented and utilized for the benefit of smallholders and others in local communities in the tropics.

The broken value chain in agroforestry and tropical forest restoration

A tree seed system can be considered as part of a value chain that begins with the source of tree seed and ends at the market for the tree product or environmental service, or even at the consumer level. The quality of initial input – the

Climbing for seed collection in a Shorea *species in natural forest in Pulau Laut, Indonesia (Photo: University of Copenhagen/Jens-Peter Lillesø)*

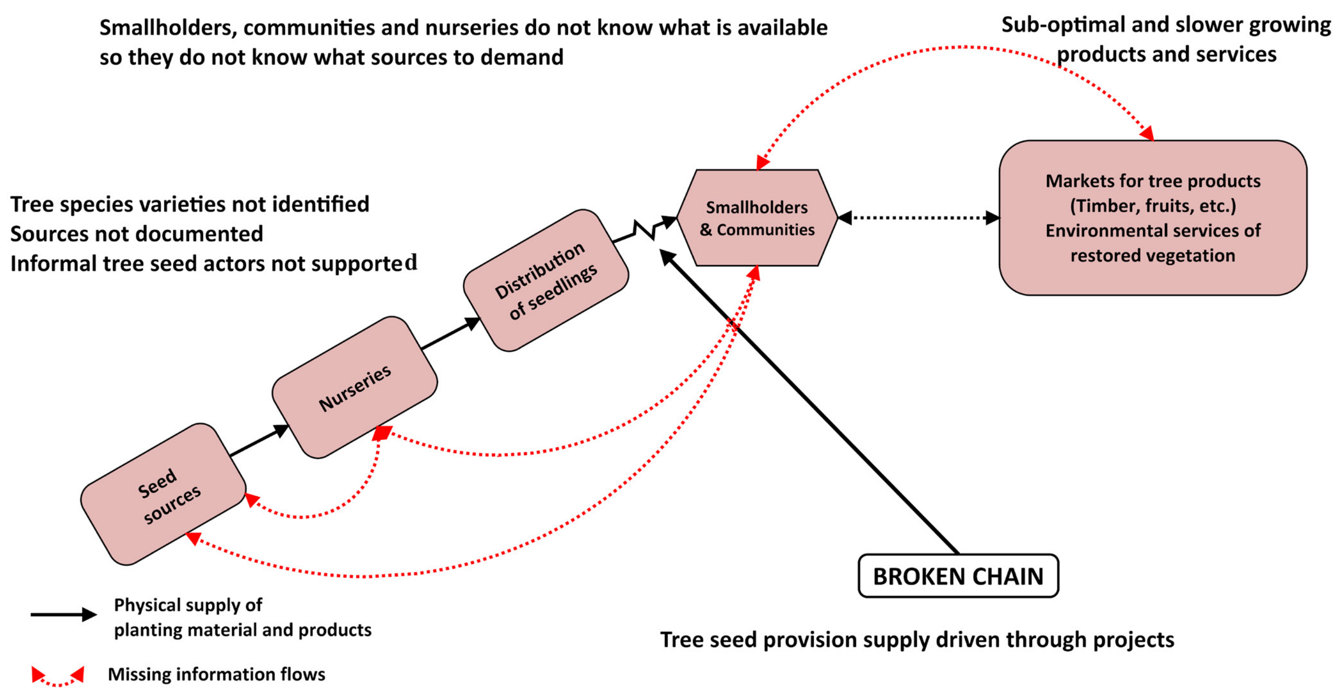

Figure 2. The broken value chain in agroforestry and tropical forest restoration that requires fixing

tree seed source – determines productivity and quality of the product or service at the end of the chain. In these terms, the often observed failure to apply quality criteria to tree seed sources represents a break in the value chain (Figure 2).

The typical 'NGO approach' to tree seed supply provides a good example of this broken chain. Non-governmental organizations and other restoration project implementers generally organize and source tree seed from undocumented (often farm tree) sources to supply project-funded nurseries, which in turn provide tree seedlings 'for free' to growers. Not only does this approach limit quality, but 'for-free' provision undermines the involvement of existing networks of small-scale commercial seed dealers and private tree nurseries, that could guarantee a more sustainable supply of better quality germplasm. The NGO approach to tree seed delivery effectively delinks input supply from product (and environmental service) provision and the market. The equivalent delivery approach for annual crops, known as 'emergency seed aid', has been severely criticized.

Creating an enabling environment for improved tree seed systems

To improve the current situation it is first necessary to engender the recognition that sourcing quality tree seed is generally only a very small fraction of the overall cost of any tree establishment activity. Second, it is necessary to promote a broader understanding that the additional benefits from planting good quality seed, in the superior products and environmental services ultimately realized, can be large. These benefits are generally much larger than any initial extra cost incurred in sourcing better quality seed (Box 2).

Encouraging a change in mind-set of restoration project coordinators to shift their emphasis away from quantity to quality is particularly important. Apart from emphasizing the efficiency benefits of focusing on quality (as outlined in the previous paragraph), another approach is to stress the ethical responsibilities of coordinating organizations to tree planters. This will ensure that the growers' activities are a success. Thus, both public interest groups and tree planting organizations themselves should be further educated about how tree seed quality affects planters, and how low quality can impose a huge burden, especially when planters are local communities and individual smallholders who depend heavily on tree planting success. It should be made clear that, unless quality tree seed is used, these growers will not obtain the benefits they have been promised for tending and protecting 'restored' landscapes.

It is also useful to learn from the Integrated Seed System Development (ISSD) approach for annual crops, where the effectiveness of both formal and informal delivery systems are recognized, and the importance of integrating the two is acknowledged. Furthermore, a key lesson from the ISSD transformation of the crop seed sector, from being supply- to market-driven, indicates that the marketing of new varieties is a key driver in seed systems.

For crop seed, there is thus a continuous demand for public investments associated with strengthening seed production entrepreneurs and dissemination systems. The key informal seed actors in ISSD for trees are seed source custodians and private tree nursery owners. They are therefore key targets for the dissemination of both planting material and information about suitable varieties of trees.

Figure 3: Facilitating an enabling environment for the transformation of tree seed systems from being supply- to demand-driven.

An enabling environment for tree seed systems would thus entail integration of the formal system – involving NTSCs and national agricultural research organizations (NARs) – with informal actors. Here, restoration projects would change their approach from direct seed supply to demand creation for seed quality, and NGOs would promote the production and distribution of quality seed by a coalition of both formal and informal actors. This could then support the transformation presented in Figure 3.

The formal system must further support the development of seed source-to-nursery rural networks by registering and describing quality seed sources in natural forests, farmland and/or plantations for immediate use. At the same time, seed source custodians who will maintain and protect such sources must be identified. For high-priority species (high-value and high-demand), the formal system must support establishment of seed production stands (seed orchards) for future planting and for genetic improvement.

Furthermore, knowledge about all sources and where they should be deployed must be made available for the use of nursery networks, smallholders and communities who are the ultimate users of tree seedlings. NGOs also have an important role here. They would be involved in facilitating the rural networks that constitute the input side of value chains for tree planting. They would also support the marketing of high quality tree products produced by high quality seed inputs.

Conclusion

The solution to the ‘broken value chain’ described above is a transformation of tree seed systems, where quality is an important parameter for the use of planting material, and where the roles of actors involved in supply are re-oriented. Here, the supply of seed is based on demand for specific varieties, instead of supply of seed of unknown quality. The goal of transformation should be to release or realize the potential of rural organizations, small-scale private nurseries and communities to participate in tree seed systems through a process of integrating both the formal and informal systems, and by supporting development of the informal sector into a well-functioning commercial entity.

There are several circumstances which suggest that it is possible to transform tree planting for tropical forest restoration and broader purposes. First, a similar transformation is already underway in the agricultural sector, where NGOs in several parts of the world have transformed from being suppliers of seed to supporting the creation of an enabling environment for informal actors to support smallholders’ adoption of new crops varieties. Second, small-scale private tree nurseries are active all through the tropics and could become knowledgeable seedling producers, if appropriately supported. Third, communities and smallholders are already custodians of forests and of tree populations on their farms; they have the potential to further develop in this role and be recognized for it. Fourth, the formal sector can, with support from NGOs, develop information exchange and certification systems that establish the quality of planting material as a determining parameter for demand and supply, as evidenced by such systems being in place in several developed countries. Finally, the technical knowledge required to support an enabling environment is available; the problem is that it has not yet been fully utilized and brought to scale, except for a few commercial tree species.

Further reading

1. Borman GD, Hassena M, Verhoosel KS and Molenaar JW. 2020. Guiding sector transformation: the case of integrated seed sector development in Ethiopia. June 2020. Wageningen Centre for Development Innovation.
2. Graudal L and Lillesø J-PB. 2007. Experiences and future prospects for tree seed supply in agricultural development support – based on lessons learnt in Danida-supported programmes 1965-2005. Ministry of Foreign Affairs. Copenhagen, Denmark.
3. Graudal L, Loo J, Fady B, Vendramin G, Aravanopoulus FA, Baldinelli G, Bennadji Z, Ramamonjisoa L, Changtragoon S and Kjær ED. 2020. Indicators of the genetic diversity of trees – State, pressure, benefit and response. State of the World's Forest Genetic Resources – Thematic Study. Rome, FAO. http://www.fao.org/documents/card/en/c/cb2492en/, https://doi.org/10.4060/cb2492en.
4. Lillesø J-PB, Harwood C, Derero A, Graudal L, Roshetko JM, Kindt R, Moestrup S, Omondi WO, Holtne N, Mbora A, van Breugel P, Dawson IK, Jamnadass R and Egelyng H. 2018. Why institutional environments for agroforestry seed systems matter. *Development Policy Review* 36: O89–O112
5. Lillesø J-PB, Graudal L, Moestrup S, Kjær EDK, Kindt R, Mbora A, Dawson IK, Muriuki J, Ræbild A and Jamnadass R. 2011. Innovation in input supply systems in smallholder agroforestry: seed sources, supply chains and support systems. *Agroforestry Systems* 83: 347-359.
6. Subedi A and De Boef WS. 2013. Promoting Integrated Seed Sector Development. ISSD Technical Notes Issue no 1. Centre for Development Innovation, Wageningen UR & Royal Tropical Institute, Amsterdam.
7. Urzedo DI, de Fischer R, Piña-Rodrigues FCM, Freire JM and Junqueira RGP. 2019. How policies constrain native seed supply for restoration in Brazil. *Restoration Ecology* 27: 768-774.

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Cover photo: A variety of species of tree seedling being watered at a tree nursery in Burkina Faso (Photo: ICRAF/Sophie Mbugua)