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RESEARCH PAPER

Tree Seed and Seedling Supply Systems: A Review of the Asia, Africa and Latin America Models

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Abstract The paper reviews tree seed and seedling supply systems in sub-Saharan Africa, Asia and Latin America. Across these regions, the review found that some of the germplasm supply systems do not efficiently meet farmers' demands and environmental expectations in terms of productivity, species and genetic diversity. In some countries, germplasm used is mostly sourced from undocumented sources and often untested. Germplasm quality control systems are only found in a few countries. Appreciation of the value of tree germplasm of high genetic quality is low. Non-government organisations (NGOs) in many African countries play a prominent role in the supply of germplasm which is usually given to farmers

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without charge. The practice of giving farmers free germplasm by NGOs in many African countries and also government participation in germplasm supply in some Asian countries has been blamed for crowding out private entrepreneurs, although this is not substantiated by any evidence to suggest that the smallholder farmers are willing and able to pay for the germplasm. In some Latin American countries, private companies, government and NGOs provide farmers tree germplasm in a partnership in which farmers provide land and labour in return. Overall, tree germplasm markets are large in Asia, due in part to large afforestation programs, intermediate in Latin America and small in Africa where smallholder farmers constitute the market. In countries where germplasm quality control is practiced, it is either through a legal framework or voluntary. A few countries in Africa, Asia and Latin America have developed protocols for certification of tree seeds based on the OECD. Some germplasm suppliers use branding as a way of differentiating their germplasm as having superior quality. To enhance the use of high quality germplasm, there is a need to demonstrate the value of using such germplasm and raise awareness of germplasm quality among the farmers and policy-makers.

Keywords Germplasm quality · Species diversity · Genetic diversity · Certification · Branding · Markets

Introduction

A sustainable supply of high quality agroforestry tree germplasm (seeds, cuttings or other propagules) is fundamental to the success of agroforestry scaling-up initiatives and tree planting in general. The lack of high quality tree planting material has frequently been identified as a major constraint to the successful establishment of agroforestry production systems (Harwood et al. 1999; Kindt et al. 2006). National tree seed centres that were established in many countries to supply high quality tree seed face challenges to reach many farmers due in part to their central location (Aalbæk 1997; Koskela et al. 2010). High prices charged by the centres are often an impediment to sales. The low seed replacement rate for trees and the small seed requirements of smallholders provides further challenges for development of viable tree seed enterprises.

To improve the supply of tree germplasm, Denning (2001) suggested that the focus of research must be on developing and applying better methods of forecasting germplasm needs, and also on establishing effective, low-cost, sustainable, community-based germplasm production and distribution systems. To this end, this paper reviews tree seed and seedling supply systems (production, distribution, markets, and quality control systems) in selected countries in Africa and Asia and to a limited extent Latin America. The paper also reviews how the challenge of providing sufficient species diversity and genetic diversity is addressed. Gaps in research are also identified.

The tree germplasm supply systems consist of three major players, namely the producers, distributors and users, each undertaking a range of activities (Fig. 1).

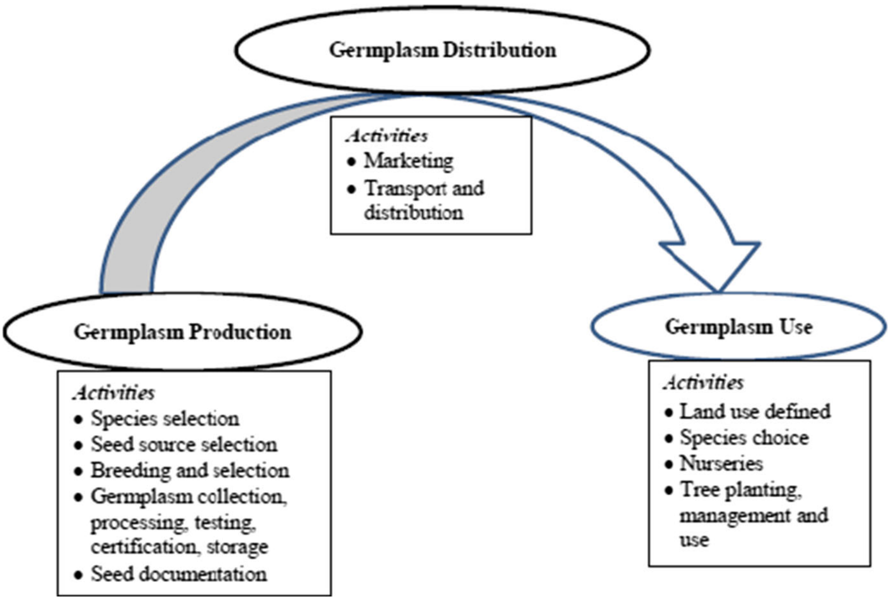

Fig. 1 Generalized tree seed supply model (adapted from Schmidt 2007)

These complex systems have many challenges, particularly related to germplasm production, quality control, marketing and distribution. Broadly, there are two types of tree germplasm supply models, namely centralized and decentralized, with several variations depending on the source of the germplasm and the actors involved in germplasm production, distribution and use (Lillesø et al. 2011). The role of the various actors [farmers, Non-government organisations (NGOs), government, private] in a sustainable tree germplasm supply model is illustrated in Table 1.

Tree Seed Production Systems

The use of low quality tree germplasm remains widespread despite many recommendations to produce and grade tree seed to reflect its genetic worthiness (Lillesø et al. 2011; Nyoka et al. 2011a) and encourage the use of high quality seed to improve the productivity of woodlots, plantations and agroforests. The use of high quality tree germplasm has largely been achieved for industrial plantation tree species in most of the developed countries of North America and the Organisation for Economic Cooperation and Development (OECD) member countries (Nanson 2001). Some developing countries including Rwanda have developed national regulations for the production of high quality tree germplasm based on the OECD certification scheme for forest tree germplasm (Kalinganire 1989).

Tree germplasm is obtained from a variety of sources which include seed stands, plantations and seed orchards (Koskela et al. 2010). In natural forests, germplasm is collected from seed zones based on geographic factors—in particular elevation,

Table 1 Appropriate roles of stakeholder in the tree germplasm production and supply chain

Activity	Actor			
	Farmers	Private sector	Public sector (government)	NGOs
Development of enabling regulations, policies and laws on germplasm quality			√	
Development of seed sources maps		√	√	
Seed collection	√	√	√	√
Establishment of seed sources	√	√	√	√
Seedling production	√	√	√	
Quality control—compulsory		√	√	
Quality control—voluntary	√	√		
Germplasm distribution	√	√	√	√
Strategic seed reserves		√	√	
Germplasm conservation and maintenance	√	√	√	
Importation and intensive testing of tree germplasm for adaptation		√	√	
Testing tree germplasm for local (non-intensive) conditions	√			√

Source Adapted from Lillesø et al. (2011)

latitude and rainfall—for deployment in comparable environments. Many countries in Africa and Asia have not developed such tree seed zone maps to aid in tree seed collection and deployment. Consequently, germplasm of most native tree species is still collected from the most accessible sections of forests without consideration of quality of the trees, and continues to be deployed indiscriminately in the landscape resulting in reduced productivity of woodlots and agroforests established from such germplasm. Limited awareness of the importance of germplasm quality coupled with absence of policy regulating germplasm quality in many countries are the likely reasons germplasm is often collected in such a cavalier manner (Harwood et al. 1999; Roshetko 2001; Mulawarman et al. 2003).

Sources of Tree Germplasm

In Indonesia, 44 % of seed collectors contracted by the seed buyers collect seed exclusively from plantations, 36 % collect seed from farmland and 20 % collect from both plantations and farmland (Roshetko and Mulawarman 2008). Approximately 74 % of farmers and organizations in Indonesia that collect tree seed to meet their own needs, source seed from farmland (Roshetko 2001). The pattern is similar in the Philippines where Koffa and Roshetko (1999) found that 66 % of the tree seed collectors in Lantapan collected seed from remnant trees on farms, 13 % collected from plantations and 13 % collected from natural forests. In Kenya, farmland is the most common source of tree germplasm, followed by plantations, natural forest and seed orchards (Mbora and Lillesø 2007; Lillesø et al. 2011). These observations are consistent with those in Malawi (Nyoka et al. 2011b) where the major source of seed are remnant trees in farmers' fields, followed by natural forest and seed orchards. A survey in Uganda established that 82 % of seed collectors collected seed from remnant trees on farms (Asare and Pedersen 2004).

The sources of tree germplasm used by farmers in the Peruvian Amazon vary with the species. For fruit tree species, more than 65 % of the germplasm is sourced from farms (Brodie et al. 1997). Although most timber tree species are naturally regenerated, when planting does occur, more than 50 % of the germplasm is sourced from farms and the remainder from natural forest (Brodie et al. 1997).

Besides own seed collections, farmers also access germplasm through exchanges with neighbours, and buying or receiving it free of charge from NGOs, government and private companies. In Uganda, for example, 7 % of farmers reported buying tree seed from the market (Asare and Pedersen, 2004) compared to 30 % in Burkina Faso (Ræbild et al. 2005). Over 12 % of the farmers in Burkina Faso indicated that they got the seed for free. In the Philippines, Koffa and Roshetko (1999) found that 79 % of the farmers obtained seed from either government agencies or NGOs, and 20 % bought or exchanged seed. A survey in 6 districts of Malawi showed that 53 % of the farmers received seed from NGOs and government, 40 % made their own collections and 7 % bought the seed (Mvula and Lillesø 2007).

Tree Seed Production Statistics

While seed production and trade statistics are readily available for agricultural crops, such information is generally not available for tree seeds (Whiteman 2005), making planning difficult for tree germplasm collectors, producers and traders. Few countries produce tree germplasm statistics. In Vietnam, tree seed production is estimated at about 300 kg per annum, against estimated seed requirements of 245–370 metric tonnes per year (MARD 2007). The annual tree seed production in Indonesia is estimated to be 1,775 metric tonnes (Roshetko and Mulawarman 2008). Based on the seed that goes through the major tree seed suppliers in Malawi, annual tree seed production is estimated at about 50 metric tonnes (Nyoka et al. 2011b). A decade ago, tree seed production in Tanzania was estimated at 8.5 metric tonnes per annum while that in Zimbabwe was over 800 kg (Nyoka 2003). There is a need for countries to develop systems to better estimate the tree germplasm demand and supply to enable germplasm suppliers to make informed decisions.

Seed Distribution Systems

One of the challenges faced by national seed centres that were established in many African countries was their inability to reach many farmers as a result of their central location (Aalbæk 1997; Koskela et al. 2010). It is estimated that these seed centres deliver less than 10 % of the farmers' tree seed demands (Graudal and Lillesø 2007). In most countries smallholder farmers are widely dispersed, making the distribution process expensive. Lillesø et al. (2011) described the government centralised supply model as expensive, inefficient and unsustainable. Harwood et al.

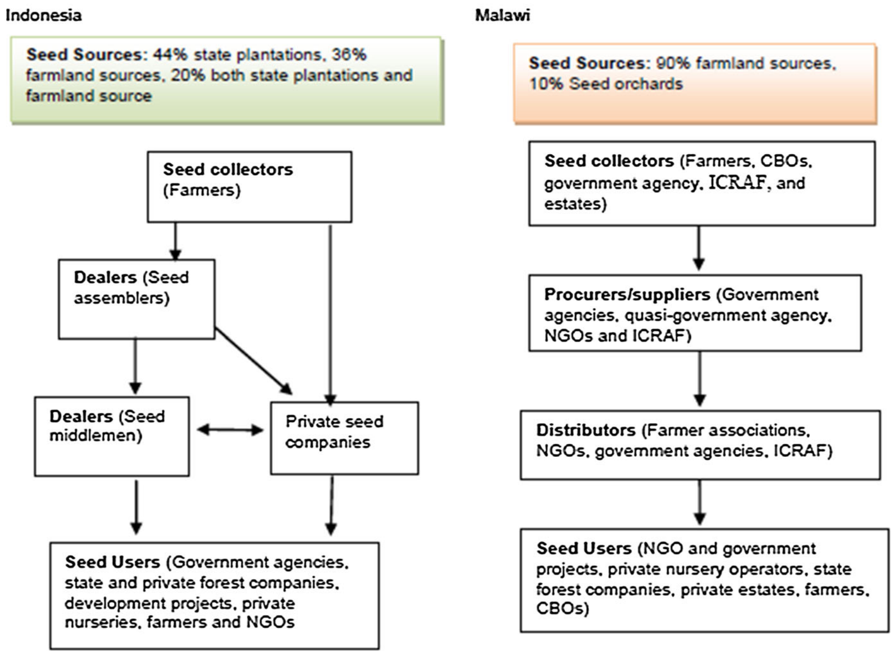

Fig. 2 Tree germplasm procurement and diffusion pathways in Indonesia (Roshetko and Mulawarman 2008) and Malawi (Pedersen and Chirwa 2005; Nyoka et al. 2011b)

(1999) also concluded that government tree germplasm distribution pathways do not always effectively reach farmers. Besides government agencies, NGOs play a major part in germplasm distribution in many countries. Although their penetration is better than government they are not sustainable as their presence is often erratic.

Farmers have in many countries been found to exchange germplasm. Lillesø et al. (2011) described such farmer-to-farmer diffusion as being slow and promoting a rapid narrowing of the genetic base as germplasm is often collected from a few mother trees. Cambodia's tree seed supply and distribution system draws on the strengths of village seed supply systems, and private and central government partnership. The communities manage seed sources, and collect and sell seeds; the private sector links the seed communities to users through the market; and the government's Forestry Administration provides the relevant legal framework and certification role (CTSP 2003; CTSP 2004).

The tree seed diffusion pathways in Indonesia and Malawi are shown in Fig. 2. Farmers in Indonesia collect tree seed under contract from seed assemblers or seed companies. An estimated 22,500 farmers are involved in seed collection activities annually. Government purchases approximately 75 % of the seed (Roshetko and Mulawarman 2008). Unlike in Indonesia where the private sector is a major player, there are no private seed companies in Malawi. Much of their role is played by the government (National Tree Seed Centre), a quasi-government agency (Land Resources Centre) and the World Agroforestry Centre (Pedersen and Chirwa 2005;

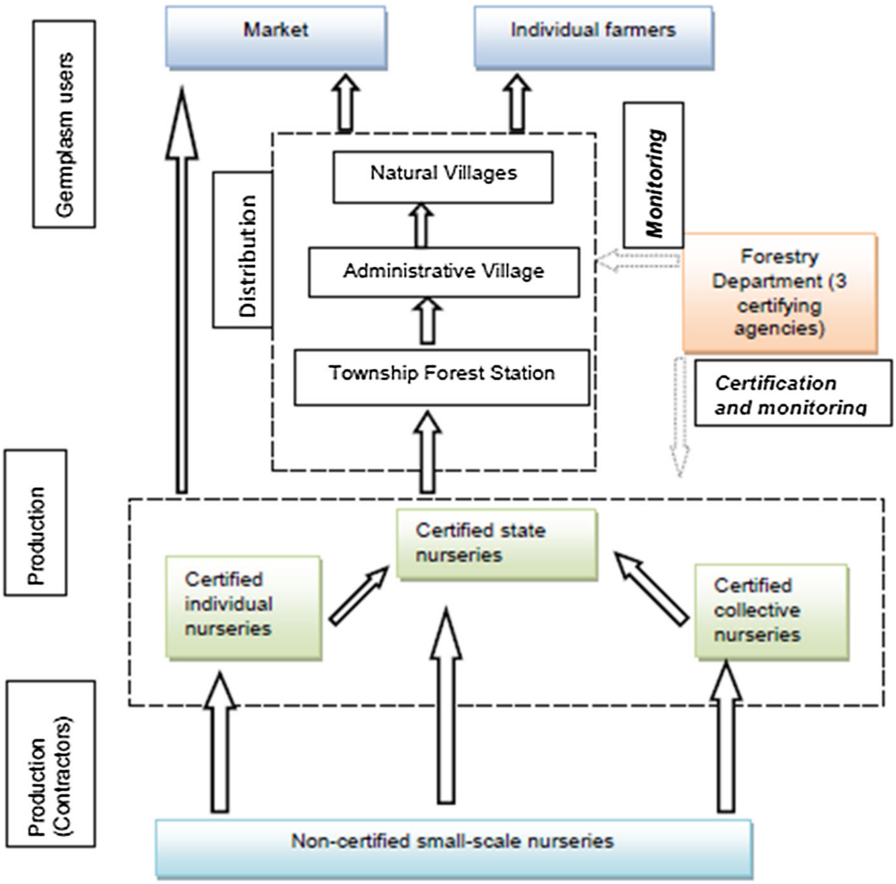

Fig. 3 Tree germplasm procurement and diffusion pathways in China (Adapted from He et al. 2012)

Nyoka et al. 2011b). Farmers collect up to 90 % of the seed that is distributed by the three organisations.

China has both private sector and state germplasm supply systems (He et al. 2012). Although smaller than the government supply, individuals and farmer groups sell their germplasm directly to farmers without going through middlemen (Fig. 3). Nurseries are certified for quality by the forestry department (Fig. 3). The participation of state nurseries in the production as well as certification has potential to compromise the quality assurance function because the government is both the certifier and the producer. Like in Indonesia, demand for tree germplasm in China is driven by the government's large afforestation and reforestation programs. State nurseries do not appear to crowd out the private players because they focus on tree species that are used in government afforestation and reforestation programs, while private nurseries focus on high value tree species, including fruit, nuts, edible oils, fodder and rubber (He et al. 2012).

Tree Nursery Types and Their Sizes

Tree nurseries are an integral part of a germplasm supply system for tree species that are established from seedlings. There are four main nurseries types that are commonly found in most countries, namely state or central nurseries, private nurseries, community or farmer group nurseries and individual farmer nurseries. As well, there are nurseries categorized as institutional (research, government and industrial) and project (Roshetko et al. 2010). There is no consensus over which nursery type is ideal. Proponents of centralised nurseries cite their efficiency and quality of tree seedlings but the distribution of seedlings beyond the nursery location is often highly expensive (Shanks and Carter 1994). In Zimbabwe, it was estimated that the cost of the central state-run nursery stock was more than twice that of farmer managed-nurseries (World Bank 1991). Individual farmer nurseries in Malawi produced nearly five times as many seedlings per farmer compared to farmer group nurseries (Böhringer et al. 2003).

Nurseries vary in size (in terms of number of seedlings) between countries (Table 2). Matenda et al. (2010) conducted a survey of tree nurseries in eastern Zimbabwe and found that 56 % of the nurseries were owned by individual farmers, 14 % by private entrepreneurs, 28 % by NGOs, schools and colleges, and the remainder by local government authorities. The survey did not include nurseries owned by forest companies. In Kenya, private, group and school nurseries account for over 80 % of the nurseries (O'Connor 1997; Basweti et al. 2001; Muriuki and Jaenicke 2001). Private nurseries were found to have a narrow range of tree species compared to group nurseries in Muranga (Nieuwenhuis and O'Connor 2000), while the opposite was observed in Meru (Muriuki and Jaenicke 2001).

Surveys of tree nurseries in Malawi revealed that 61 % were group-owned while the remainder were individually owned (Mvula and Lillesø 2007; Böhringer et al. 2003).The pattern is however reversed in southern Philippines where 54 % of the nurseries were individually operated, 40 % were group operated, and the remaining 6 % were school nurseries (Carandang et al. 2006). A few NGOs in Malawi deliberately promote individual farmer nurseries (TLC 2006) while others prefer farmer group nurseries (Mvula and Lillesø 2007).

The advantages offered by group nurseries include: environment for learning in groups, exchange of ideas and dissemination of information among the farmers, improved access to extension services, improved and less expensive service provision (Garcia 2002; TLC 2006). Group nurseries have however additional transaction costs on group organization at the expense of productivity (Böhringer et al. 2003). Lack of coordination and poor nursery management are the main disadvantages of farmer group nurseries.

Three types of certified tree nurseries, namely centralised state nurseries, collective nurseries and individual nurseries are found in China (He et al. 2012). These nurseries produce on average 800,000, 566,000, 170,000 seedlings respectively per annum (Table 2). There are also project-based nurseries and uncertified farmer nurseries but these tend to be temporary. State nurseries supply seedlings to government afforestation programs, while collective nurseries produce seedlings for members as well as for the market which includes government afforestation and

Table 2 Nursery sizes as number (mean or range) of seedlings produced annually in selected countries

Country	Nursery type					Range of species in nurseries
	Central nurseries	Group nurseries	Individual farmer	Private commercial	Others[a]	
Malawi[1]	30,000–90,000	1,852–12,181	583–3,352	10,000–200,000	na	1–19
Uganda[2]	38,000	60–24,100	355–25,000	27,000–175,800	na	1–28
Indonesia[3]	20,000–1,000,000	10,000–20,000	100–50,000	10,000–800,000	na	1–30
Philippines[4]	164,000	21,000	21,000	334,000	5,000	13
Vietnam[5]	10,000–1,500,000	25,000	15,000–1,500,000	750,000–1,500,000	na	1–10
China[6]	800,000	566,000	170,000	na	na	17
Kenya[7]	na	140–20,000	1,000–500,000	na	400–6,000	1–19
Mali[8]	1,000–5,000	300–2,000	100–1,000	10,000–50,000	na	1–25

[a] Nurseries of educational institutions; *na* not available

Source [1] Mvula and Lillesø (2007), Namoto and Likoswe (2007); [2] Asare and Pedersen (2004); [3] Purnomosidhi and Roshetko (2012); [4] Mercado and Duque-Piñon (2008); [5] Johansen et al. (2011); [6] He et al. (2012); [7] Muriuki and Jaenicke (2001); [8] ICRAF-WCA/Sahel, unpublished data) reforestation programs. State nurseries also function as research and resource centres, evaluating and introducing new species and seed sources and providing high quality propagation stock. Collective nurseries and individual nurseries produce seedlings for their own members and the market, and occasionally supply large state afforestation projects. State nurseries tend to produce mostly tree species suitable for ecological purposes (erosion control, biodiversity) while individual nurseries produce more economic species (for production of fruit, edible oils, nuts, fodder and rubber).

Brazil has extensive tree farming programs developed by NGOs, industries and government targeting small and medium size farms (Ceccon and Miranda 2012). Farmers provide land and labour, while companies together with Forest Replacement Associations (FRAs) provide inputs including high quality germplasm and technical assistance. Tree seedlings are produced in central nurseries of companies and FRAs and distributed to farmers. Between 1986 and 2007, more than 362 million trees were planted in two states. A similar program was also replicated in Nicaragua, and annual tree seedling production in FRAs central nurseries ranged between 42,000 and 442,000 seedlings between 2000 and 2009.

In Vietnam, government nurseries produce seedlings to support government afforestation and reforestation programs. Farmer nurseries also play an important role in supplying government reforestation programs, agroforestry projects, and diversifying and increasing family incomes. In turn, government nurseries support famer nurseries by providing access to high quality germplasm, technical training and information, and improved channels to market (Minh Ha et al. 2011). Tree seedling production in Thailand is undertaken by the Royal Forest Department (RFD), which has large central nurseries. Sixty percent of seedlings produced in the state nurseries in Thailand are used for government afforestation and reforestation programs and the remainder are distributed to private landholders at a subsidy (Elliott and Kuaraksa 2008). Other programs in Thailand provide loans to farmers while others providefree quota of tree seedlings. Despite the government providing seedlings at a subsidy, the demand for tree seedlings in Thailand reportedly outstrips the supply. Overall, governments' afforestation and reforestation programs are very large in Asia, averaging 202,181 ha/year in Indonesia, 233,352 ha/year in Vietnam and 2.6 million ha/year in China between 2000 and 2010 (FAO 2010).

Adequacy of government policies is a critical factor in germplasm supply systems. Place and Kindt (1997) observed weaknesses in policies on tree germplasm supply in sub-Saharan countries which include fragmentation of institutional mandates and functions, lack of coordination of planning, lack of information on germplasm demand for different species, and the poor and unstable funding environment of institutions involved in germplasm supply and utilization. For example, in southeast and east Asia, Harrison et al. (2008a) found that government policies tended to favour quantity over quality of the seedlings produced. Farmer nurseries were set up to provide seedlings to support government afforestation programs in some Asian countries but many ceased operating with the termination of government tree planting activities because they lacked resources and were dependent on government contracts. The challenge of most nurseries closing after the end of projects has also been observed in Southern Africa (TLC 2006; Matenda et al. 2010). Most nursery operators face similar challenges in both Asia and Africa which include lack of market, low seed quality and inadequate funds (Table 3).

Harrison et al. (2008a) cited a number of initiatives and policies that governments can use to improve seedling production and financial viability of small-scale nursery operators in Southeast Asia. They include improving access to resources such as up-to-date information, new and affordable technologies, availability and access to high quality germplasm, and skills in nursery management as well as financial management. They further pointed out that where smallholder farmers with low income form the bulk of the market, seedling producers should achieve low seedling prices by using appropriate low-cost production systems and tapping in on particular high-value tree species such as fruit trees.

Although nursery sizes vary across countries and ownership, Herbohn et al. (2011) indicated that a nursery producing 6,000 seedlings or more per annum could allow the operator to break even. An optimal nursery size that could provide livelihood benefits is one producing about 25,000 seedlings per annum. Very small nurseries would incur high seedling production costs, and would probably not justify the expenditure required for durable infrastructure and certified seedling production (Herbohn et al. 2011). Economies of scale in nursery operation in the Philippines were achieved at a production level of at least 90,000 seedlings per 3 months in the year (Kadda et al. 2008). Small-scale nurseries in rural Indonesia can operate profitably at an annual capacity of 10,000 because operating costs are low and market demand is low but stable (Purnomosidhi et al. 2012a, b, c). Besides these studies in Asia, there appears to be limited information on nursery viability sizes in the other countries in Africa and Latin America.

Raised seedbeds are a low-cost seedling production system that has been extensively promoted for raising large quantities of fast-growing species including *Gliricidia sepium* and *Sesbania sesban* in southern Africa. Raised seedbeds are however less suitable for some tree species that develop a deep taproot system such as *Faidherbia albida*. Polybags are the most widely used in nursery production in most countries in Asia and Africa, and have continued to be used in spite of some studies showing that seedlings produced in polytubes have a high proportion of deformed roots. They are cheaper compared to root trainers. Root trainers have been shown to produce superior seedlings and can be reused for many years but the high initial cost is often cited as a major impediment to their use by nursery operators including some large government and private company nurseries.

Besides using seeds and cuttings, some government central nurseries in Thailand, Indonesia and Vietnam produce seedlings using tissue culture (Elliott and Kuaraksa 2008; Harrison et al. 2008b). These tissue culture laboratories are costly to establish, and require high labour inputs and technical skills (Harrison et al. 2008b).

Tree Germplasm Markets

Tree germplasm buyers comprise smallholder farmers, and donor or government and privately funded afforestation and reforestation programs. Where smallholder farmers form the bulk of the buyers, the challenge is whether these resource-

Table 3 Major constraints experienced by nurseries operators in selected countries

Constraint	Burkina Faso	Malawi, Zambia, Tanzania	Kenya	Philippines (Leyte)	Indonesia	Mali
Overgrown seedlings				√		√
Lack market	√	√	√	√	√	√
Animal damage	√	√	√	√		√
Lack of adequate funds	√			√	√	√
Lack of water	√	√	√		√	√
Lack of tree seed	√	√	√	√	√	√
Lack of tree seed of desired species			√	√		√
Lack of training and information	√	√	√		√	√
Pests	√	√	√		√	
Shortage of labour	√	√	√	√	√	
Lack of nursery space		√	√			
Lack of transport for seedlings	√		√			
Low seed germination			√	√		√
Pilfering				√		
Market competition				√	√	√

Source Böhringer and Ayuk (2003); Ræbild et al. (2005); Shisanya et al. (2007); Gregorio et al. (2008); Mercado and Duque-Piñon (2008); Harrison et al. (2008a); (Gregorio et al. 2010a) constrained farmers are able and willing to pay for the germplasm. There is a need to undertake market research to determine whether these farmers are willing and able to pay for tree germplasm of their choice.

Stable tree germplasm markets are important because they offer opportunities for farmers and other germplasm suppliers to earn income from engaging in trade of seed. In Nigeria for example, many farmers and nursery operators indicated that they engaged in seed and seedling production for income generation (Babalola 2008). Some farmers in Kenya formed the Kenya Association of Tree Seed and Nursery Operators to among other things help members gain skills, access information and inputs, and develop effective linkages with market and other agencies (Muriuki 2005). Other small-scale nursery entrepreneurs are members of the Forest Tree Nursery Association of Kenya (KFS 2009). In Malawi, Mvula and Lillesø (2007) found that between 15 and 52 % of tree nurseries were established by private individuals with the objective of selling the seedlings. These cases illustrate the growing realisation that the sale of tree germplasm can also be a revenue stream.

Significant earnings from tree seed businesses have been reported in some countries in Asia and Latin America. In Central Java, Indonesia, where the majority of the nation's tree seed supply originates, farm families earn substantial income through tree seed supply: 66 % of farmers (tree seed collectors) earned at least 33 % of their dry-season (3 months) income from seed collection; 24 % earned 34 % to 50 % of their dry-season income; and 10 % earned 66 % or more of their dry-season income (Roshetko and Mulawarman 2008). An association of farmer tree seed entrepreneurs in the Philippines recorded substantial increase in farmers' income from seed sales (Catacutan et al. 2008). Cornelius et al. (2010) evaluated four smallholder tree seed and seedling production initiatives in Latin America and found that in one of the groups, gross income per member averaged $330 per annum compared to the typical cash earnings of less than $2 per day that are common in the area. They suggested that the income could be increased further through value adding, i.e. by producing and selling seedlings instead of seed. This suggestion can however create challenges in the marketing and distribution of the seedlings beyond the vicinity of the nursery because as seedlings are bulkier and perishable compared to seed.

The supply of tree germplasm to farmers without charge is believed to be an impediment to development of sustainable markets for tree germplasm. In some countries (e.g. Philippines, China, Thailand, Nigeria), the state is a major actor in the supply of tree germplasm. Reports indicate that government tree germplasm supply programs crowds out private entrepreneurs (Harrison et al. 2008b; Babalola 2008; He et al. 2012). In many African countries, NGOs have been blamed for undermining the development of small-scale germplasm suppliers through their approach of distributing free germplasm (Lillesø et al. 2011). For example in Uganda, Asare and Pedersen (2004) found that 88 % of farmers received tree seed without charge from NGOs. Reviewing policies on crop seed systems in Africa, Tripp and Rohrbach (2001) suggested that seed suppliers should shift from providing free seed and instead strengthen farmers' capacities to be effective users of the germplasm. Extending this suggestion to tree seeds could be tricky as crop and tree seed systems may not be comparable.

There are very few studies that have focused on determining the size of the market for germplasm of non-industrial tree species in most countries. Private sector interest in tree germplasm could be high if the demand was not only large but also steady. Besides a steady demand, tree seeds have a lower replacement rate[1] compared to some annual crops, which often makes tree seeds less attractive. Kugbei and Bishaw (2002) believe that small-to-medium enterprises are best suited to trade in tree seed which has a limited appeal to large seed companies.

Information on tree germplasm demand is available in some of the countries covered by this review. For example, annual tree seedling demand in Aceh province of Indonesia is estimated at five million (Martini et al. 2013). The National Greening Program (NGP) in the Philippines is reforesting 1.5 million hectares and will require 1.5 billion trees between 2011 and 2016 or 100 to 300 million seedlings annually (Herbohn et al. 2010; Israel and Lintag 2012), a huge market for germplasm suppliers. The supply of the seedlings for the NGP is funded through a World Bank loan and is open to competitive bidding giving an opportunity for farmers and private sector participation. In Vietnam, the government's Sustainable Forest Management and Development program (for both production and community forestry) aims to plant 2 million hectares of production forest between 2007 and 2015 by establishing 250,000 hectares annually which translates to a demand for over 300 million seedlings.

These limited statistics emphasize a need for countries to develop systems to better estimate the tree germplasm demand and supply, at local and national levels, to enable germplasm suppliers to make informed business decisions. Overall, the tree germplasm markets appear to be larger in Asian countries than in African countries. In Asia, markets appear to be influenced by a greater scale government afforestation and reforestation programs and also demand for commodity crops including oil palm, cacao and rubber.

Species and Genetic Diversity of Germplasm used in Planting Programs

Species richness, a component of species diversity was assessed based on the number of species found in nurseries as well as seed distributed. Surveys carried out in Latin America, Africa and Asia all suggest a limited range of tree species in nurseries. Nurseries in Malawi for example were found to have between one and 19 tree species (mean of four species) per nursery (Namoto and Likoswe 2007). In Latin America, number of species varied from two in Mexico and Central America, three in Peru; seven in the Pará state of Brazil, and up to 78 species each in Honduras, Nicaragua, Panama, Guatemala, El Salvador and Costa Rica (Cornelius et al. 2010). The number of tree species found in nurseries ranged between one and 13 with an average of six species in Burkina Faso (Ræbild et al. 2005), one and 10 tree species in Vietnam (Minh Ha et al. 2011),and up to 30 species in Indonesia (Purnomosidhi et al. 2012a, b, c, d). Three species—*Gmelina arborea*, *Tectona grandis* and *Leucaena leucocephala*—account for 70–85 % of the total seed sold in

[1] Seed replacement rate is the frequency of seed acquisition by farmers from external sources.

Indonesia for the seed year 2001 (Roshetko and Mulawarman 2008; Mercado et al. 2009). The reasons for the low number of species in nurseries and of seed sold could be a reflection of limited diversity of the species desired by farmers and may not always imply limited access to germplasm of diverse species.

When collecting tree seed from natural forest for planting, a rule of thumb is to collect seed from at least 25 seed trees. Furthermore, to reduce the chance of collecting seed predominated by half-siblings, a 100 m distance between seed trees is recommended (Dawson and Were 1997). For the same reason, there are also guidelines for collecting seed from farmland, plantations and seed orchards (Mulawarman et al. 2003; Mbora and Lillesø 2007). There is evidence to suggest that these recommendations are not being followed. In a study covering 71 nurseries in East Africa, Lengkeek et al. (2004) found that for each tree species, seeds used in the nurseries were collected from a mean of only six mother trees. In 22 % of the cases, the seed used in the nurseries was from single mother trees. Namoto and Likoswe (2007) surveyed 43 nurseries in Malawi and found that most nursery operators collected seed from between one and 26 mother trees, with a mean of just over four mother trees per nursery. Koffa and Roshetko (1999) found that 60 % of farmer seed specialists in Lantapan in the Philippines collected seed from only 1 to 5 trees. These same farmers were also observed to collect germplasm without consideration to the phenotypic appearance of the trees (Cacanindin 2010).

The reasons why farmers collect seed from less than the recommended number of trees is a matter of conjecture. For farmers raising their own seedlings, they often require only a few seeds, and collecting seed from as many as 25 trees may appear to them an unnecessary workload. It is labour saving to collect from one or two trees if those few trees can supply the required quantity of tree seed. However, in locations where much of the forest is degraded, the remaining superior trees (i.e. phenotypic) are often not enough to meet the seed demand without farmers compromising on the phenotypic quality of the trees. To overcome these challenges, Mulawarman et al. (2003), Lengkeek et al. (2004) suggested establishing local nursery or seed collector networks, through which germplasm could be mixed and exchanged as a way of increasing the genetic diversity within species.

Tree Germplasm Quality Control Mechanisms

Surveys in Honduras, Sri Lanka and Malawi found that there were challenges in the supply of tree germplasm of high genetic quality (Cromwell et al. 1996). Similar observations were also made in Indonesia and South East Asia (Harwood et al. 1999; Roshetko 2001). Although some studies have found that markets for agroforestry tree germplasm are not discerning to quality (Simons 1996), the lack of discerning market could be a consequence of a lack of awareness regarding the advantages of using germplasm of high genetic quality. Most suppliers of agroforestry tree germplasm have very limited knowledge of what constitutes high genetic quality germplasm (Roshetko 2001; Brandi et al. 2007). This could be due to lack of information and of supportive policies and regulations to guide suppliers.

There is a need to create awareness, among the germplasm suppliers and users, of the broad issues surrounding tree germplasm quality.

Tree germplasm quality issues have largely been addressed for forestry plantation tree species in the developed world and some developing countries that have functioning tree improvement programs (Kalinganire and Nanson 1984; Nyoka et al. 2011a). Germplasm quality can be controlled through either compulsory or voluntary certification. Certification is a quality assurance process that guarantees farmers consistent high quality planting material. Compulsory certification is supported by laws and regulations while voluntary certification is entirely the responsibility of the producer.

Only accredited fruit tree nurseries in the Philippines are allowed to supply seedlings to government programs. Such nurseries also receive free training in seedling production and access high quality propagation materials (scions and seedlings), obtain subsidies for pesticides and fertilizers and free soil tests, and are allowed to post their advertisements on the government website (Edralin and Mercado 2010). A similar accreditation scheme was extended to cover forest tree nurseries (Cacanindin 2010; Gravoso et al. 2010; Gravoso et al. 2010). There is also a legal framework to regulate quality of tree seed supplied to government planting programs.

Three separate germplasm certification programs exist in Indonesia, one each for fruit trees, commodity tree crops (cacao, coffee, rubber) and forest tree species (Purnomosidhi and Roshetko 2012). In China, a certification scheme for both tree seed and seedlings was gazetted (He et al. 2012). A project called Sawlog Production Grant Scheme in Uganda runs a voluntary nursery certification scheme for private nursery operators. Other countries with some form of tree germplasm control systems include Vietnam, Burkina Faso, Madagascar and Rwanda (Koskela et al. 2010). In Ethiopia, Kenya, Tanzania and Zimbabwe standard rules of the OECD Scheme are applied although to varying degrees. Nicaragua, Costa Rica in Central America have also been developing protocols for certification of tree seeds (Koskela et al. 2010).

Besides certification, branding has been used to differentiate high quality germplasm from inferior material. In Indonesia, Roshetko et al. (2013) used the approach of branding nurseries that met a set of criteria of quality termed *Nurseries of Excellence* (NOEL) while in the Philippines high quality seedlings were branded as *Q-seedlings* (Gravoso et al. 2010). There is evidence that branding of nurseries and seedlings had a huge impact on both the seedling quality and the demand (Roshetko et al. 2013).

Conclusions

Tree germplasm supply systems across many African and Asian countries have similar characteristics: sources of germplasm are not well documented; germplasm quality control systems are weak especially in African countries; and tree germplasm production statistics are not available. NGOs, private companies and government play a major role in the supply chain. Both NGOs and governments have been criticised for providing germplasm free of charge because this is deemed to crowd out private entrepreneurs. There is however no evidence to suggest that farmers without external support are willing and able to pay for tree germplasm.

Seed dealers and nursery operators in all the regions face similar challenges: lack of markets, lack of technical information and capacity and limited access to high quality germplasm. Some of these challenges like technical information and incentives could be addressed by governments.

There is lack of appreciation of the importance of using tree germplasm of high genetic quality in most countries. To enhance the uptake and use of high quality germplasm, there is a need to quantify and demonstrate its value and to raise awareness among the farmers and policy-makers. There is also a need to develop effective germplasm production and supply strategies that result in win-win situations for the farmers, suppliers and the environment: accessible and affordable, highly productive germplasm, high species diversity, wide genetic diversity, and markets.

Although some countries have introduced laws and regulations to encourage the use of germplasm of high genetic quality, it is perhaps too early to detect their impacts, because most of the regulations have been in existence for less than 10 years. Voluntary certification is being implemented in some countries that lack enabling legal framework. In other countries, branding of nurseries and seedlings appears to also have had a beneficial effect.

Nursery sizes in many African countries are very small compared to those in Asia. The reason could the market size which is very large in Asia, driven by large-scale government tree planting programs. In many African countries, the germplasm markets rely solely on resource-poor smallholder farmers, and consequently are very small. These farmers have very low income, and therefore little ability to pay for tree seedlings.

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