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Why Institutional Environments for Agroforestry Seed Systems Matter.

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Abstract

Rethinking the logic of institutional environments aiming to facilitate agroforestry smallholders in economic development, this paper compares smallholder input supply systems for crop and tree seeds in Sub-Saharan Africa and reflects on two basic challenges: (i) how to develop a large number of relevant tree crops for different agroecologies; (ii) how to reach smallholders in rural areas. Policy options for improving agroforestry input supply systems are discussed, whereby our article concludes with suggestions how sectoral approaches for crop seed systems can be modified to agroforestry seed-seedling systems. Biophysical differences have practical implications for how the logic of the 'African green revolution' would be translated into a corresponding revolution for agroforestry.

Keywords: Agroforestry, institutions, seed systems, AGRA, productivity.

1 Introduction

Great opportunities for producing value from agroforestry seeds[1] are currently wasted. To allow smallholders to realise the full productive potential of quality agroforestry seeds, institutional environments for agroforestry seeds will have to improve dramatically.

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While the development potential of agroforestry is widely accepted (Smith and Mbow, 2014; Prabhu et al., 2015), the conditions under which this potential can be realized are much less agreed upon, partly due to the complexity and diversity of agroforestry systems.

This paper shows why and how higher quality seed for agroforestry trees can increase global productivity of hundreds of millions of smallholders - and why and how institutional, market and governance failures impair such productivity increase from happening.

2 Background

Mainstream economics attributes major global benefits to plantation forestry and natural forest management. In development studies, trees are seen as deliberately maintained and planted on agricultural land in agroforestry systems. The recent revival of agriculture on development policy agendas redirected attention to the smallholder farm as a vehicle for development (World Bank, 2007; Kiers et al., 2008; Hazell et al., 2010).

When trees are planted on farmland it is logical to consider trees as contributing to agricultural enterprises. There is already a rich discussion on constraints and opportunities for smallholders' access to appropriate crop varieties. Applying that discussion to agroforestry input supply systems could enable a more focused support to smallholders who incorporate trees on their farms (Gradual and Lillesø, 2007; Lillesø et al., 2011a).

Political, institutional and social dimensions of designing and implementing an African Green Revolution have been largely ignored by the Alliance for a Green Revolution in Africa (AGRA) (Scoones and Thompson, 2011). We nevertheless find the AGRA approach of 'market led technology adoption' (Scoones and Thompson, 2011) useful for our particular purpose: to clarify institutional requirements for an AGRA-like approach to secure productivity[2] improvements in smallholder agroforestry. We selected AGRA´s Programme for Africa's Seeds Systems (PASS) programme as a case for our study, because PASS clearly defines the elements crucial to improve productivity on small farms.

2.1 The role of agroforestry in smallholder agriculture and development

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[1] We use the term "seed" to include seed and also vegetatively propagated planting stock
[2] In this context we define productivity as not only biological productivity but also value production. Furthermore small growers tend to be risk averse and might prefer a lower-productivity tree that does not fail in bad years.

Two billion people living on sub-2 hectare farms in Africa and Asia regained a role as development stakeholders when agriculture returned to the development agenda (World Bank, 2007; McIntyre et al., 2009; Hazel et al., 2010; Poulton et al., 2010; Jayne et al., 2014, Hazel and Rahman, 2014a; 2014b). Growth - or development - of rural economies, remains essential for reducing poverty in the global south (Timmer, 2007; Byerlee et al., 2009). However, several development pathways can reduce poverty. Among these, one pathway focuses on constraints to smallholders participating in markets (Byerlee et al., 2009; Hazel and Rahman, 2014a) and more particularly on how more productive seed is developed for and accessed by farmers.

Several comprehensive discussions of the crop seed input supply sector in developing countries suggests there is no single perfect mix of public, private and voluntary involvement. A blend of organisational alternatives, depending on crops and target groups, is held preferable (Maredia et al., 1999; Minot et al., 2007; Louwaars and de Boef, 2012). Productivity increases in agroforestry, however, may require additional consideration on input supply for perennial crops. Corresponding to the smallholder discussion in agricultural crops seeds, a discussion on agroforestry input supply systems enables a focused support for smallholders who incorporate trees on their farms (Graudal and Lillesø, 2007; Lillesø et al., 2011a).

2.2 Why lack of good tree planting material matters

Agroforestry include management of trees in rural landscapes and farming systems to enhance – 'productivity, profitability, diversity and ecosystem sustainability- (World Agroforestry Centre, 2013: 7). Agroforestry is therefore a part of the investment strategy of many smallholders globally, to support their livelihoods (Garrity, 2004). Agroforestry is making tree cover a common feature on agricultural land (Zomer et al., 2014) and it is well researched for its role in subsistence farming, with beneficial effects of trees on crop yields and through wood, fodder and fruit production on food security (Jamnadass et al., 2011; Atangana et al., 2014; Jamnadass et al., 2015). Agroforestry also offers commercial enterprises opportunities based on sale of tree products (Perdana et al., 2012; Cerda et al., 2014; Jamnadass et al., 2014). The wide range of species and purposes of agroforestry trees makes it difficult to define specific successful approaches for scaling up promising agroforestry technologies. Recommendations for scaling up commonly focus on the social processes of promoting agroforestry practices on farms, with limited discussion on how germplasm can be made available to smallholders (for example Dewees et al., 2011; Ajayi and Place, 2012; Coe et al., 2014). This is in contrast to the discussion for crop systems which are more commercially oriented and where the technologies promoted are closely related to specific types of improved germplasm (Pingali, 2015).

We argue in this paper that when the aim of scaling up is to reach tens or hundreds of thousands of farmers, it is essential not to underestimate the importance of quality planting material in scaling-up processes, even for relatively low-value tree crops. Plantation forestry illustrates the value that proper attention to delivery of tree planting material to growers can provide (Burdon 1977; Zobel and Talbert, 1984; Foster et al., 1995; Kjær and Foster, 1996; Evans and Turnbull 2004; Ying and Yanchuk, 2006; Ruotsalainen, 2014). Widely planted species of acacia illustrate the importance of utilising the right material, where the careful choice of an improved variety developed from superior natural provenances[3] versus using an (inbred) landrace can provide up to four times higher volume growth (Luangviriyasaeng and Pinyopusarerk, 2001; Hai et al., 2008; Harwood et al., 2015). The best acacia hybrid clones developed in Vietnam have clearly outperformed pure-species *Acacia mangium* and *Acacia auriculiformis* controls in terms of their volume production (Kha et al., 2012). The increased cost of using genetically superior germplasm is well justified, especially as it is typically only a small fraction of total establishment costs (Harwood, 2014).

Relatively few agroforestry species have been tested for their performance but two of the most widely planted agroforestry species, *Calliandra calothyrsus* and *Gliricidia sepium,* demonstrate wide differences between provenances for wood and leaf biomass (the main product), where the most productive provenances produced about 2 to 3 times the yield of the poorest provenances (Dunsdon and Simons, 1996; Duguma and Mollet, 1997; Herbert et al., 2002; Nyoka et al., 2012).

The problems of inbreeding and genetic deterioration, documented for unmanaged exotic land races of many timber trees, may eventually develop for most agroforestry tree species, once local natural forests are lost or inaccessible and on-farm trees become the dominant seed sources, although supporting evidence is not clear to date (Dawson et al. 2013).

3 Comparison of crop and tree seed input supply system evolution

Starting in the 1970s, governments and donors began to provide substantial support for crop seed systems, by establishing parastatal seed breeding corporations. In the 1980s National Tree Seed Centres were established for production and distribution of tree seed. With market liberalisation both types of organisations were dissolved, privatised or required to function as private entities, with the expectation that seed supply would be more efficient in private hands (Maredia et al., 1999; Tripp and Rohrbach, 2001; Graudal and Lillesø, 2007; Lillesø et al., 2011a).

[3] Provenance in this context refers to a geographic location within a species' natural range from which seed is sourced. Different provenances may vary widely in their performance and provenance rankings may differ in contrasting planting environments (provenance-by-environment interaction).

This privatisation had limited impact on smallholders' access to crops and agroforestry trees that are not considered profitable by large crop seed companies, which therefore focused on high yielding varieties and clones of a limited number of crops (for example maize) and industrial forestry estates that focused on developing high yielding plantations for a limited number of timber species (for example eucalypts) (Tripp and Rohrbach, 2001; Harwood, 2011; Kilimo Trust, 2011; Wheeler et al., 2015). The privatisation had thus created a transformation of input supply systems from breeding of new crop varieties by government agencies towards marketing of the most profitable varieties by private companies (Louwaars and de Boef, 2012).

To compensate for the poor performance of the formal seed sector in reaching smallholders, many donors and policymakers subsequently switched support to non-governmental organisations (NGOs) to provide seed of non-hybrid crop varieties to smallholders (White and Eicher, 1999) as well as provision of seeds and seedlings for smallholder agroforestry. The impact of this NGO approach has been limited due to: a) insufficient attention to the geographic scale of demand; b) the practice of NGOs to cover the smallholders' transaction costs making long term operations unsustainable (Wiggins and Cromwell, 1995; Tripp and Rohrbach, 2001; Lillesø et al., 2011a); and c) insufficient attention to quality of planting material by NGOs (Graudal and Lillesø, 2007).

The evolution of the seed sector in Sub-Saharan Africa can be seen, from the point of view of smallholders, as largely reflecting the attempts to respond to two challenges; (i) how to develop a large number of relevant crops/tree species for the different agro-ecologies of rainfed areas; and (ii) how to support sustainable distribution networks that can reach smallholders in rural areas in the context of enabling smallholder's participation in markets (deVries and Toenniessen, 2001; Tripp and Rohrbach, 2001; Minot et al., 2007)

In more recent years, a new approach, led by the Alliance for a Green Revolution in Africa (AGRA) has emerged, with a sectoral approach seeking to address several bottlenecks simultaneously. Supporting investments in breeding for varietal preferences of smallholder farmers by relatively smaller private seed companies and public breeding institutes, AGRA´s Programme for Africa's Seeds Systems (PASS) aims to develop distribution networks to reach smallholders in rural areas (Adesina et al., 2014).

3.1 Organisational implications of biological differences and similarities between seed systems for crop seed and agroforestry

Given the strong similarities in the constraints faced by smallholders for both crop and agroforestry seed (above), biological differences between annual crops and perennials have implications for the institutional framework and policy options available for organisation of seed production and distribution of seedlings.

Seed production and distribution for agroforestry trees are fundamentally different from crop seeds. The development of crop seed can be clearly separated into three functions (i) Breeding seed, (ii) Foundation seed (mainly developed by public actors), and (iii) Commercial seed (mainly multiplied by commercial actors), enabling a division of labour between public and private actors. However, for most tree species seed sources embody the above three functions at the same time (Lillesø et al., 2011a) Consequently *it is difficult to separate development of improved tree seed into public and private responsibilities*. The root cause is the much longer period required for trees, both for testing genetic quality and for establishing commercial tree seed production.

Sources of planting material for agroforestry can be separated into five types (see Figure 1 and Box 1). Each type has different characteristics, portraying the way genetic quality is described, and organisational aspects of accessibility and procurement. One of the five types[4] 'Breeding Seedling Orchards' (BSOs) is an essential part of breeding for improvement of most tree species, while 'Vegetative propagation' is also used as part of advanced breeding programmes and for selecting and perpetuating clones in participatory breeding of fruit trees. However, in agroforestry a third type 'farmland source', which has few merits apart from easy access, is the most commonly used type.

Box 1. Classification of seed source for agroforestry and their roles for breeding of trees

I. In terms of improving growth and quality, **seed orchards** of tested material are usually the most important type. Seed orchards are planted for the purpose of production of seed of a certain quality and are often (but not always) part of a wider genetic improvement programme with both breeding and deployment populations. Justification for the intensity of breeding is in principle related to the expected benefits, which are closely related to the expected plantation area or number of smallholders growing a particular tree crop. Seed production areas (SPAs) at the low end of intensity (low investment) contain mixtures of a diverse set of seed families, while at high intensities orchards are part of a detailed breeding strategy (Wheeler et al., 2015). Breeding Seedling Orchards (BSOs) (Barnes, 1995), enable simultaneous testing and selection of better genetic material in different planting environments (corresponding to improvement of crop varieties in agriculture). However, seed orchards and BSOs[5] are conspicuously rare in agroforestry.

II: **Natural forests** are also important sources of materials for improvement, and there are typically substantial genetic differences in productivity among different natural provenances (geographic sources). They provide the base of genetically diverse material of indigenous species to be established in BSOs. However, they are very rarely used for this purpose in agroforestry (Lillesø et al, 2011a), and it is often difficult or impossible to deliver seed directly from natural forests to farmers.

III. **Vegetative propagation** (cloning) is prominent in agroforestry for propagation of selected

[4] See Box 1 for a description of our use of seed source nomenclature
[5] For convenience we will henceforth refer to both types of orchards as BSOs

ideotypes of fruit trees (Simons and Leakey, 2004) and at advanced stages in breeding programmes for commodity crops and industrial plantation tree species where species have been genetically tested for superiority of individual genotypes across a range of environments (Jain and Priyadarshan 2009; Griffin 2014, Harwood, 2014). Cloning can thus be applied for only for some agroforestry species.

(IV) In terms of genetic quality, **farmland sources** (remnant or planted trees of unknown origin in agricultural landscapes) is a source characterized by minimum knowledge on genetic quality and maximum risk of low quality in particular for low density species (Dawson et al, 2013). Yet, for the majority of tree species, farmland source is the most frequently utilised source type in agroforestry (Lillesø et al., 2011a).

(V) Trees planted in **plantations** may often serve as high producing seed sources, where seed collection is easy. The origin of plantations is often unknown. There is a grey zone between 'plantations' and 'planted farmland seed sources'. For the purpose of classification, we suggest that trees planted in shelterbelts, farm border-lines, and permanently intercropped are considered to be farmland seed sources, whereas trees planted as even-aged blocks (most often in monoculture) are considered plantations.

For any seed source, predictions about performance are only valid within a certain range of environmental conditions and management practices (recommendation domain) outside of which growth and health of trees may be diminished or outright fail.

Breeding of trees for agroforestry targets improvement in the genetic quality of seed so as to deliver higher yields of desired end products (improved productivity). Most tree species are predominantly outcrossing, so selfing or mating between closely related individuals gives inbred offspring with slower growth and poorer survival. In agroforestry practice, initial productivity gains are frequently possible through improvements in delivery systems that allow the sub-optimal genetically degraded material of farmland sources to be replaced by best natural-forest sources. Further gains are then obtained through breeding, with gain depending on breeding strategy, investment and time. Sexual breeding typically involves crossing among selected superior individuals in seed orchards. Depending on species, vegetative propagation of outstanding individuals (cloning) can in some species deliver additional gains. The process of tree breeding is thus distinctly different from most annual crops that tolerate inbreeding.

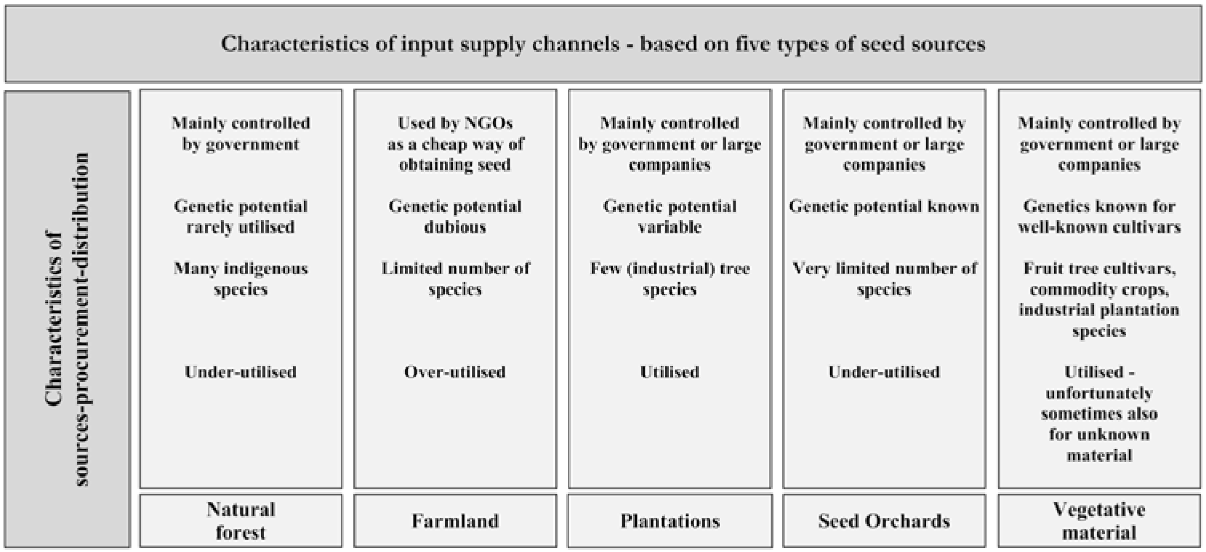

Figure 1. Characteristics of the five types of agroforestry sources in relation to the frequency of use and the potential for improving quality and productivity. Source: Modified from Graudal and Lillesø (2007).

A fundamental problem in seed supply of certified modern crop varieties to smallholders is transaction costs distorting seed markets by depressing the effective level of both the amount supplied and demanded at a given price, with the result that less material is traded and at a higher price than the social optimum. Wiggins and Cromwell (1995) demonstrate that this problem is to a large extent a problem of asymmetrically held information, resulting in market failure since *farmers do not know what is on offer and what difference it might make to their livelihoods, while sellers know too little about what farmers may demand*. This explains why commercially produced crop seed is rare in marginal/low income areas and may also explain why, as a social or institutional response to the market failure, NGOs have become dominant in the delivery of seed to smallholders by absorbing most of their transaction costs.

This argument corresponds, in agroforestry, to the use of farmland sources (own saved crop seed) versus obtaining seed from BSOs (modern crop varieties). The information asymmetry identified by Wiggins and Cromwell (ibid.) is accentuated in agroforestry, because BSOs generally are not made available by the public or private sector, making it difficult for NGOs to offer improved agroforestry species to farmers (Ræbild et al., 2005; Brandi et al., 2007; Mbora and Lillesø, 2007; Mvula and Lillesø, 2007; Harrison et al., 2008; Leakey et al., 2012; Mwaura and Dawson, 2012).

An intuitively simple explanation for the absence of BSOs in agroforestry is that selection and breeding of superior planting material generally takes place over a longer time-scale and it is therefore not an economically attractive investment. This argument is, however, contradicted by industrial plantation forestry, where development of superior tree germplasm via seed orchards and clonal selection is an integral part of the business, simply because investments in improved planting material make economical sense (Foster et al., 1995; Harwood, 2014). Superior planting material is also produced for some of the world's most important perennial commodity crops (see box 2), which are grown on large estates as well as by smallholders (Jain and Priyadarshan, 2009).

For lesser known agroforestry species such as for the fodder species, 'calliandra' (*Calliandra calothyrsus*), early establishment of BSOs can be justified because investments would break even if just one out of 20 BSOs were ever utilised (Scherr and Franzel 2002). This insight, however, did not lead to a single BSO being established (personal observation J-P.B. Lillesø).

The main constraint for development of BSOs in agroforestry is therefore a problem of scale, both in terms of production and in terms of distribution networks. We find that the root cause of this constraint is an institutional mismatch between the nature of the demand and supply of agroforestry seed, which is different from crop seed. Individual farmers require less tree seed (in the form of seedlings), both in terms of lower quantity per area and longer time intervals, than crop seed. The potential supply of seed is also different. BSOs will invariably have a large production capacity because quality requirements call for a minimum number of unrelated trees to pollinate each other in the source, leading to repeated production of very large quantities of seeds, over a period of many years. Consequently, demand and supply invites calculations at a landscape level, to justify investments in improved tree seeds and determine how best to balance supply and demand through efficient distribution networks across very large areas.

4 Organisational implications of diverse demands for planting material by smallholders.

In Africa, the discussion about smallholder agricultural development has been translated into action by AGRA. AGRA aims to improve smallholder productivity and sales of annual crops through four interrelated programme areas of Seed Systems, Soil Health, Market access, and Policies and Partnerships. The Seed Systems programme aims to encourage public and private seed companies to breed a wider variety of crops, relevant for smallholders in rainfed areas, and also to develop commercially viable networks of small-scale, entrepreneurial agro-dealers (small shops dealing in a variety of agricultural inputs such as pesticides, fertilizer as well as seed). AGRA activities include training, facilitation of smallholder access to affordable financing and provision of 'smart subsidies' aimed at resource-poor farmers to increase demand for crop seed (deVries and Toenniessen, 2001; Minot et al., 2007; Toenniessen et al., 2008; MacRobert, 2009; Adesina et al., 2014).

AGRA's bundling of mutually supportive actions with the aim of developing seed systems that can reach smallholders with quality planting material has no parallels in agroforestry tree planting in Africa[6], including tree planting campaigns such as the 'Great Green Wall of the Sahara and the Sahel Initiative' (African Union) and 'Billion Tree Campaign' (United Nations Environment Programme). See Bozzano et al. (2014), Graudal et al. (2014), Dawson et al. (2014), Koskela et al. (2014); and Thomas et al. (2014) for a more general discussion on use and transfer of genetic material of trees.

The productivity and quality of trees should be essential parts of the planning process for support to tree planting. Improving input supply and value chains for smallholder agroforestry could in principle follow the same logic as AGRA, except that in most cases agroforestry trees are planted as seedlings rather than being sown from seed. In contrast to agricultural crops for which the life cycle is completed within one growing season, most tree species must be planted early in the rainy seasons for seedlings to have time to send roots deep into the moister soil layers before the onset of the dry season. As a consequence, the important distributors of agroforestry planting material are nurseries rather than seed dealers (agro-dealers). Raising seedlings is a specialised business and seedling nurseries are already ubiquitous in rural areas in the tropics (Ræbild et al., 2004; Brandi et al., 2007; Mbora and Lillesø, 2007; Mvula and Lillesø, 2007; Harrison et al., 2008; Mwaura and Dawson, 2012; Leakey et al., 2012). Hence, nurseries are vital components of the agroforestry value chain, which is illustrated in Figure 2. The thin arrows point to drivers and the thick arrow shows where the chain breaks, seen from an agroforestry perspective.

[6] The Swedish NGO VI-Skogen comes closest, but the NGO does not develop independent seed systems (personal observations of main author, see also Lillesø (in prep.)

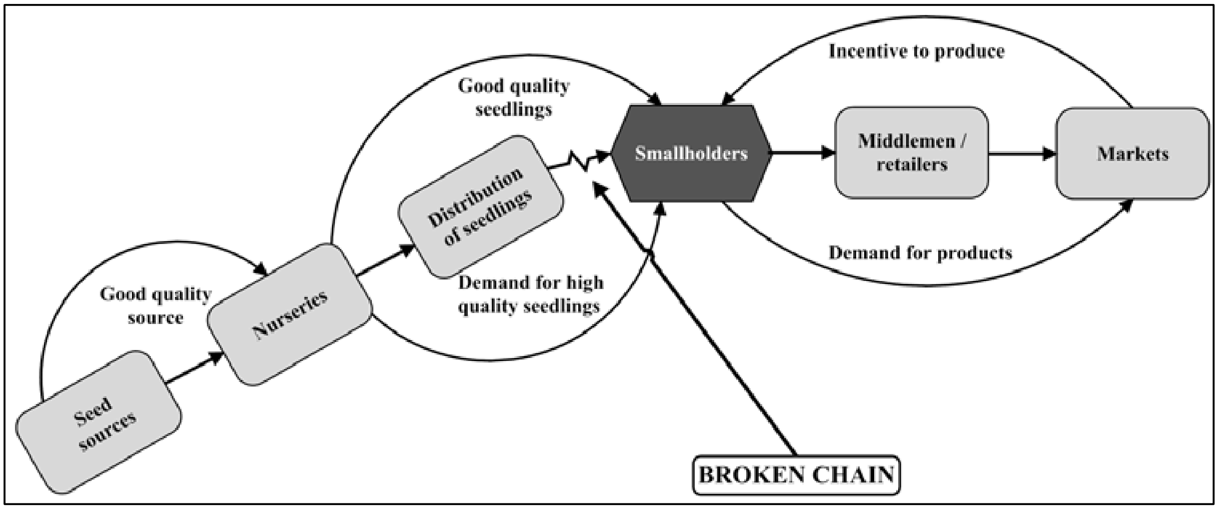

Figure 2. The full value chain for agroforestry showing the relationships between the different links in the chain, drivers and the point where the chain breaks – de-linking input supply from production and markets. Source: Authors (Lillesø, Holtne and Moestrup).

4.1 The NGO support approach to agroforestry

The NGO approach (the 'NGO model') typifies the broken value chain, where NGOs finance and organise seed supply, often by paying community groups to collect seed and raise seedlings that are distributed for free to members (Böehringer et al., 2003; Böehringer and Ayuk, 2003). Nurseries are thus established for the purpose of meeting NGOs' planting targets (number of farmers planting trees) for a specific area during the life time of the NGO project and with limited consideration for the sustainability and efficiency of nursery networks and limited concern for improving productivity of the tree species. NGOs generally organise and supply tree seeds and seedlings on a relief basis (free of charge) thereby replicating approaches that have been severely criticised in crop seed systems (Wiggins and Cromwell, 1995; Tripp and Rohrbach, 2001; Sperling et al., 2008; Sperling and McGuire, 2010), and undermining the business of the existing networks of small-scale commercial seed dealers and private tree nurseries (Brandi et al. 2007; Mvula and Lillesø, 2007; Ræbild et al., 2005, Oduol and Franzel, 2014, Nyoka et al., 2011, Lillesø et al., 2011b).

Despite the limitations of the broken value chain, the NGO approach has worked for certain species. Over the last two decades, several successful agroforestry development projects have involved tens or hundreds of thousands of smallholders growing ´fertilizer trees´ and fodder shrubs. In Malawi, the Agroforestry Food Security Programme and earlier donor-funded projects involved distribution of leguminous trees and shrubs for soil fertility replenishment (Nyoka et al., 2011). By 2005, about 250,000 farmers in five southern African countries had adopted fertiliser tree cultivation (Sileshi et al., 2008; Ajayi et al., 2011). In Kenya, the milk industry's development of networks of cooling trucks that reaches deep into the countryside has been a major driver for smallholder commercialisation of milk production. This, in turn, has helped to drive the demand for calliandra (fodder tree) seed, demonstrating the importance of linking inputs with the product market through the value chain (Place et al., 2009).

Successful NGO projects are characterised by their use of fast growing shrubs that produce seed within a short time span after planting/sowing (typically one or two years) enabling fast turnover of seed. In southern Africa the seed production and distribution model utilised is based primarily on NGO seed delivery to communities, and the repayment by smallholders of seed 'loans' (Nyoka et al., 2011). In Kenya, seed production and distribution models have been based on farmer-to-farmer dissemination of seed from farms as well as on a network of vendors - the Kenya Association of Tree Seed and Nursery Operators - trading seed collected from farmland trees (Wambugu et al., 2011). Despite their success with respect to the number of smallholders adopting useful agroforestry practices, the quality of most of the material distributed has not been widely tested and distribution has often taken place with little, if any, concern for genetic management of the species (for example Jamnadass et al., 2005; Mbora and Lillesø, 2007). Furthermore, the approach is simply not feasible for most agroforestry tree species, which produce seed several to many years after being planted.

4.2 Alternatives to the NGO model (commodity crops, outgrower schemes, low-input breeding)

There are several existing alternatives to the NGO model, characterised by attention to the breeding of more productive and disease resistant material and by making the material available to smallholders. These alternatives have in different ways and with varying success attempted to establish a full unbroken value chain.

For the commodity crops (cocoa, tea, coffee, rubber) intensive breeding programmes with well-known improved varieties and downstream value chains constitute one model, often dominated by large transnational companies. Much of the improvement work focuses on development of improved clonal planting materials - and less on seed sources - that have specific and homogenous product characteristics, as well as resistance to pests and diseases. Smallholders have been able to access the improved planting material to varying degrees. Since colonial times tropical tree crop commodities for export were mainly produced on large estates, but smallholder production has gradually become dominant during the last century (Hayami, 2010; Byerlee, 2014). For most of these crops, the increasing smallholder participation appears to have come about spontaneously, because smallholder farms are increasingly competitive with increasing land scarcity and industrial estates have no inherent advantage in growing these crops (Ochieng, 2007; Hayami, 2010; Byerlee, 2014). Access to improved varieties, however, remains a key constraint for smallholder productivity. The levels of adoption of best possible planting material are very variable and often far below what would be socially and economically desirable (see box 2). An important advantage of large estates is clearly their ability to access and utilise higher yielding planting material. Well-governed state programmes or collective action can compensate for this as is the case for tea in Sri Lanka and Kenya, and rubber in Thailand (Ochieng, 2007, Byerlee and Rueda, 2015). The same applies to private initiatives such as the Mars/ICRAF cocoa programme in West Africa (see box 4).

Box 2: Tropical "plantation" crops – Rubber, Coffee, Tea and Cocoa.

Rubber (*Hevea brasiliensis*): The vast majority of the world´s rubber supply comes from Southeast Asia. Smallholders account for almost 90 percent of rubber production in Thailand; 89 percent in India and Malaysia; and 83 percent in Indonesia (Viswanathan, 2008). Rubber plantations are expanding rapidly in in southern China and adjacent northern Laos and Myanmar, where Chinese researchers have developed hybrids that can grow at higher elevations and in areas with distinct dry seasons (Fox and Castella, 2013; Fox, 2014). Improved planting material is mainly produced by bud-grafting. Government support to clonal gardens and distribution networks appear to be major determining factors for varying levels of adoption of improved planting material among smallholders (Barlow, 1997; Sturgeon and Menzies, 2006; Manivong and Cramb, 2008; Viswanathan, 2008; Feintrenie and Levang, 2009; Sturgeon, 2010).

Coffee (*Coffea arabica*, "arabica" and *Coffea canephora*, "robusta"): Production is spread across the tropics with more than 65% of all coffee being produced on small farms (Barlow, 1997; Sturgeon and Menzies, 2006; Manivong and Cramb, 2008; Viswanathan, 2008; Feintrenie and Levang, 2009; Sturgeon, 2010). Much of the world's coffee is still produced by cultivars released some five to eight decades ago from relatively simple selection and breeding programmes and often multiplied by seed. Cultivars of the self-pollinating arabica are true-breeding lines; while those of the outbreeding robusta are open-pollinated cultivars produced from selected seedling and clonal gardens. Clonal robusta cultivars are rarely used in smallholder production systems, because of the logistics and costs of mass propagation and distribution (Van der Vossen, 2001). Smallholders' access to improved material is constrained by limited availability of production orchards and distribution networks (Neilson, 2008; Kufa et al., 2011; Avelino et al., 2015).

Tea (*Camellia sinensis*): China, India, Kenya, Sri Lanka, Vietnam, Turkey, Indonesia and Japan account for about 90% of world production and tea varieties can be grown over a wide range of climates (Nair, 2010). Tea requires processing within 24 h after harvest, which initially was an argument for government policies to favour large estates. Smallholders are, however, able to utilise or contribute to the existing processing infrastructure. In Kenya and Sri Lanka smallholders contribute respectively 62% and 72% of production. In Assam, India - where government policies until recently favoured large estates - only 30% of the tea area is on smallholder land (Byerlee, 2014). Nursery tea plants are raised from both seeds and stem cuttings under shade (Nair, 2010), and the relative ease with which planting material can be produced vegetatively contributed to smallholder adoption of improved varieties (for example Ochieng, 2007).

Cocoa (*Teobroma cacao*): More than 90% of all cocoa produced worldwide comes from small farms (ICCO, 2013 in Dawson, 2014). In Africa planting material is mainly produced in seed gardens, whereas clones are increasingly promoted in the Americas and to some extent in Asia (Vaast and Somarriba, 2014). In West Africa, which is the largest producing region in the world, surveys indicate that the use of improved material remains very low (Asare and David, 2010; Asare et al., 2010).

There are major opportunities for improving smallholder productivity and incomes through the use of improved planting material in new management systems. A highly intensive model is now promoted in Indonesia and West Africa by the MARS Company and World Agroforestry Centre (ICRAF). The model makes knowledge and planting material available through Cocoa Development Centres linked to Village Cocoa Centres, which in turn are directly linked to smallholders (http://www.mars.com/global/brands/cocoa-sustainability/cocoa-sustainability-approach/technology.aspx).

A characteristic of large scale industrial forest plantations in the tropics is the use and breeding of well-defined planting material. Estimation of provenance[7] variation of species is a major starting point for the selection and domestication of well-known species in the main genera used (*Acacia*, *Eucalyptus*, *Pinus*, and *Tectona*), which account for the majority of tropical timber plantations. In advanced stages of breeding programmes, use of clones is common, especially for eucalypts (Evans and Turnbull, 2004; Harwood, 2014). Although high yielding planting programmes are usually done for estate forestry, there are cases where breeding has improved productivity and quality of particular tree species for a specific market (and subsequently expanding markets) to be grown by smallholder producers. Two prominent examples are programmes for domestication of acacias in Vietnam and of poplars in northwest India, involving around 200,000-250.000 smallholder growers in each country, growing improved trees (see Box 3). Both programmes continuously improve the quality of planting material and major efforts are placed in distribution networks as well as the communication of improved practices and technologies to thousands of smallholders.

Box 3: Outgrower schemes for wood production –Pulpwood in Vietnam, poplars in India.

Vietnam

Vietnam has established 1.1 million ha of acacia plantations for wood production, managed on 5- to 10-year rotation cycles. Nearly 50% of the resource is managed by small growers holding 1–5 ha woodlots. The primary uses are pulpwood, the majority of this being exported, and production of sawn timber (Nambiar et al., 2015). Domestication of acacias in Vietnam has involved three decades of collaboration and funding from Government forestry research organisations in Vietnam and Australian research and development organisations (Fisher and Gordon, 2007). Acacia domestication has involved not only the research on genetic improvement, but also developing nursery infrastructure enabling smallholder growers to access improved clonal planting material throughout the country, and extension training in basic silvicultural methods (Nambiar et al., 2015). Although over 500,000 ha of clonal acacia hybrid plantations have been established, two other important acacia species (*A. crassicarpa* and *A. mangium*) are difficult to clone and planting stock is raised from seeds, mostly either collected from local plantations or imported from selected natural provenances. Key steps for improving input supply systems include: improved access to quality-attested, genetically improved planting materials at affordable cost through a network of local seed production areas; and communicating improved growing practices that protect soil and site resources to thousands of small growers (Nambiar et al., 2015).

[7] See footnote on the use of provenances

India

The private company WIMCO Ltd started introducing poplars to smallholders in north Indian states around 4 decades ago. Farmers grow poplar on farm land in compact blocks or on field boundaries together with agricultural crops – at the start of the rotation, sugar cane and winter wheat and - when the trees approach canopy closure - shade-tolerant crops such as ginger turmeric, fodder, or leaf vegetables (Newman, 1997; Dhiman, 2012a). The original market for the wood was match production, but the main product is now plywood (Kareemulla et al., 2005). Insect pests and diseases require continuous development of resistant clones. (Dhiman, 2012a). Universities and WIMCO releases new clones and technical guidance to growers. WIMCO nurseries are complemented by a large number of small scale private nurseries who procure original and pure propagation material of identified clones from WIMCO and multiply them for growing nursery stock for sale to smallholder growers. Almost all of around 300,000 hectares' poplar planting in India is by farmers on their farmlands in the northern states and the number of farmers involved has been estimated to be at least 200,000 (Dhiman, 2012b; Dhillon et al., 2013).

In smallholder agroforestry systems there are many different potential tree products and corresponding species for which productivity could be further improved. Neither the NGO model - with its lack of attention to quality, nor the alternatives for commodity crops and for outgrower schemes - with their large investments into development of a few varieties and clones, are optimal for the majority of agroforestry species. The challenges in agroforestry are to identify and make known the recommendation domains for sources of species that are planted and to establish levels of breeding intensities that are commensurate with the expected benefits from breeding. Thus for many species simply identifying seed sources for specific recommendation domains may be sufficient to avoid the use of sub-optimal material, while for other species some level of genetic improvement may be justified, leading to a new challenge of how to maintain viable breeding populations for species that are not 'protected' by being part of highly commercial commodity value chains or outgrower schemes.

Two types of low-input approaches have been tried out, which could be applied to domesticate a much larger number of promising agroforestry species (see Box 4). One of the models, which has been successful in West Africa, is participatory plant breeding of indigenous fruits, where superior clones are identified and propagated in collaboration between scientists and smallholder farmers. The other model is based on a Multiple Population Breeding Strategy, which basically consist of testing the genetic variation of trees while at the same time producing seed for specific environments across the country in BSOs. This model has been tried out in Zimbabwe and Nepal - in both cases the model was in its incipient stage, when it was curtailed by the state and donors due to circumstances that had nothing to do with the models perceived feasibility (in Zimbabwe due to political turmoil and in Nepal due to a development agency's withdrawal and subsequent lack of funding for development of markets for products).

These low-input models could tackle the challenge of breeding many tree species for many different environments and making improved seed available to large numbers of smallholder growers with limited investments. However, the models need to be expanded to include experience and recommendations on how to integrate seed sources into value chains (Dhakal et al., 2005; Degrande et al., 2013; Tembani et al., 2014 (see Box 4).

Box 4: Application of low-input breeding strategies for many species in many different environments.

West Africa: participatory plant breeding of indigenous fruits

The outstanding project in this field has been the domestication of several indigenous fruit tree species, by the World Agroforestry Centre's 'Food for Progress' programme in Cameroon. The approach is spreading to other parts of the tropics (Tchoundjeu et al., 2008; Leakey et al., 2012). Participatory tree domestication is carried out in collaboration between scientists and farmers and consists of several steps: (i) selection of priority fruit tree species; (ii) identification of the most promising "ideotypes" of trees and fruits, (iii) developing low-tech vegetative propagation techniques, and (iv) support for establishment of commercial nurseries through rural resources centres (RRC). Production of clonal planting material is knowledge-intensive (Degrande et al., 2013). The RRC approach is quite similar to the Mars/ICRAF approach for cocoa (see box 1).

Zimbabwe: breeding timber trees

Zimbabwe was one of the first countries to tackle the challenge of breeding many tree species for many different environments. In the early 1980s they adopted and implemented the Multiple Population Breeding Strategy, which basically consist of testing the genetic variation of trees while at the same time producing seed for specific environments across the country in Breeding Seedling Orchards (Barnes, 1995; Tembani et al., 2014). Pines and eucalypts met demands for sawn timber, poles and to some extent firewood (especially for tobacco curing) through establishment of industrial plantations and eucalypt woodlots by small-scale farmers. The political and economic meltdown beginning in early 2000 resulted in a decline in tree planting and associated tree breeding activities. Most of the professional and technical capacity in forest research and development was lost over a short period of time as skilled researchers left the country or moved to other sectors. Donor support and international collaboration that was crucial in developing the tree planting sector declined. The programme led by the Forest Research Institute had achieved significant genetic gains for pines and eucalypts. Although mainly for the plantation sector, smallholders also benefitted through improved access to productive species and breeds (Tembani et al., 2014).

Nepal: breeding indigenous species

The tree domestication programme in Nepal (Tree Improvement and Silviculture Center/Unit - TISU) has since 1994 been inspired by approach used in the Zimbabwe of breeding timber trees, however with a focus on indigenous species (Lillesø et al., 2001a; Lillesø et al. 2001b; Dhakal et al., 2005; Kjær et al., 2006). Smallholders utilise a large number of tree species in multiple ecological zones. Because of the country's mountainous terrain there is great ecological variation over small geographic distances. Smallholders thus need to utilise well-adapted seed sources matched to their local planting environments. Fodder and fruit tree species are particularly important for income generation (Lillesø et al., 2001b). TISU has implemented a strategy that supports collection of seed for immediate use (by defining seed sources within planting zones and collecting from a fair number of un-related trees), while at the same time establishing Breeding Seed Orchards to produced improved seeds for future use (as soon as 4 years, because many fodder species are early seed producers (for example Jha et al., 2006). The experience from the programme has been that technical and biological obstacles to improved seed production can be addressed. However, the key challenge is to develop distribution systems where quality criteria and productivity are linked to specific seed sources for specific areas. This challenge requires development of markets for smallholder products as well as distribution networks for quality seedlings.

5 A blend of organisational alternatives to replace the predominant NGO approach: the case of Ethiopia.

The case of Ethiopia illustrates the predominant NGO approach to seed/seedlings provision in Africa. Two of the authors (A. Derero and J-P.B. Lillesø) evaluated the tree seed input supply sector with the aim of identifying leverage points for improving efficiency (Derero, 2012; 2013; Derero et al., 2015). The evaluations are based on two separate surveys: tree seeds and seedling supply survey conducted in selected Woredas of Arsi and Wolaita Administrative Zones in 2012 and a similar survey conducted in North Shewa, Southern Tigray, Hadiya and Bale Zones in 2013 in Ethiopia. The findings from Ethiopia are relevant to situations where tree seed is distributed to facilitate or promote tree planting by many dispersed smallholders.

Tree planting is a strong priority for the Government of Ethiopia and tree planting targets are expressed in several national strategies, which are implemented by government agencies in collaboration with a large number of national and international non-government organisations. A huge amount of tree seed is procured and distributed in Ethiopia with the majority of seed used in nurseries (supported by government offices and NGOs) to produce seedlings for planting in small woodlots and other farmland-niches. Additionally, a large amount of seedlings is distributed and planted to restore natural vegetation and for watershed protection. Only a very small amount of seedlings are provided to large scale commercial plantations (mainly replacement plantings after harvests of timber).

A government agency, the Forestry Research Centre (FRC), has been a major actor in production and distribution of tree seed since 1975, but is logistically unable to satisfy the demand. FRC estimates that it meets roughly 20% of the national tree seed demand and distributes some 58 species. Over 70% of the seed collected by FRC comes from either plantations or natural forests. About 25% comes from trees in farmlands, urban areas and other compounds. Only 1% comes from seed stands established by FRC. FRC generally collects seed from a minimum of 20 mother trees in the seedlots that it distributes, however, species-specific collection guidelines for collection by the private sector are lacking.

26 licensed tree seed suppliers have been identified in Ethiopia. The main centre of private tree seed supply is Sodo town of Wolaita Zone, where over 20 licensed tree seed suppliers have been active since 2004. Interviews with three seed traders in Sodo, suggest they procure and distribute seed of over 50 different tree, grass and vegetable species, of which 34 are trees and shrubs, from all over the country (Figure 3). 95% of the seed is purchased by Government offices and NGOs and 90% of the seed is collected from farmlands, urban areas and other compounds.

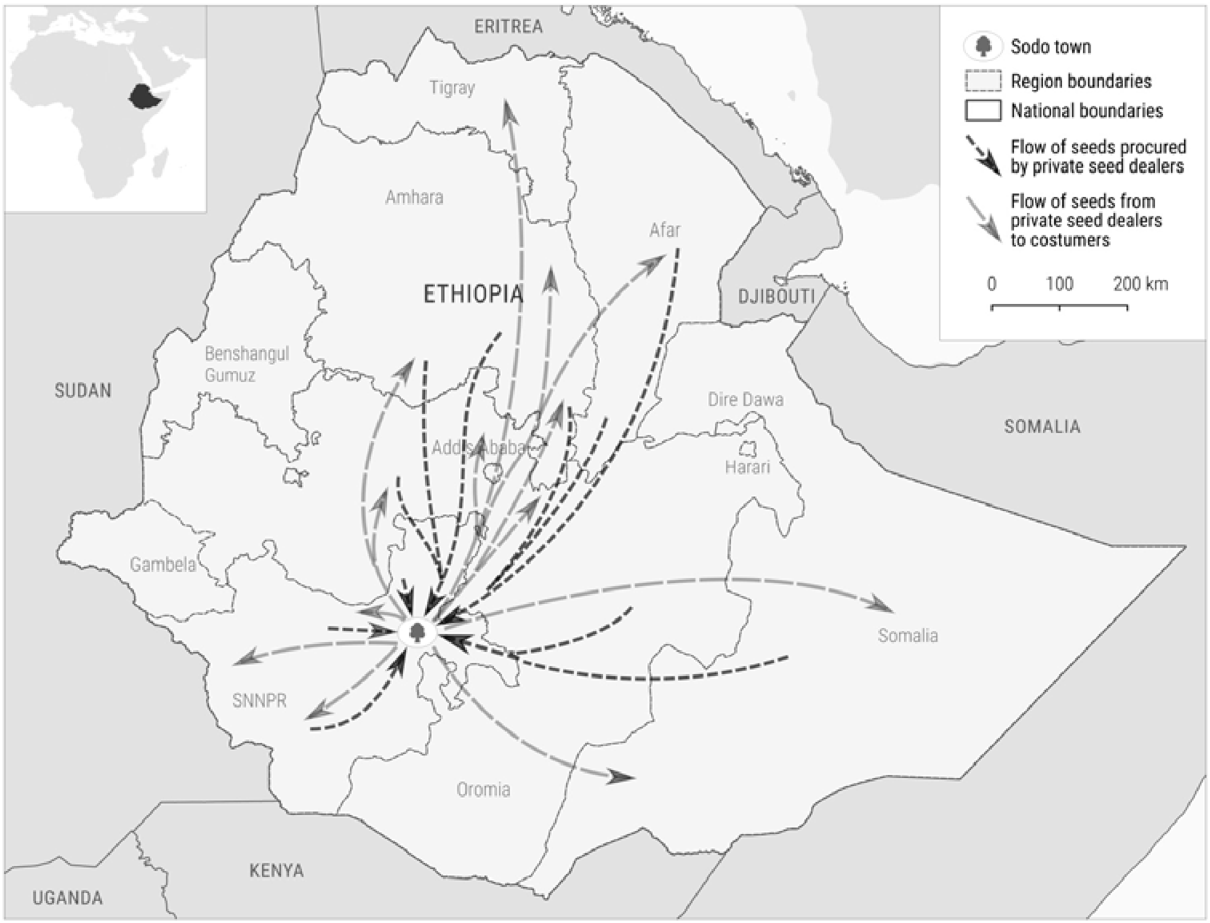

Figure 3. Flow of agroforestry seed by private seed dealers in Ethiopia. Sodo is the hub of seed flows – as indicated by the arrows. Source: Modified from Derero et al. (2015).

The overview presented in fig. 3 illustrates rough estimates of the flow of seed and seedlings produced in the Ethiopia. Seed and seedling production and distribution in Ethiopia follows the principles of the 'NGO model', except that most of the seed is procured by private actors (our study corroborates FRC's estimate that it provides around 20%). Almost all seed is purchased by NGOs and government offices in order to produce seedlings, which are provided as gifts to farmers and communities. [8] Although the study is only a snapshot of the situation, we can conclude that some of the most important requirements for ensuring the productivity, quality and survival of planted trees are not fulfilled.

5.1 Fundamental problems and a way forward

First of all, Ethiopia has highly diverse climates and soils spanning a wide range of altitudes and latitudes (Aalbaek, 1993; Friis et al., 2010; Lillesø et al., 2011b). Careful matching of sources of planting material to planting sites is therefore essential for ensuring productivity and survival. Seed production and distribution by both the private sector as well as FRC fails to follow the national seed zonation system or any other strict guideline, which is intended to ensure appropriate species/site matching (Aalbaek, 1993).

Secondly, 90% of seed procured by traders is collected from trees in farmlands, urban areas and other compounds. Therefore, the genetic quality and origin of the seed is not known and performance is likely to be suboptimal compared to seed deliberately chosen to match a planting site.

Thirdly, seed sources developed to improve productivity and product quality is practically non-existent in the smallholder tree planting sector. Immediate availability of seed appears to be the overriding factor in distribution chains. Information about quality is not provided with seed/seedlings distribution hence we can also conclude that tree planters are not aware of the (probably low) quality of the planting material that they receive.

6 Conclusions and policy recommendations

Knowledge is already available on how to provide the best possible planting material from the range of immediate and future seed sources. We know investment in best collection practices and distribution networks for improved seed sources gives high returns for most species. Still, however, planting materials delivered to smallholder farmers often has a quality that would be considered unacceptable by the industrial tree plantation or agriculture sectors.

We have discussed similarities and differences between crop and agroforestry input supply systems and have argued that agroforestry could be improved by learning from crop input supply systems and considering alternatives to the prevailing NGO model, which breaks the value chain. In particular, the sectoral approach of AGRA could improve agroforestry, although biophysical

[8] Seedlings of well-known fruit cultivars are sometimes sold. This phenomenon of fruit trees having a price has been observed in several other studies. We argue elsewhere that the fruit cultivars are unique among agroforestry planting material by having easily recognised genetic and known commercial value (see Graudal and Lillesø, 2007)

differences between crop seed and tree seed have practical implications for translating the logic of the 'African green revolution' for smallholder agricultural crops into a corresponding revolution for agroforestry.

Improving agroforestry input supply systems, through market-led technology adoption, will require a sectoral approach seeking to address several bottlenecks simultaneously. The two major constraints - (i) identification, establishment, management and commercialisation of tree seed sources; and (ii) establishing commercial nursery networks - will not be overcome spontaneously. However, the alternatives to the NGO model that we have analysed in this article do indicate that it may be possible to improve the systems.

So what are the policy options for changing the situation for the better?

First of all, it is important to recognise that tree improvement (and the resulting seed sources) provides a continuum of quality, which to a large extent is proportional to investments into breeding. The level of breeding should thus be commensurate with the expected benefits. For many agroforestry species a relatively low level of improvement, corresponding to avoiding the use of clearly inferior material, is appropriate. Technical issues that could be solved by the public sector are to develop species/provenance specific recommendation domains for all relevant species[9] and to identify appropriate seed sources in surviving natural forest (and even in farmland). Such sources may be managed by communities provided that they have sufficient incentives (see below). Widely-planted species, offering major potential for smallholder livelihood improvement through their tree product yields, merit greater investment in breeding. Experience from crop seed systems, where large scale private investment into breeding for smallholder crops is largely limited to hybrid varieties, indicate that the public sector needs to take the lead role in developing new tree crops, but management of sources and sale of seed could be handed over to the private sector (see below). This is similar to AGRA's approach to breeding.

Secondly, a large number of small-scale private tree nurseries in many African countries survive despite competition from free NGO seedlings and constitute an untapped opportunity for building business networks to produce and distribute quality planting material, including for the commodity tree crops. The public sector and NGOs have a central role to promote genetic quality as a key concept in the networks, so that other actors, including seed and seedling distributors and smallholder growers, are aware of the advantages of utilising improved seed. This requires that growers can demand and obtain seedlings of known, superior sources from nurseries and that

[9] This can be done for both indigenous and exotic species and the information made available via an internet website and mobile phones, some preliminary examples are to be found on www.vegetationmap4africa.org

nurseries can access these sources. Although quality seed usually does not add substantially to the total cost of seedling production[10], a well-organised distribution system is required to fully utilize such sources. Quality cannot be seen by visual inspection and because most species are outbreeding and genetically diverse, there is no genetic signature of the seed that can guarantee that it came from a particular seed orchard. Quality assurance must be based on trust and transparency in the value chains – and a prerequisite is that information flows freely back and forth from producers to consumers. The public sector has a role of setting the standards (as has been suggested for many years), but standards only become relevant when improved sources are available to distribution networks. This is similar to AGRA's approach to agro-dealer networks.

Implementing better input-supply systems will require provision of support, subsidies and incentives, at least in the transitional stages. This can be justified to the extent that the NGO model is replaced (considering that the NGO model corresponds to a full subsidy for tree planting with no exit strategy), but support should be part of broader agricultural development programmes that enable smallholders to participate in markets for tree products.

The main role of the public sector would be to develop the information on species' suitability in recommendation domains and to guide and verify the development of improved seed sources. The cost of doing this will reduce, once successful information-based demand and supply is functioning. This will create the incentive for private business to manage and market improved seed sources. The role of NGOs would change from providers of seed and seedlings to facilitators of information flows in the system.

We suggest that changes be implemented progressively, starting with making information available on planting domains and improved seed sources for all relevant agroforestry species (on internet platforms and for smartphones). A next step could be implementing pilot projects which develop nursery support and information systems for priority agroforestry tree species. In most countries there will be an ongoing need for public and private sector investment in seed source development and performance verification, but this would not be a huge cost (compared to distributing free seedlings via NGOs). Once improved sources are developed and known, subsidies that support their production and distribution can gradually be reduced. This may take years or decades, because farmers' motivation to use improved seed depends on their perception of benefits to them arising from improvements in product value chains.

[10] This usually holds true for seed based material, although clonal fruit tree planting material is more costly than seed based material of the same species.

The main constraints for improving agroforestry productivity are thus of an institutional nature. Improved input chains require greater levels of collaboration and information flow between actors to promote quality planting material, as an important parameter for distributors and tree planters. As shown by the case of commodity crops, high demand for a particular agroforestry tree species with well-defined improved varieties still requires concerted efforts into distribution networks, in order for smallholders to access more productive planting material. The case of calliandra in Kenya strongly indicates that investment into breeding will provide excellent returns for widely planted species. The Ethiopian seed sector case shows that private sector initiative alone is insufficient and how a major potential exist for public-private collaboration in repairing the broken agroforestry value chain to provide substantial benefits for smallholders.

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