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Agroforestry
Tree Domestication

A Primer

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World Agroforestry Centre, United Nations Avenue, Gigiri, PO Box 30677, Nairobi 00100, Kenya
Tel:+254 20 7224000 or via USA: +1 650833 6545; Fax:+254 20 7224001 or via USA: +1 650833 6646
Email:worldagroforestry@cgiar.org - Website: www.worldagroforestrycentre.org

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Manuscript/Production Editor: Kris Vanhoutte

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Papuan farmers demonstrating grafting © S. Lambert

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FOREWORD

The fate of the world's forests has never been higher on the political agenda and a great many organisations, including the World Agroforestry Centre (ICRAF), are raising awareness about the importance of sustainably managing forests and trees on farms. In the absence of trees, we not only lose a rich source of timber, fuel wood, foods and medicinal plants, but the life support systems and environmental services important for all human life.

Trees occur inside and outside forests. What happens outside the areas officially classified as forests has a huge bearing on what happens inside them. Currently, 43% of the world's farm land – over 1 billion ha – has more than 10% tree cover and 160 million ha has more than 50% tree cover. While the number of trees in forests is steadily declining, the number of trees on farmland is increasing. In many parts of the tropics, agroforestry is providing essential products and services that can help relieve the pressure on the natural forest domain.

There are a number of reasons why agroforestry is an integral part of the forest story, and why it is destined to become increasingly important over the coming years. Over the past two decades, the World Agroforestry Centre has pioneered practices of tree domestication, focusing, in particular, on bringing wild fruit species out of the forests and onto farmland. Now, tens of thousands of smallholders in Africa, Latin America and Asia are growing superior, high-yielding varieties of indigenous trees like safou and bush mango.

The benefits for farmers have been twofold. They are increasing their incomes and investing the profits from agroforestry to pay school fees, improve their homesteads and gain access to better healthcare. At the same time, domestication programmes have meant that rural families no longer have to harvest as much food from natural forests. This has reduced pressure on wild resources, as have other agroforestry activities, such as the growing of woodlots and medicines on farms.

ICRAF is involved in training scientists, development workers and others on agroforestry tree domestication practices. The current publication provides resources collected to support these activities. We hope that the readers of this manual, once suitably 'primed' on the meaning of domestication and the activities involved, will use this information to explore and undertake research and development work on this topic. Our intention is that smallholders' livelihoods will benefit through a 'second wave' of plant domestication that is focused on currently underutilised tree species. Major challenges in the future will be to scale up successful domestication approaches developed over the last years, and to better engage with markets and the private sector.

Anthony J Simons
Director General
World Agroforestry Centre

Dennis Garrity
Former Director General
World Agroforestry Centre

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They worked together with co-authors from several collaborating partner institutions: Roger Leakey (James Cook University, Australia), Christine Holding Anyonge (Food and Agriculture Organization of the United Nations, Italy), Patrick Van Damme (Ghent State University, Belgium), Joanne Russell (James Hutton Institute, Scotland), Jens-Peter Lillesø and Lars Graudal (both Forest & Landscape, Denmark).

Others who provided inputs to the development of this primer included Hannah Jaenicke (Consultant), for the Unit on 'Tree nursery practices', and World Agroforestry Centre staff He Jhun, Julio Ugarte and Jianchu Xu, who contributed case study information.

Ian Dawson (ICRAF) and Chris Harwood (CSIRO, Australia) edited and cross-referenced the text of individual units to develop them into a standardised form. Ramni Jamnadass, as the Leader of ICRAF's Global Research Priority on Quality Trees, provided overall leadership and supervision of the production of this publication. Jan Beniest (ICRAF) coordinated the inputs of the various authors and developed the annex on organising a learning event on agroforestry tree domestication. Kris Vanhoutte edited, designed and desktop-published this publication.

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INTRODUCTION

Agroforestry is all about using trees on farms and in landscapes for the benefit of rural communities and other land users. At the centre of agroforestry innovation and adoption is the agroforestry tree or shrub that provides products and services such as fruit, fodder, firewood, timber, medicine, soil fertility, shade, erosion control and carbon sequestration. People have noticed tree-to-tree variation within individual species and have taken advantage of this by selecting, propagating and bringing into cultivation superior types with a view to optimising products and services for human benefit. We know that the processes of domestication started thousands of years ago for some species, but more recently modern knowledge has enabled scientists to work in collaboration with farmers to continue and expand these activities.

Research on tree domestication is undertaken by the World Agroforestry Centre (ICRAF) through one of its Global Research Priorities (GRPs), on Quality Trees. A list and description of GRP activities at the centre, which is useful for understanding domestication research in context, is given on ICRAF's website (www.worldagroforestrycentre.org/). The GRP on Quality Trees addresses the Centre's research on the domestication, utilisation and conservation of superior agroforestry tree germplasm, and aims to increase farmers' access to improved germplasm of priority tree species, through the better functioning of tree seed and seedling delivery systems. Such research can involve collaboration among many organisations, projects and networks at national, regional and international levels: agroforestry is a multi-disciplinary research and development field.

Besides conducting 'research for development' on agroforestry tree domestication, ICRAF also builds and strengthens the capacity of others interested and active in this field. For many years, the Centre has been organising short learning events on the subject for scientists, technicians, development specialists, policy makers, extension staff and teachers. The demand for these courses continues to rise. Increasingly, the topic of agroforestry tree domestication is also being taught at formal educational institutions throughout the world. The demand for these courses means that good teaching materials are required.

The purpose of publishing *Agroforestry tree domestication: a primer* is twofold. First, it provides an opportunity to synthesise basic information about important agroforestry tree domestication issues, using recent research results obtained by ICRAF and its collaborating partners. Second, it provides a resource for learners and teachers to use and contextualise for their own purposes. Our intention is to update the primer regularly, so that readers will have access to the latest information on the subject. We welcome input.

For this first version, resource persons from ICRAF, in collaboration with a number of other authors, have developed a series of 15 units structured into 5 modules on key topics related to agroforestry tree domestication, as described below.

Module 1 Tree domestication in context

Module 1 is a single unit (Unit 1) that describes some of the basic principles of tree domestication. The challenges facing farming today and how these may be addressed through agroforestry tree domestication are discussed. It describes the wide range of coordinated activities that are required in domestication to address multiple bottlenecks.

Module 2 Choosing the right tree

Module 2 consists of four units (Units 2 to 5) that relate some of the procedures involved in determining how best to focus research and development efforts in tree domestication to address opportunities and needs. Unit 2 considers basic participatory rural appraisal approaches by which scientists and development experts can work with and involve farmers. Unit 3 describes ethnobotanical methods which allow the relationships between people and plants to be explored, making the most of local community knowledge. Unit 4 describes a particular priority setting procedure that has been devised by ICRAF and partners for determining which subset of a potentially wide range of useful tree species to focus activities on. Unit 5 explains approaches to value chain analysis that determine the market potential of particular species, and the most important interventions that need to be made to address limiting factors in improving livelihoods.

Module 3 Evaluating variation

Module 3, which is made up of three units (Units 6 to 8), considers ways by which tree species can be characterised in order to make informed decisions in the choice of what to cultivate, and then how to manage plantings. Unit 6 describes basic principles involved in designing field experiments to evaluate trees, while Unit 7 considers the specific cases of provenance and progeny field trials designed to explore patterns of genetic variation in tree species. Unit 8 takes a different approach to evaluation, describing some of the molecular marker methods that are now widely used to characterise genetic diversity in tree species.

Module 4 Obtaining quality germplasm

Module 4 contains four units (Units 9 to 12) that place emphasis on the ways by which good quality germplasm is brought into domestication programmes. It is concerned primarily with 'formal' aspects of germplasm provision rather than the particular 'farmer' level issues that are discussed in the following module. Unit 9 considers the different approaches that can be used when collecting tree germplasm, to develop the best strategy for a particular species. Unit 10 relates the approach that should be taken when procuring tree seed from nationally or internationally operating suppliers. Unit 11 explains principles for the establishment of tree seed production stands to supply the demand for good quality germplasm in planting projects, while Unit 12 describes the techniques that can be used to vegetatively propagate tree species.

Module 5 Delivery to farmers

Module 5 consists of three units (Units 13 to 15) that, through theory, practical guidelines and case studies, consider how farmers actually access good quality tree planting material. Unit 13 relates some of the principles of good nursery practice so that smallholders are able to obtain plants of good physiological quality. Unit 14 considers the different methods by which smallholders' currently access tree planting material and how germplasm delivery can be made more sustainable. Unit 15 describes the participatory domestication approach developed by ICRAF and partners that is based on farmers gaining access to germplasm in the wild, and receiving training and support to domesticate species themselves.

Each unit begins with a 'fast track summary' that explains the learning objectives, provides a summary of the main learning content and indicates key resources. The main text of the unit reflects the views of its authors on a subject and lists additional references that have been used to develop its content. The units and the final annex to this publication on learning methods should allow readers to develop their own training materials from this primer if they so wish, adapting and contextualising to suit the opportunities and needs of their particular audiences and environments.

This primer is designed to give its readers a solid grounding in this broad and complex subject and its component topics, thus helping to address a growing need for capacity in 'research for development' on agroforestry tree domestication.

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Module 1

Tree domestication in context

Unit 1 – Tree domestication for small-scale farmers

Ramni Jamnadass, Ian Dawson, Daniel Ofori and Roger Leakey

Unit objectives

After studying this unit, readers will be able to:

- Define agroforestry tree domestication, and explain similarities to and differences with domestication as applied to annual crops or 'industrial' tree species.
- List and describe global challenges facing farming today and explain how agroforestry and tree domestication can play a role in helping smallholders address their needs.
- List the various research issues and constraints facing tree domestication, which need to be addressed for successful intervention at the farm level.

Summary

The domestication of annual crops began over 10,000 years ago and involved processes of selection, breeding and adaptation of germplasm to fulfil human needs. For trees, the same processes are involved as with annual crops, but the great majority of tree species are still essentially wild or are only early stage, incipient domesticates. This history – or lack of it – of domestication influences how tree species should be domesticated in the future. It provides both unique challenges and unique opportunities.

This unit provides a working definition of agroforestry tree domestication that highlights its complex nature. The successful cultivation of agroforestry tree species requires the implementation of various 'research for development' activities that address many issues, opportunities and constraints of the different stakeholders involved. By applying scientific knowledge and by careful planning and coordination of different activities, the chances of success and the pace and extent of gains made from domestication are likely to be much greater.

Tree domestication can help address a number of global challenges. The diversification of farming systems through the introduction and improved production of domesticated trees can help to generate resilient rural economies that provide income, employment and other business opportunities for local people.

Key resources

- Leakey RRB, Tchoundjeu Z, Schreckenberg K, Simons AJ, Shackleton S, Mander M, Wynberg R, Shackleton C, Sullivan C (2007) Trees and markets for agroforestry tree products: targeting poverty reduction and enhanced livelihoods. In: Garrity D, Okono A, Parrott M, Parrott S (eds.) World agroforestry into the future. The World Agroforestry Centre, Nairobi, Kenya, pp. 11-22.
- Leakey RRB, Weber JC, Page T, Cornelius JP, Akinnifesi FK, Roshetko JM, Tchoundjeu Z, Jamnadass R (2011) Tree domestication in agroforestry: progress in the second decade. In: Nair PK, Garrity D (eds.) The future of agroforestry. Springer, USA (in press).
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Placing tree domestication in context

For food crops, the term ‘domestication’ is generally used to describe the selection, breeding and adaptation of germplasm to increase production and quality during cultivation. Genetic changes are made in order to meet particular human needs and to fit production into particular environments. There can be a continuum of activity, from management in the wild, through traditional plant breeding, all the way to the creation of transgenic (genetically modified) organisms using modern biotechnology methods. Crop domestication appears to have begun with barley and other cereals in Eurasia around 10,000 years ago. The event that triggered it appears to have been a rise in the size of the human population and a greater demand for food. (For those readers interested in the history of agricultural crop domestication, Harlan [1975] provides an excellent introduction to the topic.)

Cereal domestication ranks as one of the greatest technological advances in human history, with domesticated maize, wheat and rice now crucial staples that provide more than half of the energy intake of the world’s human population. Through continued genetic improvement and better management, world cereal production has greatly increased from ancient times and, indeed, has more than doubled in the last 50 years alone. While this has allowed larger human populations to be fed, heavy reliance on a few cereals and other crops has made present-day food supply vulnerable: a major pest or disease epidemic that swept though one of these crops would have very serious implications for human welfare.

Intensive domestication can lead to changes that result in a plant (or animal, since the same processes are involved) being unable to survive unaided in the wild. In this situation, a species can become completely dependent on humans for its continued existence. A good case in point is cultivated barley: the most important event in its domestication was the development of the non-brittle rachis. This meant that seeds remained on the plant after the crop had matured, allowing humans to harvest them. While good for humans, this trait prevents natural seed dispersal and wild regeneration: domesticated barley cannot survive for long in the wild.

A number of food-providing trees have been manipulated by humans through selective harvesting and propagation for several millennia. These include cacao, fig, orange, olive and apple, all of which remain important food providers. In general, though, the vast majority of the world’s 60,000 or so tree species are found in their original wild state or, perhaps for a thousand or so, as early stage incipient domesticates that have been subjected to rather limited selection and management (Miller and Gross 2011). It is fair to say that very little of the tree planting material that is currently available to small-scale farmers in low-income nations in the tropics has been ‘genetically improved’ in any way.

Partly, trees have not been domesticated because until relatively recently it was possible to meet a large part of the demand for tree products by harvesting them from wild stands without any need for cultivation. In the last fifty years or so, however, the situation has changed for the worse as natural forests have increasingly been cut down to make way for agriculture, and as timber has been unsustainably harvested in increasingly large volumes from wild stands. The loss of natural resources is becoming an ever more acute problem. Again, a relative neglect in domesticating trees reflects the difficulties in manipulating them: trees are large organisms that take up a lot of space, making their study expensive. Most of them also take a long time to mature sexually, meaning that breeding work can be slow, tedious and – again – expensive.

Despite these constraints, commercial plantation-based forestry has merited the expense of breeding work and some fifty or so ‘industrial’ tree species (including acacias, eucalypts, pines and poplars) have genetic improvement programmes underway. Most of these initiatives are less than 70 years old, although a few go back significantly further. Attempts by breeders to genetically improve tropical agroforestry tree species that have potential for

smallholders but not for large-scale commercial production started later, in the 1970s, but have not gone beyond a few species; work on leucaena (*Leucaena leucocephala*) is perhaps the most advanced. Although ‘formal’ breeding has been limited, other approaches have been used to bring a range of agroforestry tree species into cultivation, as described in this primer.

Addressing global challenges through tree domestication

In the past, tree cultivation by smallholders received only limited attention by scientists and the global development community. This situation changed around 20 years ago when it is was recognised that smallholder cultivation of trees in agroforestry systems that combine trees with annual crop cultivation and other farm activities could be very useful for addressing several of the global challenges that agriculture faces (Table 1). Presently, it is estimated that worldwide around 1.2 billion people practice some form of agroforestry (Garrity 2004) and it has been estimated that more than 500 million people, many being smallholders, live in agricultural landscapes that have at least 10% tree cover (Zomer *et al.* 2009).

In this context, tree domestication to increase productivity, resilience and value is an essential activity: it can help to combat the poverty, malnutrition and generally low health status of many local communities; it can provide mitigation and adaptation opportunities to combat climate change; it can improve energy security and increase limited agricultural productivity; and it is able to help prevent deforestation and biodiversity loss. The following units of this publication explore some of these issues further.

Table 1 Examples of current and emerging global challenges facing agriculture, and the possible roles of agroforestry and tree domestication in addressing them

Challenge	Nature of challenge	Solutions involving agroforestry	Examples of the possible role of tree domestication/areas for research
Poor nutrition and low health status	Hundreds of millions of poor people in the tropics continue to suffer from 'hidden hunger', due to limited nutrient availability. The poor also struggle to access medical treatment. Both lead to poor health	Grow a spectrum of healthy tree foods that diversify diets and provide essential nutrients year-round. Do the same for medicinal trees. Products that have strong market potential can provide farmers with income to buy other foods and medicines, and cash to invest in farm inputs that raise yields of staple crops, boosting overall food security	• Develop 'portfolios' of indigenous fruit tree species/cultivars that have the right nutritional properties (protein, fat, fibre, vitamin and/or mineral profiles), and optimise methods for the planting and management of these on farms • Identify and bring into cultivation medicinal trees with high quality active ingredients, for local health care systems and for wider use • Find better ways to multiply and deliver fodder tree seed to farmers in order to support the production of dairy and meat products, thereby improving communities' diets • Conduct value chain analysis to bring new products (fruit, medicine, dairy products, etc.) more efficiently to markets
Climate change	CO_2 and other greenhouse gas (GHG) emissions are resulting in global warming, increasingly variable weather conditions, and more extreme weather events. This is causing declines in staple crop production and large season-to-season variation in yields, especially of modern high-yielding crop varieties that are sensitive to environmental change	Grow a range of trees with flexible ecological requirements in diverse farming systems to provide complementary and compensatory production to staple crops. This spreads production and livelihood risks and provides resilience in the face of possible drought, pest epidemics, etc., that are linked to global warming	• Identify, through eco-physiological research, and bring into cultivation, a range of tree species/selected types that are well matched to predicted new environmental conditions, and/or that grow well under a variety of different circumstances (i.e., 'plastic' trees) • Select more productive tree types that fix greater amounts of carbon and thereby better mitigate GHG emissions, leading to livelihood benefits for farmers through carbon credit sales. Trees that also provide other products while fixing carbon, such as fruit, medicine or timber, may provide the best incomes

Table 1 continued

Challenge	Nature of challenge	Solutions involving agroforestry	Examples of the possible role of tree domestication/areas for research
Restricted energy availability	Fossil fuels contribute widely to world energy supply, but reserves will run low in the face of increasing demand, while use results in GHG emissions and climate change. Poor communities have never had the energy resources needed for their proper development	Grow a range of 'bioenergy' trees, in combination with other energy crops, as renewables that can contribute to local and global fuel security	• Identify and bring into cultivation tree species/selected types that produce high calorific value wood, bioethanol, biodiesel, etc. more efficiently, so that balances in GHG emissions and farmers' revenues from production are positive • Identify and bring into cultivation tree biofuels that can grow on marginal lands not already being used for agriculture (to minimise competition with food production), and that do not require forest to be cleared for planting (to limit natural forest loss)
Limited agricultural productivity	Increasing human populations mean that more food must be produced. However, steps to increase production are countered by degrading farm environments, e.g., by declines in soil fertility (nitrogen, phosphorus and potassium deficiencies estimated to affect 59, 85 and 90% of crop land, respectively)	Apply integrated soil fertility replenishment systems (e.g., rotational fallows or intercropping) that harness biological nitrogen fixation to increase crop yields with minimal cash inputs	• Identify and distribute to farmers superior types of tree legumes that fix nitrogen efficiently and release it effectively to crops. Ensure that microsymbiont interactions are also considered and optimised during distribution • Develop and disseminate farm management practices that mean trees do not overly compete with crops within agricultural landscapes (do not displace food production), but where possible are complementary in function
Forest and biodiversity loss	Pressure for farmland and excessive extractive harvesting is resulting in forest clearance and degradation. The outcome is a loss of ecosystem services locally, regionally and globally (e.g., water catchment protection, biodiversity), and reduced access to forest products for local communities. The loss of biodiversity annually has been estimated in value at 1.5 trillion US Dollars	Cultivate a range of trees to provide alternative sources of timber and non-timber forest products, reducing pressure on remaining natural forest and conserving biodiversity in farmland. Promote 'intelligent markets' for products that help to support biodiversity (e.g., use of certification schemes)	• Identify and bring into cultivation forest tree species/varieties that efficiently provide important products for local communities, are of conservation concern, and have market potential. Methods based on the participatory domestication of locally-available genetic resources may be ideal • Research to domesticate indigenous species may allow a movement away from a reliance in some locations on exotic trees that displace local biodiversity in farmland

An example of value: domesticating tree foods for poverty alleviation

As an example of the current and future potential value of tree domestication for smallholders, consider the export value of a range of tree commodity crops (Fig. 1). Not all of the value of production of these foods is captured by small-scale farmers in the tropics, as income also accrues to large-scale plantation owners, and not all global production is in the tropical region. However, taking the top four commodities listed in Fig. 1 by 2008 export value – palm oil (from *Elaeis guineensis*), coffee (primarily from *Coffea arabica*), cocoa (*Theobroma cacao*) and tea (primarily from *Camellia sinensis*) – a significant fraction of production, totalling billions of US Dollars in value, is due to smallholders.

Increased improvement of these species through genetic selection, breeding, etc., will clearly bring smallholders greater opportunities in the future. If so for these species, then why should not farmers also benefit economically from bringing other, new tree foods into cultivation? And not only foods: why not also new medicines and timbers, and other types of use, too? Certainly, there is a whole range of other edible agroforestry tree products (AFTPs) that are currently underutilised, but if promoted in the right way could raise significant revenues, as well as providing health benefits through consumption.

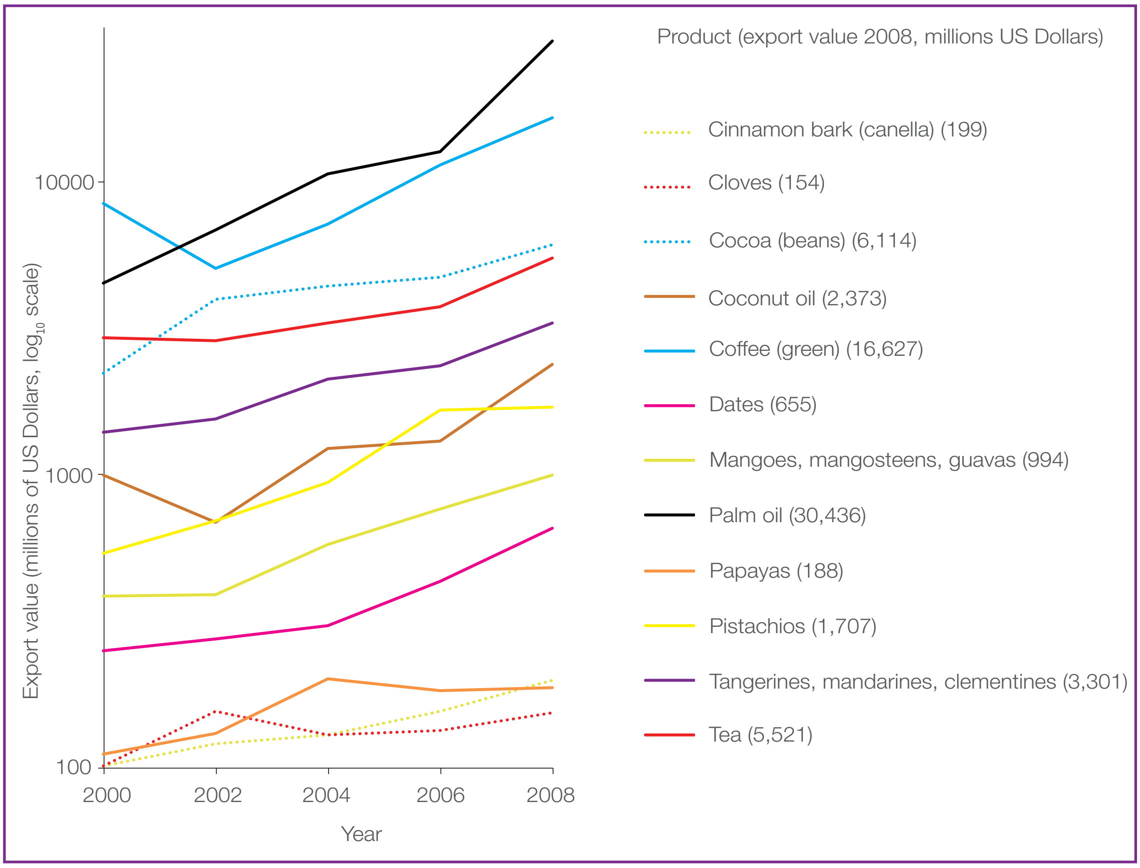

Figure 1 The potential value of AFTP domestication: building a case based on existing edible tree commodities grown in the tropics. Upward trends in worldwide export values, 2002 to 2008, are shown for 16 products (some products are grouped during data collection, e.g., mangoes, mangosteens and guavas). Note that values are shown on a $\log_{10}$ scale and are based on data from every 2^{nd} year (see more data at faostat.fao.org/). Actual export values for 2008 are given in brackets.

Tree domestication defined in a smallholder agroforestry setting

Genetic improvement and domestication are often considered to be equivalent terms for 'industrial' tree species. In the setting of small-scale farming, however, tree domestication has taken on a much wider meaning, to encompass the many different activities that are needed to address the problems that farmers face and promote tree cultivation. Some of these activities are illustrated in Fig. 2 and are described in the following units of this publication. Genetic improvement is only one component in the process of domestication, with social and political inputs often of equal or greater importance as biological ones, as outlined further in Box 1. The critical point is that domestication is concerned with the coordination of a range of actions determined by the needs of both farmers and markets.

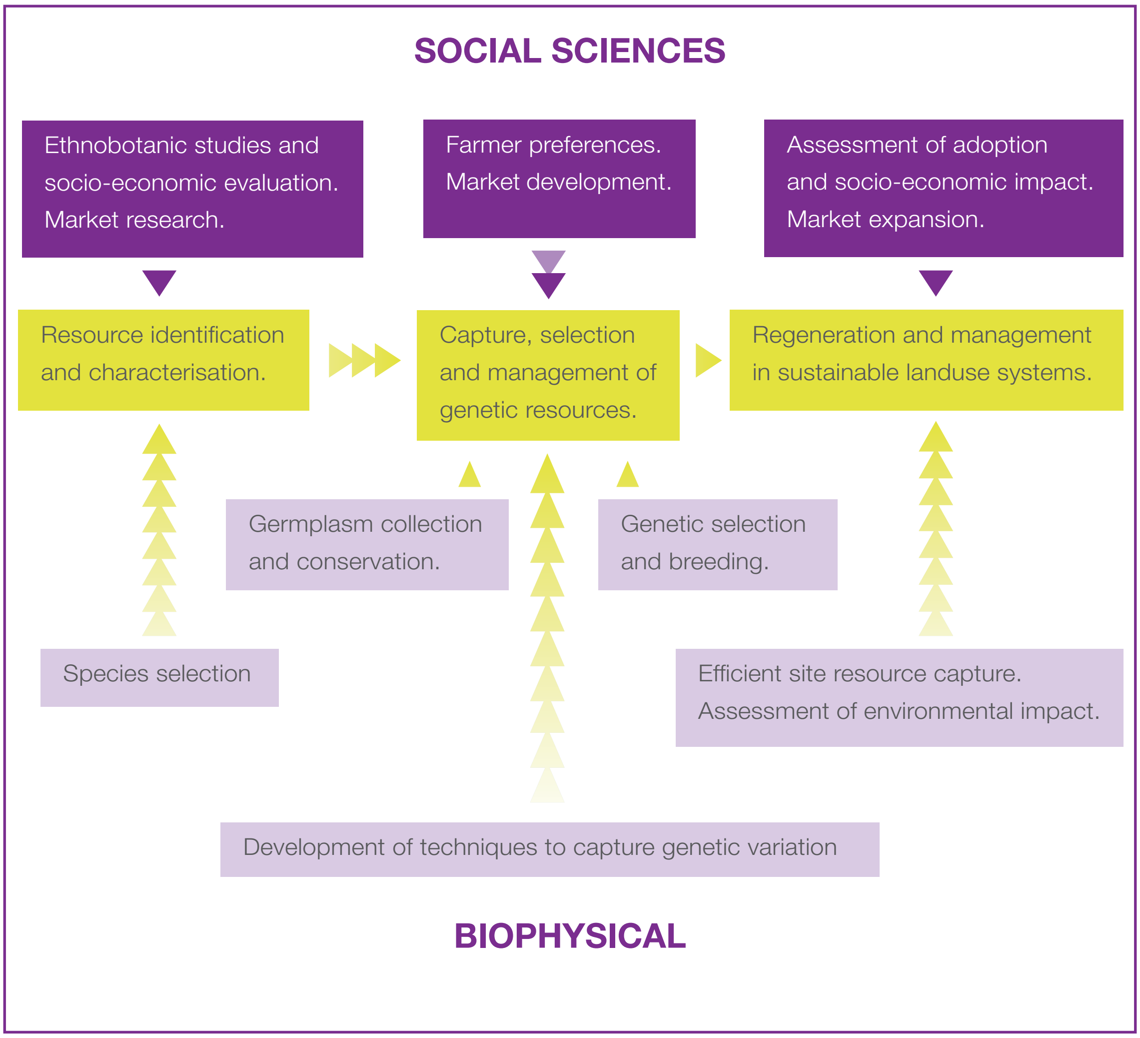

Figure 2 Various biophysical and social science activities in tree domestication for smallholders.

Box 1

The breadth of activities involved in domesticating agroforestry trees for smallholders

Important areas for intervention include the following:

Generating new knowledge on trees This may include: studying specific cultural practices on use; and determining important species and types for producers, processors and consumers. It may also include scientific research on: the extent of the available genetic resource and its value; the genetic enhancement of priority species; the best ways to manage trees in farmland; and the best approaches for postharvest handling and processing. Once appropriate materials and practices have been developed, they need to be delivered to farmers.

Communicating knowledge better This may involve: farm demonstration sites that show suitable planting materials and management methods; the collection and dissemination of successful promotion stories with farmers and consumers; the reduction of information asymmetries during promotion (especially to make sure farmers are properly informed); the lobbying of policy makers and other influential interest groups to support activities; more targeted media campaigns with consumers; and the continued development of educational curricula for schools, universities, etc. that promote agroforestry trees.

Removing policy barriers to production and marketing This may include: the initiation of national dialogues on the use of tree products; the promotion of policies that enhance access to existing and new markets (e.g., through less costly certification schemes and by the reduction of other non-tariff barriers); and the better protection of farmers' intellectual property rights to local knowledge on the use, management and improvement of taxa (so that farmers benefit when this knowledge is used more widely).

Improved market development This may involve: entrepreneurial training to support value chain development; the fostering of private-public partnerships; the organisation of buyer-supplier fora including trade fairs; the promotion of credit and grant schemes for marginalised stakeholders; and carrying out market surveys on preferences, risks, compatibilities, etc.

Better partnerships between all stakeholders This may include: encouraging strategic alliances between producers at national and international level to combat constraints to production; the promotion of multi-disciplinary research teams and regional networks to properly address farmers' problems; and the strengthening of relationships among all participants in value chains.

Adapted from a publication by Jaenicke and Höschle-Zeledon (2006) on the interventions needed to promote the better use of currently underutilised plant species.

Coordinated programmes for smallholder tree domestication

Box 2 provides a good example of a coordinated tree domestication programme that involves many different elements that are being undertaken in parallel to address a number of constraints to developing a successful business. It is based on the edible oil-producing tree *Allanblackia*. Coordinating different actions increases the prospects for success, although it does not guarantee it. Whether the *Allanblackia* initiative, known as Novella Africa, is successful will depend on whether it is possible to bring hundreds of thousands of trees into cultivation in the next few years.

The timeframe, resources required and impacts of action in different potential areas of intervention should be considered before beginning any domestication programme. The appropriate level of involvement of local people in the tree domestication process also needs to be considered. A decentralised, participatory strategy that involves local communities in most aspects of the process can be adopted in the right circumstances; this approach is described in Unit 15 of this primer.

Box 2

Novella Africa, an integrated tree domestication programme on *Allanblackia*

The seed of the African *Allanblackia* tree, a genus of nine species, produce edible oil with a significant global market potential of more than 100,000 tonnes annually. As a result, Unilever, ICRAF and the World Conservation Union (IUCN), along with national research institutions, farming communities, market traders and others, have formed a private-public partnership to work on the tree. This initiative is known as 'Novella Africa', and is intended to develop a sustainable *Allanblackia* oil business in a number of countries in Central, East and West Africa (www.allanblackia.info/).

Although the potential for *Allanblackia* as a new crop is evident, past experience based on other tree crops shows that promotion must be handled carefully if small-scale farmers are to benefit substantially and sustainably (e.g., to prevent 'market capture' by large-scale growers and to ensure the market for oil continues in the long term). Careful management is also required if outcomes for the environment are to be positive (see more below). Conservation considerations are especially relevant for the geographic regions where *Allanblackia* is found growing wild, which are global hotspots of biodiversity. To address concerns, a coordinated strategy for tree domestication, which incorporates market, cultivation and conservation elements in parallel, is being applied.

Developing a coordinated strategy has involved addressing the different perceptions of the various specialists involved in particular areas of work. It has been important for 'market delivery' specialists to understand the 'biological' complexities that are involved in bringing a new tree into cultivation and the need for research. At the same time, it has been important for 'cultivation' specialists that operate in the public sector to understand the commercial pressures of markets and that 'sufficient' rather than 'optimal' answers are required to allow the species to be grown commercially. It has also been necessary for 'conservation' specialists to trust the private sector in their commitment to the sustainable management of the tree. To deal with misconceptions, open and constant communication between partners from different backgrounds is required, to reach consensus and encourage innovation in reaching new solutions.

Box 2 continued

Developing the oil market *Allanblackia* seed harvesting operations by villagers are underway in Ghana, Nigeria and Tanzania, currently mostly from natural forest stands. Seed once harvested by individuals is brought together by local coordinators at the village level and then transported to central facilities for processing, where oil amounting to about one-third of total seed weight is extracted through crushing. Presently, most oil is then purchased by Unilever and exported for product development. Importantly, Unilever provide a guaranteed market for oil, set at a premium to other food oils.

Cultivating in smallholders' farms The potential demand for *Allanblackia* oil is much greater than the supply which can be sourced sustainably from natural stands. As a result, a programme to bring the genus into cultivation is underway and economic analysis has confirmed that planting is a financially viable exercise. Methods to improve seed germination have been devised, as have successful approaches for vegetative propagation. High variation in fruit size and seed yield is evident in natural stands, suggesting that local selections may result in significant genetic gains (see also Unit 9 of this publication); targeted germplasm collections of seed and clonal material have begun. Collected germplasm is being distributed directly to farmers, and is also being used to plant mother blocks for further (vegetative) propagation and for field trials.

Promoting biodiversity and sustainability Rural communities need economic incentives such as the sale of *Allanblackia* seed from wild stands to take a greater interest in managing natural forests. In addition, small-scale farmers require new business opportunities such as that provided by *Allanblackia* planting to expand the range of crops that they grow and to conserve biodiversity in farmland. Through these methods, Novella Africa offers positive impacts for biodiversity; however, wild harvesting of seed may result in over-exploitation of natural forest resources, and there is no guarantee that cultivation will prevent this. To support sustainable wild harvesting, guidelines on 'best practice' for seed collection have been disseminated, while the integration of *Allanblackia* into smallholder cocoa production systems is being promoted to support farm diversification.

Adapted from Jamnadass *et al.* (2010).

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Future directions in tree domestication

In a recent literature review based on more than 400 publications, Leakey *et al.* (2011) assessed the progress that had been made in agroforestry tree domestication over the last ten years in comparison to the decade before. In the first decade, 1992 to 2001, there was a focus on assessing species potential and the development of propagation techniques. In the second decade, 2002 to 2011, more emphasis was placed on new techniques for assessing variation, on product commercialisation, and on adoption and impact issues.

For the decade 2012 to 2021, Leakey *et al.* (2011) suggest that a major challenge worldwide will be to scale up successful agroforestry tree domestication approaches. This requires a better understanding of the impacts of current initiatives, as discussed for example in Unit 15 of this primer on participatory tree domestication. A second major challenge will be to better engage with markets and the different stakeholders involved in market development; one approach to do this is via value chain analysis, discussed in Unit 5 of this publication. Better engagement with markets will require greater involvement of the private sector in the processing and trading of AFTPs, and a greater recognition by policy makers of the importance of AFTPs in agriculture, to allow the development and adoption of supportive policies.

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Module 2

Choosing the right tree

Unit 2 – Participatory rural appraisal approaches

Roeland Kindt, Christine Holding Anyonge and Sammy Carsan

Unit objectives

After studying this unit, readers will be able to:

- Explain the role of participatory rural appraisal (PRA) in agroforestry tree domestication.
- Describe modes and types of participation by local people in PRA and suggest some 'do's and don'ts' when interacting with them.
- List and describe some commonly used tools for PRA, and formulate the various steps and activities involved in a PRA exercise.

Summary

PRA allows those guiding agroforestry tree domestication activities to interact with the individuals and communities who will ultimately benefit. As a result, the knowledge, opportunities and constraints of local people are taken into account in the research and development process.

There are different modes and types of participation – cooperating, consulting, collaborating, co-learning and collective action – involving communities, while several common sense 'do's and don'ts' regulate the interaction between participants in the PRA process.

PRA uses a number of tools whose function is to stimulate discussion and the sharing of information, as well as to allow reflection and analysis. It is, however, not a rigid exercise. Those involved should be prepared to adapt approaches to accommodate emerging issues and the views of those concerned. A PRA exercise must be properly planned, implemented and evaluated if its results are to guide research and development.

Key resources

- Cornwall A, Jewkes R (1995) What is participatory research? Social Science and Medicine, 41, 1667-1676.
- Messerschmidt DA (1995) Rapid rural appraisal for community forestry: the RA process and rapid diagnostic tools. The International Institute for Environment and Development, London, UK.
- Scoones I, Thompson J (eds.) (2009) Farmer first revisited: innovation for agricultural research and development. Practical Action Publishing, Rugby, UK.

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Participatory rural appraisal and tree domestication

The term participatory rural appraisal (PRA) refers to an ever-growing number of participatory methods for working with local communities to gain insights into the knowledge they have accumulated, the particular constraints they face and the possible opportunities to overcome these. The guiding principle of PRA is that all stakeholders are involved in the identification of problems and the generation of possible solutions in a shared learning process that makes use of the different knowledge systems of the participants (Table 1). PRA approaches thus emphasise 'how' information is obtained, as much as the 'content' of what is collected (Table 2). PRA seeks a holistic (as opposed to a reductionist) understanding. It provides the context to show when tree domestication activities are, and are not, part of a relevant solution to the problems faced by communities. PRA can also show which aspects of tree domestication – productivity improvements, access to germplasm, providing information on tree management, market development, etc. – are most important in a given situation.

Table 1 Different modes of participation involving local communities in research. Outsider control decreases down the table, while the potential for sustaining local action and ownership increases. The appropriate level of participation will vary depending on the question being addressed; in PRA the focus is on 'co-learning'

Mode of participation	Type of participation by local people
Cooperating	Tasks are assigned, with incentives; outsiders decide agenda and direct the process
Consulted	Local opinions asked, outsiders analyse and decide on a course of action
Collaborating	Local people work together with outsiders to determine priorities. Responsibility remains with outsiders for directing the process
Co-learning	Local people and outsiders share their knowledge to create new understanding and work together to form action plans, with outsider facilitation
Collective action	Local people set their own agenda and mobilise to carry it out, in the absence of outside initiators and facilitators

Taken from Cornwall (1995).

Table 2 Some 'do's and don't's' for PRA

Do's	Don't's
Do remember that you are a learner and leave your status and experience behind	Don't act superior to the informants
Do show interest and enthusiasm in learning. Recognise and respect informants and their knowledge	Don't feel that there is nothing more to learn
Do follow protocol in making prior arrangements for meeting	Don't take informants for granted
Do create an atmosphere of confidence, trust and enjoyment	Don't blunder around looking confused
Do provide an opportunity for everyone to speak, but do not force people to participate	Don't monopolise discussions
Do listen carefully and facilitate an information flow	Don't interrupt
Do follow a logical order in asking questions	Don't ask for too much information at once
Do recognise success in farmers' own experimentation	Do not 'over promise' on the possible contributions of scientists to solve problems
Do record the names of informants and give them credit for the information they provide	Don't forget to show your appreciation

Taken from Messerschmidt (1995).

PRA tools

PRA methodologies are adapted to the skills of the research team, the time and resources available for work, the focus of the study and the location of the exercise. PRA is based on learning by doing; protocols evolve based on meetings between team members that include the local community. PRA has developed several tools (or exercises) to facilitate data collection (Box 1). Their function is to stimulate discussion and the sharing of information, and allow reflection and analysis. Exercises should be easy to learn, fun to do and allow the voices of many people to be heard. Some tools are better in involving large numbers of people (e.g., maps) and can be used at the beginning of a survey in order to involve the larger community. Where information is lacking, interviews may then be used, perhaps targeting people that appear to be particularly knowledgeable.

Box 1

Some tools for PRA

Illustrations and diagrams Drawings, including people, objects, places, actions, processes, and relationships, can stimulate discussion on specific subjects, especially in cultures with language barriers or with high illiteracy rates. Images are often remembered better than written information, but care has to be taken that the community interprets the pictures in the same way as the wider PRA team.

Maps Maps can collect information on the locations of particular resources and other features, and can indicate the relationships between them. Maps can show topography, farm and field boundaries, soil type, water sources, forested land, land use systems and any other information that can be spatially defined. Existing maps, aerial photographs and satellite imagery can be used as a starting point. Historical trends in farming patterns, forest cover or other features can be shown. Maps drawn as part of a PRA exercise are ideally made at a location that has a good view of the surrounding landscape or by walks through the area with respondents. Transects, which are essentially one-dimensional maps that follow a line through a landscape, perhaps along an ecological (e.g., wet to dry) or land management (e.g. farm to forest) gradient, can also be used, and may summarise information simply.

Seasonal pattern charts These are used to collect information on changes that occur over time. When the basic time unit is a month, a calendar can be drawn involving a grid of twelve columns and x rows corresponding to the different activities for which information is collected. When local people have their own calendars and definitions of seasons, these should be used.

Matrices Seasonal pattern charts are an example of a matrix; more generally, matrices are useful for collecting quantitative information through the number of observations recorded in a particular cell, when observations indicate a score for a certain item or characteristic. A common approach used in Africa is the Bao game, in which the holes of the game board represent a particular option, and respondents place stones in the holes depending on their scores/priorities. The number of stones given to each option can then be tabulated.

box 1 continued

Sorting, ranking and rating Letting people rank, rate or sort options, possibly through the use of matrices, can give qualitative and quantitative information on the choices they make and how objects or concepts are classified. A number of methods are available for ranking, including through pairwise comparison (each option compared with each other and the preferred noted) or triadic comparison (as above, but options compared in groups of three and the results then summarised).

Semi-structured interview (SSI) SSIs are used in conjunction with the other tools mentioned above. SSIs can be conducted with individuals or groups and are open-ended and interactive. At the centre is a set of questions that reflect hypotheses that the PRA team wish to address. These hypotheses may have been generated through the use of other tools. Questions asked during SSI should not be leading but neutral in nature (e.g., not 'do you use this tree for timber?', but 'what do you use this tree for?'). If different members of the team (from different disciplines) ask different types of question, then data can be compared and a wider understanding obtained.

Planning, conducting and evaluating PRA

Before starting a PRA, the overall purpose of the work should be clearly set out by the research team and the local community. Objectives should not be too broad as to be unreachable in the time available, nor be too narrow as to prevent flexibility in gathering and analysing information. Flexibility is required, as the nature of PRA is that specific objectives may need to be reformulated during implementation as a result of partner interactions. This is sometimes referred to as 'designing as we go', as illustrated by Lengkeek and Carsan (2004) who describe the progress of a participatory tree domestication research project in farmers' fields in Kenya. The subject of how to undertake participatory research with communities is covered further by Gonsalves *et al.* (2005), and Scoones and Thompson (2009).

At the start, the expectations of the community need to be addressed and their permission obtained for PRA to take place. Team members should be trained in PRA methods and adequate time needs to be allocated for the collection of data in the field, and subsequent analysis and report writing. In the field, participants need to be selected to provide an overview of knowledge on a subject. This is then complemented by targeting specific groups for particular information. One procedure to identify local specialists is to start with a random sample of respondents and ask them to name a small number of people who know most about a certain topic. Each of these 'candidate specialists' is then visited and asked to again name specialists. The names that are mentioned most often should represent the 'genuine' specialists who should be consulted further. The results of the PRA should be validated with the community and discussions held on how information will be used. Difficulties experienced in data collection and analysis should be documented, and the effectiveness of methodologies analysed and changes proposed.

An example of an actual PRA exercise involving agroforestry timber production is given in Box 2. This example demonstrates the importance of linking PRA to market development, as explored through value chain analysis in Unit 5 of this publication. PRA activities also need to be linked with extension services. These are the systems that facilitate the access of farmers to knowledge, information and technologies; that facilitate their interaction with partners in research, education and agri-business; and that assist them to develop their own technical, organisational and management skills (Christoplos 2010).

Box 2

A PRA of smallholder timber production around Mount Kenya

PRA led by a combined team of foresters, agricultural extension officers and others was used to assess farmland timber production and marketing activities on the eastern slopes of Mount Kenya. Focus group discussions, stakeholder meetings, household interviews and workshops with groups of farmers and saw millers established current practices for farmland timber marketing, and identified constraints and opportunities.

Farmers identified several challenges to marketing including the following:

- Poor management of timber trees by the use of wrong pruning, pollarding and thinning methods.
- Poor valuation techniques.
- The low price for timber offered by buyers.
- Frequent conflicts with neighbours and family during felling.
- Permit requirements to cut trees.

Saw millers on their part reported the challenges of poor access to farms and limited information on available timber supply, leading to low investment, outdated machinery and poor timber recovery rates.

Through PRA, key training and organisational support needs for farmer groups were identified, and recommendations for institutional stakeholder involvement were made.

As a result, farmers were trained in:

- How to value and harvest timber of selected species already on farms.
- The handling of tree seed and the development and management of tree nurseries for the establishment of new timber stands on smallholdings.
- Silvicultural methods, including in the management of natural regenerants of indigenous species in farmland, and in the planting and appropriate management of exotic timbers already found growing in the landscape.

Farmers were also assisted in the formation of timber marketing groups. Training was given in group organisation and management, and in book-keeping skills. A district-level workshop of chiefs was also held to clarify and streamline laws and regulations governing farm timber harvesting and marketing.

See Holding *et al.* (2011).

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Unit 3 – Ethnobotanical methods

Patrick Van Damme and Roeland Kindt

Unit objectives

After studying this unit, readers will be able to:

- Discuss the importance of ethnobotany in agroforestry tree domestication.
- Describe the process of collecting herbarium samples.
- List and describe methods commonly used for ethnobotanical surveys.
- Present and analyse case studies of ethnobotanical surveys relevant for agroforestry tree domestication.

Summary

Ethnobotany deals with the relationship between people and the plants they know and use in their environment. This information is important to those interested in successfully domesticating agroforestry trees, and needs to be obtained from a broad spectrum of representatives of a community. Important considerations are described here for the selection of interviewers and interviewees.

Local knowledge obtained from communities needs to be matched with scientific information about the species being studied, such as their botanical classification. This is facilitated by collecting plant parts in the field and matching these with existing herbarium samples.

There are several methods that can be used for ethnobotanical surveys, which vary in the qualitative and quantitative information they provide. Most are based on PRA approaches (Unit 2). Which methods are relevant depend on the objectives of the study. Many examples of ethnobotanical surveys are reported in the literature, and these can be used to highlight and illustrate various important concepts and principles.

Key resources

- Martin GJ (1995) Ethnobotany: a methods manual. Chapman and Hall, London/New York, UK/USA.
- Cunningham AB (2001) Applied ethnobotany: people, wild plant use and conservation. People and Plants Conservation Manual, Earthscan Publications Ltd, London, UK.

Ethnobotany and tree domestication

Ethnobotany is the study of the relationship between people and the plants found around them, placing plants and their uses in a cultural context. It provides an understanding of how trees are used and managed, by whom, how this varies by location and ethnicity, and if and how local communities discriminate variation within and among related species. By studying local peoples' classification of plants and by comparing to 'scientifically' assigned species and genus names, the level of importance of a plant can often be deduced. The more local names there are, i.e., if there is 'over differentiation' compared to scientific names, then generally the higher the local value of the plant. Such studies require the collection of plant samples, along with their local names, in the field and then confirming their botanical names in herbaria (Box 1).

The collection of ethnobotanical information is crucial for understanding which trees should be brought into cultivation, in what way, and – once they have been planted – how they should be managed to yield the range of products required by different users. For example, local knowledge may guide collectors to particularly valuable types of a tree for certain uses, and/or to certain locations where genetic diversity is known to be high. Such knowledge is often held by the community as a whole rather than by single individuals, so broad survey is generally required.

Where local knowledge is disappearing, recording it through survey may be the only way to conserve it. In this instance, communities need to be left with a record of results in a form that is understandable to them (in the right language and format, etc.) and that can be used in the future.

Box 1

Collecting herbarium samples

Herbarium specimen collection involves sampling and preserving plant parts that enable their scientific determination. The collection of fertile plant parts (flowers, fruits, seeds) can be particularly important for description at the species level. Normally, a number of specimens will be prepared for each plant collected, in order for each of the different institutions taking part in the exercise to receive a sample.

The basic tools for the collection of samples are a field press and notebook. The field press is typically made of two hardwood mesh frames. Plants are placed in newspaper inside blotting paper that is changed regularly after collection. In between blotting papers, corrugated cardboard or aluminium ventilators are placed to facilitate drying. Each specimen is tagged with a number that references it to information collected in the field notebook.

The field notebook should contain all data that will be presented on the voucher of a herbarium specimen, including the collector reference, sampling date, site name and coordinates, local name, and any other useful information. Whenever possible, information on the phenology of the species (flowering and fruiting) should be recorded.

Herbarium specimens are often also used for molecular marker characterisation (see Unit 8). Alternatively, a separate leaf specimen (often dried with silica gel in a snap-top plastic sachet) for molecular analysis may be collected, at the same time as the herbarium sample. Mature seed that can later be grown up in the nursery for further analysis may also be collected.

Selecting interviewees and interviewers

As knowledge on plants varies within communities, a combination of random and targeted selection of informants is normally made. Random sampling provides an overview of knowledge that is then complemented by targeting specific groups that provide particular information. Specific group selection may be based on gender, income, age, profession or other variables. Women and men frequently use trees for different reasons and classify them in different ways, while older people may be 'gatekeepers' of information handed on from previous generations. An example of how age can relate to knowledge on the different uses of species is given in Box 2.

Traditional medical practitioners, blacksmiths, beekeepers, craft workers, etc., will also all hold different information on use. Many women informants will not confide with male interviewers, nor men with women interviewers, and thus survey teams are needed that include women and men. Older researchers may be more respected than students, but the latter may establish a better rapport with young people; an age balance in the interview team is therefore useful. A survey team may include botanists, linguists, anthropologists and/or economists.

Methods for ethnobotanical survey

Rapid ethnobotanical surveys are usually based on the methodologies of PRA (see Unit 2). They gather qualitative information, providing a 'sketch' of the interactions of people with plants. In-depth surveys may follow after rapid assessments, to provide a wider understanding of local ethnobotanical knowledge systems and quantitative data that can be statistically analysed and exploited. Quantitative research requires that data are collected as systematically as possible, with a sufficient number of respondents to allow statistical analysis. Quantitative ethnobotany has developed greatly during the last two decades and is able to compare the relative usefulness of plants and rank peoples' priorities. The approach tells us which tree species are most valuable for specific uses, for example firewood or beekeeping, and whether different groups attach different importance to certain species. Some of the methods used for ethnobotanical survey, and the possible scope of data collection for in-depth quantitative studies, are listed in Boxes 3 and 4, respectively.

A case study of an actual survey undertaken in agroforestry landscapes is given in Box 5. In this instance, complete tree species inventories of farms showed the importance of village-to-village sharing of planting material in promoting agricultural diversification and ensuring farming system resilience in western Kenya.

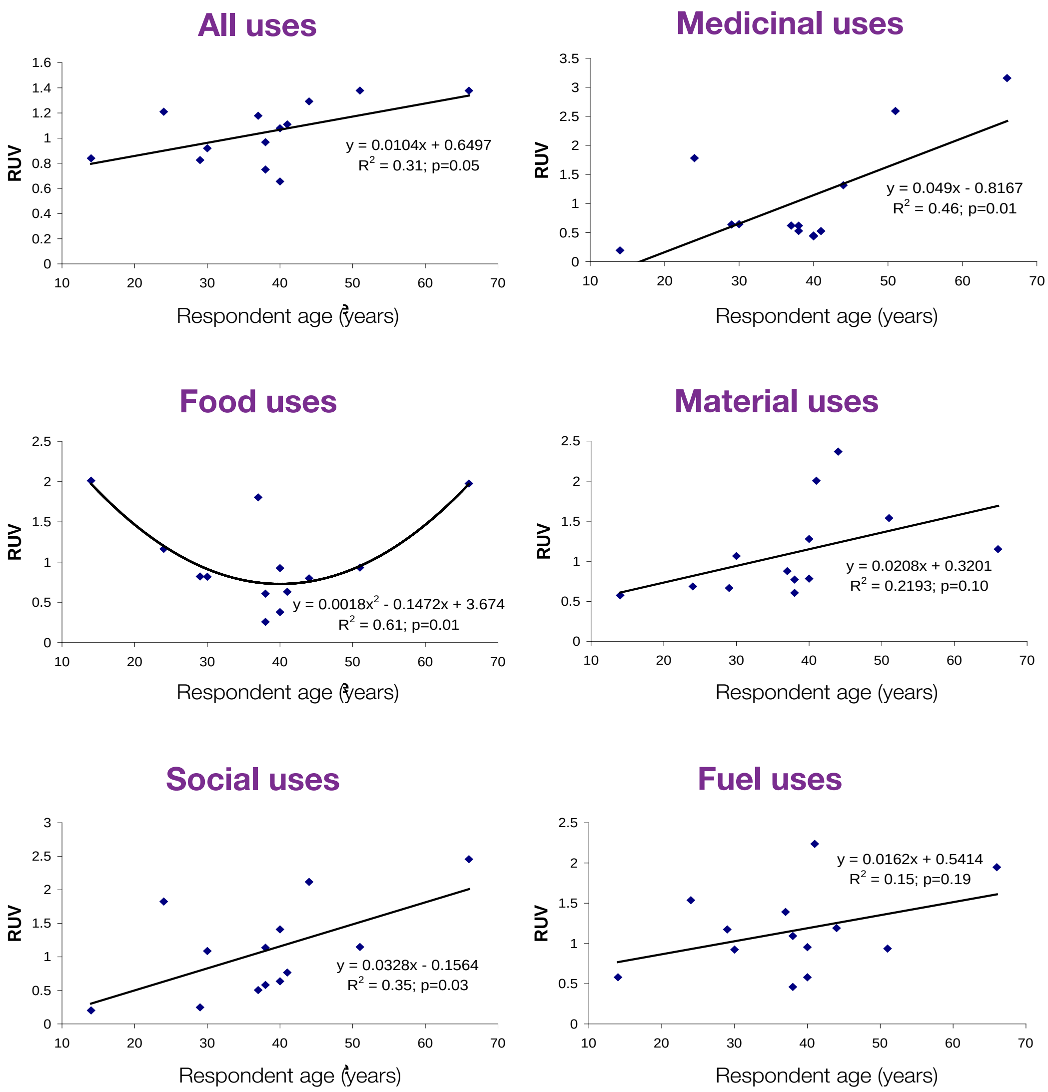
Estimating the completeness of a survey

Martin (1995) provides easily calculated parameters related to breadth, depth and replication that can be used to estimate the completeness of an ethnobotanical survey. Changes in these parameters as a survey continues should be studied. A rule of thumb is to finalise a survey when the breadth and depth no longer significantly change with additional observations, while at the same time an acceptable level of replication has been achieved. Species accumulation curves – graphs that plot the total number of species encountered against sample size, such as the number of people that are interviewed or the number of farms that are visited – can be useful to assess how complete a survey is (Box 6).

Box 2

An example from the Amazon of the relationship between respondent age and the assignment of use for different categories of plant products

The graphs below show relative use values (RUV), which provide an estimate of respondents' knowledge on the use of a species, in an ethnobotanical study conducted in the Bolivian Amazon to characterise plant use by Yuracaré and Trinitario communities. Values are given by the age of respondent for a number of categories of plant use. The data show that older people generally have more recall on uses for particular categories of plant, and may therefore be good informants, although this is not always so (see the case of food).



Taken from Thomas (2008).

Box 3

Methods for ethnobotanical survey

A simple method to gather ethnobotanical information is to ask respondents, without prompting, to make a list of all of the plants growing around them that they consider important. This will likely yield an incomplete list of important plants with very different uses, but by comparing independent responses an idea of key species and uses should emerge.

Another approach often used is a 'walk in the woods', in which local participants lead field trips to the places they visit when they normally collect plants, to point out useful species. Results with this approach are, clearly, season-dependent. Closer to the house, a walk through homegardens or crop fields can be undertaken.

The use of semi-structured questionnaires to interview people, designed around a checklist of topics, is another popular approach for collecting information. They provide the interviewer and participant some degree of freedom in questioning and answering. Structured questionnaires, in which all informants have to answer a series of exactly the same questions, allow little freedom but may be useful for collecting quantitative data.

To assist in interviews that are not conducted *in situ* (i.e., in the forest or homegarden, etc.), it is sometimes useful to use plant 'props'. These may be freshly collected plant material, dried herbarium specimens or photographs. Fresh plant material is the best option for recognition, but samples are perishable and so this approach is often not practical.

Box 4

Possible scope of in-depth ethnobotanical surveys

In-depth surveys may involve the following:

- The collection and identification of herbarium specimens of all plant species at a study site.
- Correct phonetic transcription of all local names of plants; interpretation of the meaning of local names and possible links to local use.
- Collection of local knowledge on plant parts used, detailed description of preparation and frequency of use, cultural value, and past and current management practices, of all plant species of interest.
- Describing the environment (location, elevation, climate, geology, vegetation type, species diversity, etc.), people (ethnic group, language, population size and distribution, migration, education, etc.) and interactions between them (land use patterns, tenure systems, human disturbances, etc.).
- Standardised sampling and chemical analysis of plant species to validate (or dispute) indigenous knowledge and belief systems.

Taken from Martin (1995).

Box 5

Ethnobotanical surveys on-farm: a case study of tree species composition and use in western Kenya

Complete ethnobotanical tree inventories of 201 farms from four villages in western Kenya were conducted to determine if differences in tree species composition and use existed between farms. This was done with regard to both taxonomic identity and the primary function of trees (e.g., for fruit, timber, medicine production).

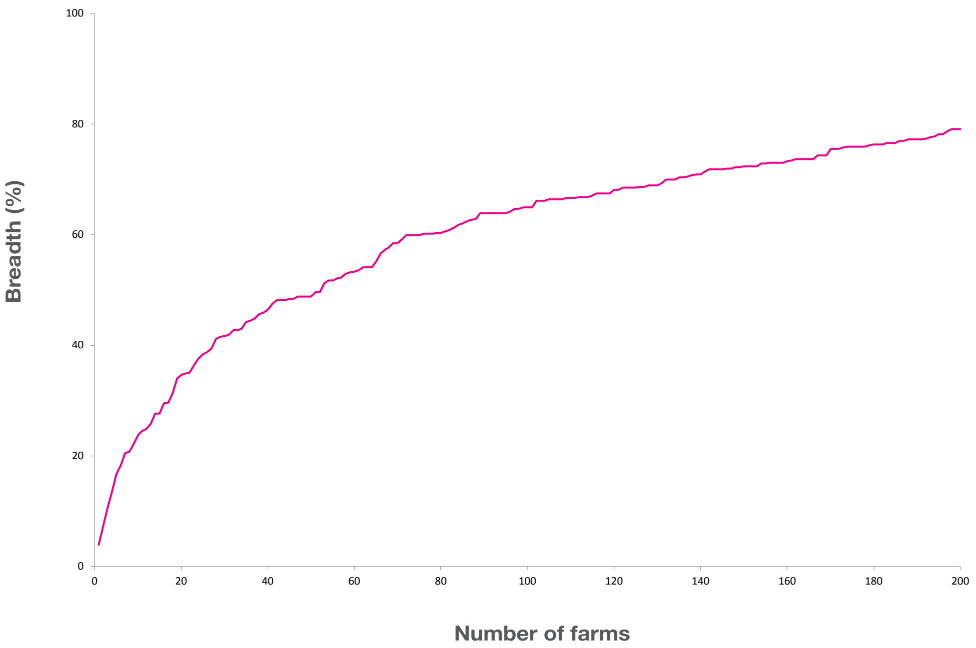
Partitioning of variation indicated wide heterogeneity between farms in both composition and use. For five important tree functions – beverage, charcoal, construction, fodder and medicine – two species dominated the compositional differences. For these functions, diversification of the farming landscape – potentially brining greater resilience to farmland production and conserving biodiversity more widely in agricultural land – could be achieved by village-to-village sharing of planting material, even in the absence of any new species introductions.

As a method of diversification this approach provides several advantages, such as the fact that local knowledge on a species is available and the species has already been tested in appropriate agro-ecological conditions. In addition, germplasm, and information on use and management, can be shared through farmer-to-farmer exchange visits. The data of this case study therefore inform tree germplasm delivery strategies for western Kenya. Such strategies are essential to bring indigenous and exotic trees into wider cultivation (see Unit 14 for further information on germplasm distribution strategies).

Case study of Kindt *et al.* (2006).

Box 6

Estimating the completeness of on-farm surveys around Mount Kenya



A survey of 265 farms across all districts surrounding Mount Kenya was undertaken and a bootstrap method used to estimate the total number of tree species present (482, including both indigenous and exotic trees). The vertical axis in the above graph shows the breadth of the survey, calculated as the ratio of the total number of species that were encountered on a specific number of surveyed farms against the total expected number of species. The total number of species encountered was estimated with the 'specaccum' function of the BiodiversityR software package (with the option of the 'collector' algorithm).

The results show that for 200 surveyed farms, nearly 80% of the total expected number of species had been encountered. The results conform to the typical pattern of species accumulation curves, where many new species are encountered at the beginning of a survey, and much larger efforts are needed to encounter new species during later phases (e.g., the 100 farms sampled during the second phase of this survey only resulted in an increase of breadth from 65% to 79%). These results show that, in areas with large numbers of species (as in many tropical landscapes), it is usually difficult to sample all species.

Taken from Kindt and Coe (2008), which also explains use of the BiodiversityR software package.

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Unit 4 – Species priority setting procedures

Steven Franzel and Roeland Kindt

Unit objectives

After studying this unit, readers will be able to:

- Explain the need for species priority setting in the context of agroforestry tree domestication.
- List and describe the steps involved in the priority setting process.
- Give examples of agroforestry tree species priority setting exercises that illustrate the steps involved.

Summary

PRA exercises and ethnobotanical surveys (Units 2 and 3) will yield information about agroforestry tree preferences, management and use. Since it is, however, not feasible to conduct tree domestication research on all of these trees, it is important to prioritise which species to work on. Farmer preferences, market opportunities and 'researchability' are key issues in species priority setting, and should be more so than researchers' own interests. Priority setting may need to be repeated periodically as preferences change.

ICRAF and partners have developed a species priority setting exercise that involves the following steps: team building and planning; assessment of clients' needs; assessment of species preferred by clients; ranking of products; identification of a limited number of priority species; valuation and ranking of priority species; and a final choice. Scientists at ICRAF have conducted and documented many such priority setting exercises, and these illustrate the concepts and principles involved.

Key resources

- Franzel S, Jaenicke H, Janssen W (1996) Choosing the right trees: setting priorities for multipurpose tree improvement. ISNAR Research Report No. 8. The Hague, The Netherlands.
- Franzel S, Akinnifesi FK, Ham C (2008) Setting priorities among indigenous fruit tree species in Africa: examples from southern, eastern and western Africa regions. In: Akinnifesi FK, Leakey RRB, Ajayi OC, Sileshi G, Tchoundjeu Z, Matakala P, Kwesiga FR (eds.) Indigenous fruit trees in the tropics: domestication, utilization and commercialization. CAB International, Wallingford, UK, in association with the World Agroforestry Centre, Nairobi, Kenya, pp. 1-27.

Species priority setting and tree domestication

As there is a very large number of tree species that could potentially be domesticated and for which planting could be promoted, it is essential to determine which should be the focus of attention, in order to make the best use of the limited resources available for support. The objective of prioritisation as part of a domestication programme is to determine the tree species for which attention will likely result in the highest impact for users; in the current context, impact is generally measured in terms of the increases in income and welfare that are likely to be realised by resource-poor farmers.

In the past, researchers' own interests and views of the importance of different trees were probably the most important criteria in setting priorities among species, but this did not necessarily capture the needs of local people and of markets. The method presented below, on the other hand, is designed to provide a more objective and systematic procedure for priority setting, and for the definition of research activities. It encourages participation and integrates the views and expertise of different stakeholders, including resource-poor rural households, scientists at national and international research institutions, market intermediaries, consumers and policy makers.

As producer and consumer preferences change with time, priority setting needs to be repeated at regular intervals. It should seek out species that are likely to have 'robust' medium- to long-term markets, so that there is time for promotion activities to deliver genuine impact. Ideally, there should be a number of avenues to market, so that farmers are not dependent on a single market player whose withdrawal from the market would put farmers in a position of vulnerability (Franzel *et al.* 2008).

After species priority-setting, it is possible to determine the level of international cooperation that is appropriate in domestication research on a particular tree species. For example, international performance trials may be appropriate for identifying superior planting material and/or management methods if a species has wide, across-country importance. Alternatively, an emphasis on local approaches for improvement, such as the participatory domestication method (see Unit 15), may be more appropriate if a species is important over a more limited geographic range.

Steps in priority setting

Species priority setting for agroforestry trees is often constrained by limited data. A procedure has been developed which builds on widely available but 'shallow' information to make initial screenings, and then gradually collects and develops more specific information to make final decisions. The seven steps in the guidelines described in Box 1 and summarised in Table 1 are based on experience gained during prioritisation exercises conducted by ICRAF and partners in various locations. These locations include the humid and semi-arid lowlands of West Africa, the medium altitude zones of southern Africa, and the humid tropics of Peru. The possible use of vegetation maps, in step 2 of the procedure, is described further in Box 2.

Examples of species priority setting

Using the above guidelines, or variations of them, priority setting exercises led by ICRAF have been undertaken at different times in over a dozen countries in sub-Saharan Africa, as well as elsewhere. Typical results, for Cameroon, Kenya and Malawi, are given in Table 2. Background information on the use of the indigenous species listed in this table is given in Box 3. In these exercises, the objective was to define priority food trees in each country, of both indigenous and exotic origin.

Results for the three countries illustrate that some species have been found to be important in several nations; for example, baobab (*Adansonia digitata*), ber (*Ziziphus mauritiana*) and tamarind (*Tamarindus indica*) were priorities in both Kenya and Malawi. (Clearly, consensus is greater when comparing neighbouring countries rather than distant nations, as in this comparison.) In other instances, priority species are specific to a nation or sub-region due to ecological restrictions or traditional use patterns. In the case of marula (*Sclerocarya birrea*), which is found throughout dry sub-Saharan Africa, prioritisation was not ubiquitous due to different use histories (traditional use in southern Africa, not East Africa); the species was therefore important in Malawi (and is also so in other countries in the southern Africa region), but not in Kenya. Priorities not only vary between countries but also within them; for example, in Kenya, exotic fruits are preferred in high rainfall areas, while indigenous fruits are more popular in low rainfall districts.

Most of the priority setting exercises with which ICRAF has been involved have not included step 6 (Box 1). This is because full valuation surveys are time-consuming and complex, although a case study approach for obtaining rough estimates of product values can be applied, rather than detailed household surveys. Priority setting exercises can also be undertaken at the project level, as Reubens *et al.* (2011) did to set priorities among tree species for land rehabilitation in northern Ethiopia. Researchers screened 91 species across 45 attributes and recommendations were given for species to plant in public places, where the criteria focussed on land rehabilitation, and for species to plant on farms, where criteria also included farmers' valuation of tree products and services.

The exercise of setting priorities provides numerous additional benefits beyond selecting key species. It helps devise domestication strategies, improves the linkages between the stakeholders involved, and facilitates rapid progress in germplasm collection and propagation. In addition, it strengthens relationships with donors and policy makers, because it provides a clear basis for supporting domestication research.

Box 1

Steps in species priority setting

The priority setting process can be considered to involve seven basic steps, as described below (see also Table 1). Through the process, the number of species considered is gradually reduced. Steps 1 and 2 may be conducted together in a preliminary stakeholders' workshop, steps 4 and 5 together in a second workshop, and step 7 in a final meeting, while steps 3 and 6 are based on field work. The set of procedures is flexible and can be adapted to meet particular needs; for example, step 6, on valuation, can be omitted if a detailed ranking is not needed.

Step 1. Team building and planning This involves building an effective team among the participants from the different institutions leading the exercise, developing a consensus on the application of the priority setting approach, and any modifications that may be required to the basic model.

Box 1 continued

Step 2. Assessment of client needs A review of secondary information is needed to define user groups, identify their main problems and determine the types of agroforestry products that may best meet their needs. User groups may be defined by agro-ecological zone (coffee land use system, tea land use system, etc.) or by socio-economic status. A starting list of which species are appropriate to consider for promotion can be determined by PRA exercises and more specific ethnobotanical studies (Units 2 and 3), and through resources such as ICRAF's Agroforestree Database (AFTD, www.worldagroforestrycentre.org/resources/databases/agroforestree). The AFTD contains data on the use, ecology and management of more than 600 tree species planted by smallholders across the tropics. In addition, vegetation maps of species distributions that are linked to use databases can be consulted (see Box 2).

Step 3. Assessment of species preferred by clients (field work) Where data on user preferences are not available, semi-structured field surveys are often used in which farmers list the tree species they grow, harvest and use, and rank them according to their perceived value, for both home use and sale. Farmers are asked why they value particular trees most. It is important that users be stratified by important criteria, such as gender and agro-ecological zone. Gender is often a key factor in determining which species, cultivars and products are deemed valuable; women should be interviewed separately and their preferences analysed independently. Similarly, data should be analysed by agro-ecological zone, if it is likely that preferred species will vary across zones. Visits to tree nurseries (Unit 13) are also a good way to find out what species farmers are interested in, although absence of a species does not necessarily reflect a lack of interest, as it may rather reflect inability to access germplasm (Unit 14).

Step 4. Ranking of products Tree products and services are ranked in order of their potential importance for solving the present and future problems of farmers. This goes beyond what farmers prefer, to include information that farmers may not be aware of such as trends and future market opportunities, and species and products with which they are not familiar. Thus, two analyses that are needed for ranking products are a market survey and an assessment of new tree-based technologies that may become important in the future. For example, farmers may not mention trees for improving soil fertility, but scientists may believe that such trees will become important in a particular location over the next 10 years because of declines in food production and increasing human populations. Similarly, farmers may not be aware of the emergence of overseas markets for a particular tree product, but researchers may want to give higher priority to trees with such potential. Only the species that provide the most important products are considered in the following stages.

Step 5. Identification of a limited number of priority species Researchers refine the list further by ranking species on their 'researchability' (the potential of research to achieve impact in domesticating the species, e.g., whether rapid productivity increases are likely to be achieved), expected rates of adoption (e.g., is the species easy to propagate and grow?) and non-financial factors that modify the objective of increasing financial value. Such factors may involve gender, i.e., the potential of women to benefit from growing the species. Another such factor is the potential value of cultivation to contribute to conserving the species, if it is susceptible to losing genetic diversity.

Step 6. Valuation and ranking of priority species (field work) Detailed data may be collected from farmers and markets to estimate the value of products of the species remaining on the priority list, and to update information on researchability, expected adoption, and modifying factors.

Step 7. Final choice The results of the exercise are synthesised and the choice of priority species is approved in a final consultation.

Box 2

Using vegetation maps during species selection

Scientists from ICRAF and Forest & Landscape, Denmark (FLD) have developed interactive vegetation maps that can be used as a decision support tool for the selection of suitable indigenous tree species to grow in particular ecological zones. So far, these maps are available for Africa only.

The basic hypothesis of using vegetation maps to select suitable tree species is that the distribution of a particular vegetation type provides a good approximation of the areas where those species that are known to occur within that vegetation type are suitable for wider planting. Maps also help to provide information on where germplasm for a particular species is likely to be obtained from.

The Useful Tree Species for Africa tool consists of map layers of vegetation types, which are displayed in Google Earth, linked to a database on species composition for vegetation types and tree uses. It can be applied as a first filter to select species that are ecologically suitable for planting for particular functions in particular locations in African countries.

The Useful Tree Species for Africa tool, and an explanation of how to use it, are given on ICRAF's website at: www.worldagroforestrycentre.org/our_products/databases/useful-tree-species-africa (Kindt *et al.* 2011).

A screen print from the Useful Tree species for Africa tool Shown is a map of Africa with vegetation zones superimposed. Using the zoom function in Google Earth provides detailed information for any particular location on the continent. Highlighted below is Somalia-Masai *Acacia-Commiphora* deciduous bush land and thicket. For this vegetation type, through clicking on the appropriate link, the tool then leads to information for 57 useful tree species.

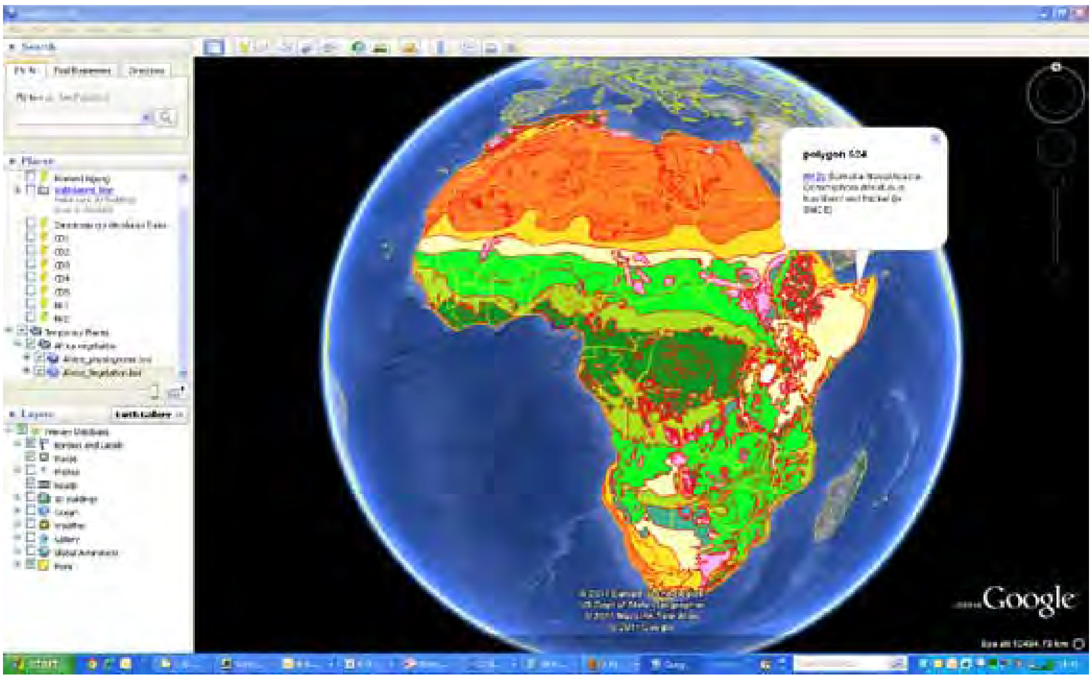

Table 1 An overview of the steps involved in the species priority setting process (for a description of steps, see Box 1)

Step	Rationale	Objectives/Output	Technical leadership	Participants	Information required	Methods	Time and resources[1]
1. Team building and planning	The skills and knowledge of many people are needed to set priorities	Agree on concepts/methods, assemble team, obtain commitments to participate, define target area for study	Research manager or network coordinator	National and international researchers. Social and biophysical scientists	Experience of conducting similar priority setting exercises; familiarity with trees; information on agro-ecology	Planning workshop	1-2 days, along with Step 2
2. Assessment of client needs	Results of research should make the greatest possible contribution to the welfare of clients (especially farmers)	Define user groups and their problems. Identify the types of products that farmers are most interested in and that may best meet their needs	Social scientist	National and international researchers. Social and biophysical scientists. Database specialists	Description of user groups; description of farmers' problems; long term trends	Planning workshop; review of secondary information (census data, species databases, vegetation maps, etc.)	1-2 person-weeks to review secondary data
3. Assessment of species preferred by clients	A clear understanding of farmers priorities is required	List of trees preferred by farmers, their suitability for agroforestry practices, and the products they provide	Ethno-botanist or social scientist with field survey experience	Interdisciplinary survey team. Social and biophysical scientists	General information on trees that farmers have and their uses	Farmer preference surveys (stratified by gender, etc.); review of secondary data on preferences and practices	6-12 person weeks (2-4 people for 3 weeks) per survey, depending on area covered/ number of clients consulted. Two-thirds of time for field work, one-third for analysis and reporting
4. Ranking of products	By ranking products, the focus is on those trees that provide the most important products. The range of tree species being considered for promotion is reduced at a low cost	Choice of 1-2 products and a list of tree species that provide them	Agroforestry specialist	National researchers from social and biophysical disciplines	Current and future importance of products (including market potential)	Workshop; reports on farmers' preferences and diagnostic surveys; expert consultations; desk study	2-3 days for workshop, along with step 5. Desk study may take a month or more to complete
5. Identification of a limited number of priority species	List of priority species needs to be reduced to a number for which detailed information can be collected. 10 or 20?	Select priority species on the basis of their researchability, expected adoption, market potential and other criteria	Agroforestry specialist	National and international researchers	Biological, economic and social data on researchability, expected adoption, market potential, etc.	Workshop; desk study	2-3 days for workshop. Desk study may take a month or more to complete
6. Valuation and ranking of priority species	If researchers wish to draw up a limited number of species, say 5, and rank them, then more detailed information is required	Rank a limited number of species by value of production. Update information on researchability, expected adoption, and modifiers	Economist	National survey teams	Field level data on production, marketing, consumption and future trends for products of priority trees	Household survey on values of tree products. A case study approach may be used to make rough estimates	12-16 person weeks (3-4 people for 4 weeks) per survey, depending on area covered and number of clients consulted. One assistant x 2 months for data analysis. One researcher x 3 weeks for analysis and reporting
7. Final choice	Sufficient information is available to make decisions on which species to promote, and how	Choose final species, define research objectives. Write a final report	Research manager or network coordinator	National and international researchers. Social and biophysical scientists	From steps 1-6	Workshop to develop consensus. Species ranked on key criteria	1-2 days

[1] The time required will vary depending on circumstances. Estimates given are based on experiences in Cameroon and Nigeria.

Bush mango

Kolanut

Njansang kernels

Table 2 Ten food trees identified through priority setting exercises as targets for promotion in each of three African countries. The same species may also be important in other nations, but Cameroon, Kenya and Malawi are chosen as representative nations from Central, East and southern Africa, respectively. Background information on the indigenous tree species that are listed here is given in Box 2. Species that are listed in more than one country are shown in bold

	Food trees ranked highly for promotion (in alphabetical order)	
Country	Indigenous origin	Exotic origin
Cameroon	*Allanblackia* species	**Avocado (*Persea americana*)**
	Bitter cola (*Garcinia kola*)	**Citrus species (e.g., orange, *C. sinensis*)**
	Bush mango (*Irvingia gabonensis/I. wombolu*)	**Mango (*Mangifera indica*)**
	Kolanut (*Cola nitida*)	
	Njansang (*Ricinodendron heudelotii*)	
	Safou (*Dacryodes edulis*)	
	Star apple (*Chrysophyllum albidum*)	
Kenya	**Baobab (*Adansonia digitata*)**	Apple (*Malus domestica*)
	Ber (*Ziziphus mauritiana*)	**Avocado (*Persea americana*)**
	Desert date (*Balanites aegyptiaca*)	***Citrus* species (e.g., orange, *C. sinensis*)**
	Tamarind (*Tamarindus indica*)	**Macadamia nut (*Macadamia tetraphylla*)**
		Mango (*Mangifera indica*)
		Papaya (*Carica papaya*)
Malawi	**Baobab (*Adansonia digitata*)**	**Avocado (*Persea americana*)**
	Ber (*Ziziphus mauritiana*)	***Citrus* species (e.g., orange, *C. sinensis*)**
	Marula (*Sclerocarya birrea*)	**Macadamia nut (*Macadamia tetraphylla*)**
	Tamarind (*Tamarindus indica*)	**Mango (*Mangifera indica*)**
	Wild loquat (*Uapaca kirkiana*)	**Papaya (*Carica papaya*)**

Modified from Jamnadass *et al.* (2011).

Box 3

Background information on indigenous food trees identified through priority setting exercises as targets for promotion in Cameroon, Kenya and/or Malawi (see Table 2 for particular countries where a priority; the same species are also important in some other nations)

Allanblackia A genus of nine species found in the humid forests of Central, East and West Africa, the tree grows to 40 m tall and produces a large fruit that contains between 14 and 90 seeds. The seed produces an edible oil of interest to the global food industry as well as for local use in cooking and soap production (www.allanblackia.info/). Oil from two species, *A. parviflora* and *A. stuhlmannii*, has received the approval of the European Union Novel Food Regulations that certify safe usage as a foodstuff in European markets, making these priorities for cultivation.

Baobab *Adansonia digitata*, a tree with a large swollen trunk that can have a diameter of up to 10 m, is a long-lived (up to 2,000 years) species located in arid and semi-arid savannah in sub-Saharan Africa. The edible white, powdery pulp found in the fruit is very rich in vitamin C and vitamin B2 and is used to make a refreshing drink. Young leaves are also rich in vitamin C and are in high demand by local people in West Africa as a soup vegetable.

Ber *Ziziphus mauritiana,* a spiny evergreen shrub or small tree up to 15 m high, is native to drylands in Africa and Asia. The fruit is important to local people because it can be eaten fresh or dried and can be made into a floury meal, butter, or a cheese-like paste, used as a condiment. The fruit is a good source of carotene, vitamins A and C, and oils. A refreshing drink is prepared by macerating the fruit in water. The use of ber in India can be traced back as early as 1,000 BC.

Bitter cola *Garcinia kola*, native to the moist lowland tropical forests of Central and West Africa, is a medium-sized evergreen tree. The bitter kernels are highly valued in Central Africa and are chewed as a stimulant. The kernels are also used for the treatment of coughs, bronchitis and liver disorders. Split stems and twigs are used as chewing sticks. A recent inventory revealed that the species, which is currently harvested mainly from the wild, is close to commercial extinction in Ghana.

Bush mango *Irvingia gabonensis* and *I. wombolu*, collectively known as bush mango or dika nut, are economically important long-lived fruit trees native to moist lowland tropical forest in Central and West Africa. The fruit mesocarp of *I. gabonensis*, sweet bush mango, is appreciated by local people as a fresh fruit snack. Ground kernels of both species are used to thicken and flavour soups, although those of *I. wombolu*, bitter bush mango, are most valued and fetch high prices in cross-border trade, contributing significantly to local economies.

Desert date *Balanites aegyptiaca*, a spiny shrub or tree up to 10 m high, is a species with a wide ecological distribution across Africa. The fleshy pulp of both unripe and ripe fruit is eaten dried or fresh. The fruit is processed into drinks in West Africa and is valued as a soup ingredient in East Africa. Young leaves and tender shoots are used as a vegetable, which are boiled, pounded and fried.

Box 3 continued

Kolanut *Cola nitida*, an under-storey evergreen tree that generally grows to 9 to 12 m tall, is native to lowland tropical forests in Central and West Africa. Nuts, which contain caffeine, kolatine and theobromine, are chewed as a stimulant. The nuts taste bitter when chewed at first but they leave a sweet taste in the mouth later. Chewing cola nuts before drinking water thus helps to render the water sweeter. The nut is widely used for social ceremonies.

Marula The long-lived tree *Sclerocarya birrea* has an extensive distribution across dryland savannah habitats in the sub-Sahara. The fruit pulp of *S. birrea* subsp. *caffra*, widely distributed in southern Africa, is used to produce jam, juice, beer and, in South Africa, the internationally available liqueur Amarula Cream, while the oily kernels are consumed raw, roasted and in sauces. In addition to current use, archaeological evidence indicates human harvesting of fruit extending back 10 000 years.

Njansang *Ricinodendron heudelotii*, a fast-growing tree reaching up to 50 m in height, is found primarily in Central and West Africa, often in secondary forest. Kernels carry a high economic value. A spicy sauce made from them is widely used in stews, and the high oil content of the seeds makes them suitable for use in the soap industry. In Cameroon, it is also valued for its medicinal properties and is used to treat constipation, dysentery, eye infections and female sterility, and also as an antidote to poison.

Safou *Dacryodes edulis* is a medium-sized evergreen tree found in the humid tropical zone of Central and West Africa. It has been cultivated by farmers in southern Nigeria and Cameroon for many years, and is considered 'semi-domesticated' in some areas, based on planters' selective seed sampling. Widely sold with a high economic value in local markets, the highly nutritious fruits have an oily texture similar to avocado and are eaten boiled or roasted. The fruit pulp is rich in vitamins and amino acids.

Star apple *Chrysophyllum albidum*, a long-lived tree which grows to 35 m tall, is a canopy species of lowland mixed rainforest that is distributed from West Africa to western Kenya. The fleshy and juicy fruits are popularly eaten, and can be fermented and distilled for the production of wine and spirits.

Tamarind *Tamarindus indica*, a tree growing to 30 m tall, has an extensive distribution through much of the tropics, but is believed to have originated in Africa, where it is found across dryland savannah regions. The species was cultivated in Egypt as early as 400 BC. The fruit pulp is used to prepare juice and jam, and is an important ingredient in curries, chutneys and sauces. The ripe fruits of 'sweet' types are eaten fresh as a snack.

Wild loquat *Uapaca kirkiana*, a small- to medium-sized evergreen or semi-deciduous tree, is found in the miombo woodlands of southern Africa. The fruit of *U. kirkiana* is highly regarded and is eaten fresh as well as being used to prepare jams and beverages. Harvesting of fruit from wild stands is an important coping strategy during times of extreme hunger.

Taken from Jamnadass *et al.* (2011). For further information on these species, see the AFTD (web address given in Box 1).

Additional references

Jamnadass RH, Dawson IK, Franzel S, Leakey RRB, Mithöfer D, Akinnifesi FK, Tchoundjeu Z (2011) Improving livelihoods and nutrition in sub-Saharan Africa through the promotion of indigenous and exotic fruit production in smallholders' agroforestry systems: a review. International Forest Review, 13, 338-354.

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Unit 5 – Value chain analysis

Eddah Nang'ole, Steven Franzel, Christine Holding Anyonge, Dagmar Mithöfer

Unit objectives

After studying this unit, readers will be able to:

- Describe how value chain analysis (VCA) contributes to agroforestry tree domestication.
- Suggest tools that can be used for VCA, and list and explain the various steps involved.
- Discuss practical examples of the use of VCA for agroforestry tree species and products.

Summary

This unit explains what VCA is and how to conduct such an analysis. VCA characterises the processes by which products are brought from production to consumption, and evaluates the organisation, operation, performance and dynamics of a particular market, including the interrelationships between the different actors and structures involved.

VCA can be used to identify constraints where changes need to be made in current practices, in order to make smallholder tree domestication a more profitable enterprise. By focusing the limited resources available for promotion on these constraints, there is a higher likelihood of realising genuine livelihood improvements for farmers.

There are several tools that can be used for VCA, such as rapid market appraisal (RMA) and more rigorous approaches that test the statistical significance of hypotheses. This unit provides recommendations to be considered to improve the operation of a value chain, and gives practical examples based on kolanuts, calliandra seed, pygeum bark and smallholder timber.

Key resources

- Kaplinsky R, Morris M (2002) A handbook for value chain research. International Development Research Centre, Ottawa, Canada.
- Van den Berg M, Boomsma M, Cucco I, Cuna L, Janssen N, Moustier P, Prota L, Purcell T, Smith D, Van Wijk S (2009) Making value chains work better for the poor: a toolbook for practitioners of value chain analysis. Making Markets Work Better for the Poor (M4P), Hanoi, Vietnam.
- Betser E (2001) Rapid reconnaissance surveys in market research. The World Agroforestry Centre, Nairobi, Kenya.

Value chain analysis and tree domestication

Value chain analysis (VCA) characterises the processes by which products are brought from production to consumption, through a range of activities such as input supply, harvesting, processing, storage, transport, marketing and financing, and seeks to understand how value is created (Box 1). VCA evaluates the organisation, operation, performance and dynamics of a particular commodity market, and the interrelationships between the different actors (input suppliers, producers, traders, processors and distributors, etc.) involved. In the literature, terms such as supply chain analysis and market chain analysis are sometimes used interchangeably with VCA.

VCA can be used to identify constraints and opportunities for intervention in a chain. In the context of smallholder agroforestry, VCA can be used to foster the integration of farmers, who are traditionally 'price takers' rather than 'price makers', into markets for tree products. It can identify the particular leverage points where changes need to be made to make smallholder tree domestication a more profitable enterprise. By focusing the limited resources available for promotion at these key points, the likelihood of realising genuine livelihood improvements for smallholders is increased.

Prior to undertaking VCA, a decision needs to be made on which sub-sectors, types of products or commodities should be prioritised for analysis. Selection may be made based on unmet demand in the market, potential to add value, and/or potential to improve livelihoods. The prioritisation of chains for analysis should involve a broad spectrum of stakeholders, such as local policy makers, farmers and private enterprises.

Box 1

The uses of value chain analysis

According to Kaplinsky and Morris (2002), value chain analysis can be used to:

- Systematically map the actors participating in the production, distribution, marketing and sale of a particular product.
- Identify the distribution of benefits among actors in a value chain, through an analysis of margins and profits.
- Examine the role of upgrading of a value chain (e.g., improvements in yield, diversification, enhanced product quality, stronger actor linkages) in reaching a better balance between risks and rewards for different participants.
- Assess the role of governance – the structure of relationships and the coordination mechanisms that exist between actors – in the value chain, to help identify new institutional arrangements to improve capabilities.

Steps in value chain mapping

Mapping is about finding different ways to represent the connections that exist in value chains. According to Van den Berg (2009), it is important to map core processes, identify and map the main actors involved and the relationships between them, and map volumes, geographic flows and value. Each of these is considered below, with case studies given based on agroforestry tree products.

Mapping core processes

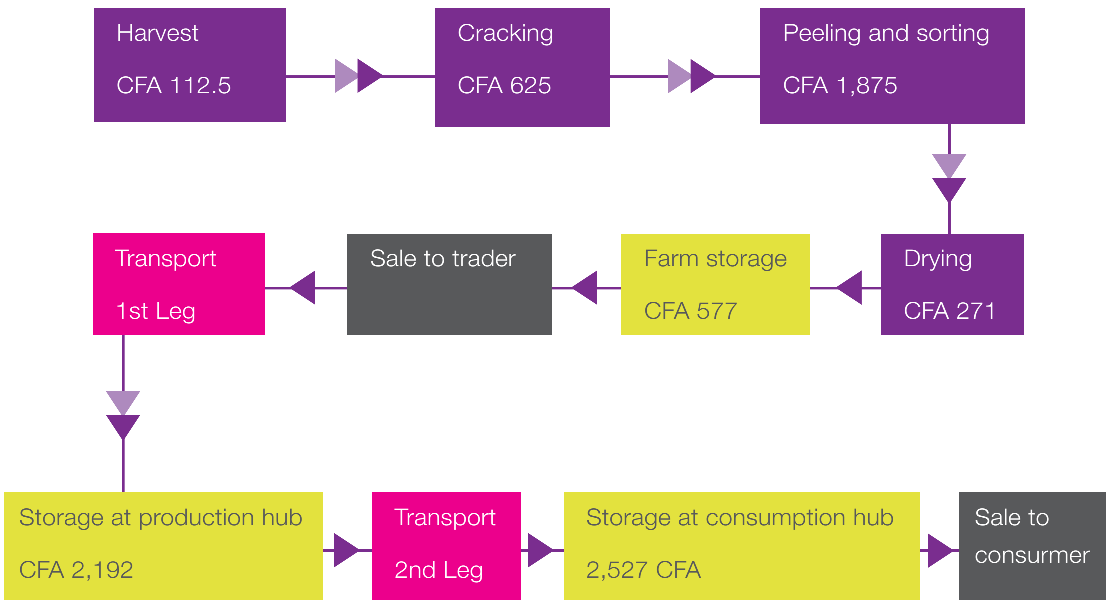
This involves distinguishing the major processes that products go through before reaching the final consumption stage. Box 2 shows an example of core process mapping for the kolanut value chain in Cameroon. In this instance, analysis indicated that storage was the most costly element, and interventions have therefore been targeted to this issue.

Box 2

Map of core processes for the kolanut value chain in Cameroon

The figure below shows the major processes, with associated costs, in the value chain for kolanut (*Cola nitida*) in Cameroon. Kolanuts are widely consumed in Central and West Africa and have important social significance. The figure shows that storage (at production and consumption hubs) brings high costs, partly as a consequence of losses caused by pest damage. ICRAF and partner organisations have therefore focused on reducing storage costs through introducing methods for pest control. This allows greater value to be apportioned lower down the chain with farmers. Interventions have also been made to help farmers to work in groups for bulk sales, increasing prices and the incomes they earn.

The kolanut value chain in Cameroon Shown are the processes in the chain and the distribution of costs (variable costs in Central African Francs [CFA] per basket of 1,000 nuts, 1 USD ~ 500 CFA at the time of study).



Adapted from Facheux *et al*. (2006).

Identifying and mapping main actors
This involves categorising actors according to their main occupation, such as producers, collectors and processors. Franzel *et al.* (2007), for example, carried out such an exercise for the leucaena (*Leucaena leucocephala*) leaf meal value chain in Tanga, Tanzania, where leaf meal is an important feed for dairy cows. VCA indicated that the actors collecting leucaena leaves, processing them into meal, and transporting and marketing the product, were poor. On the other hand, VCA indicated that the dairy farmers that fed the meal to their animals were relatively wealthy. The results of VCA were used to recommend that interventions focus on collectors, processors and transporters, since these were the poorer actors in the chain. One measure recommended was to introduce simple practices for drying leaf meal, particularly during the rainy season, and compressing it to make transport easier.

Mapping relationships
These exist vertically, for example, between sellers and buyers, and horizontally, among enterprises pursuing the same activity in a value chain (e.g., processors in the above example on leucaena). Understanding collaboration and competition in these relationships is essential, in order to promote fairer, more transparent and more trustful chain partnerships, especially for the rural, vulnerable poor.

Mapping volumes
This involves quantifying the size of the different components of a value chain. It may include measuring the volume of product, the number of each type of actor involved and/or the level of employment associated with a particular step. It provides an indication of the scale of intervention needed in a value chain. If many parties are involved at a particular step, it may be expensive to contact them individually to bring about change, and group discussions may be a more efficient approach. Alternatively, it may be more cost effective to intervene in another part of the chain where there are fewer participants to deal with.

Mapping geographical flows
This involves following the trail of value chain activities geographically, thereby capturing the spatial dimension of product flow. Mapping starts at the place of origin and records how the product travels from intermediary trader to wholesaler, retailer and finally to consumer. Box 3 shows an example based on calliandra, a tree grown for fodder, in Kenya. Calliandra produces seed better in western than in central Kenya, resulting in a deficit in seed availability to grow fodder in the latter region. Interventions therefore aimed to better link seed suppliers in western Kenya with farmers requiring seed for planting in central Kenya.

Mapping value
This involves looking at monetary flows through a chain, and the costs and margins that each actor contributes and receives. This enables researchers to determine how profitable a value chain is for each participant, and allows interventions to create more balance if financial benefits or risks turn out to be skewed to particular actors. The steps involved in mapping value are to: (1) identify operational costs and required investments, (2) calculate prices and revenues per actor, (3) calculate financial ratios (gross margin, net income, net margin, breakeven point, etc.); and (4) establish the relative financial position of actors. In addition, researchers need to estimate the ‘opportunity cost’ of engaging in a particular market and not with another, as the participation of actors in one activity may prevent their involvement in an alternative.

An example of a calculation of net income, for traders of pygeum bark in Cameroon, is given in Box 4. The bark of this tree is traded worldwide for the treatment of prostate conditions. It had been believed that traders earned more than their fair share of profit from the bark value chain, but in fact VCA indicated their net income, as a percentage of capital invested, was roughly comparable to returns earned in other sectors. This suggested that the market was fairly competitive and that traders were not colluding to fix prices.

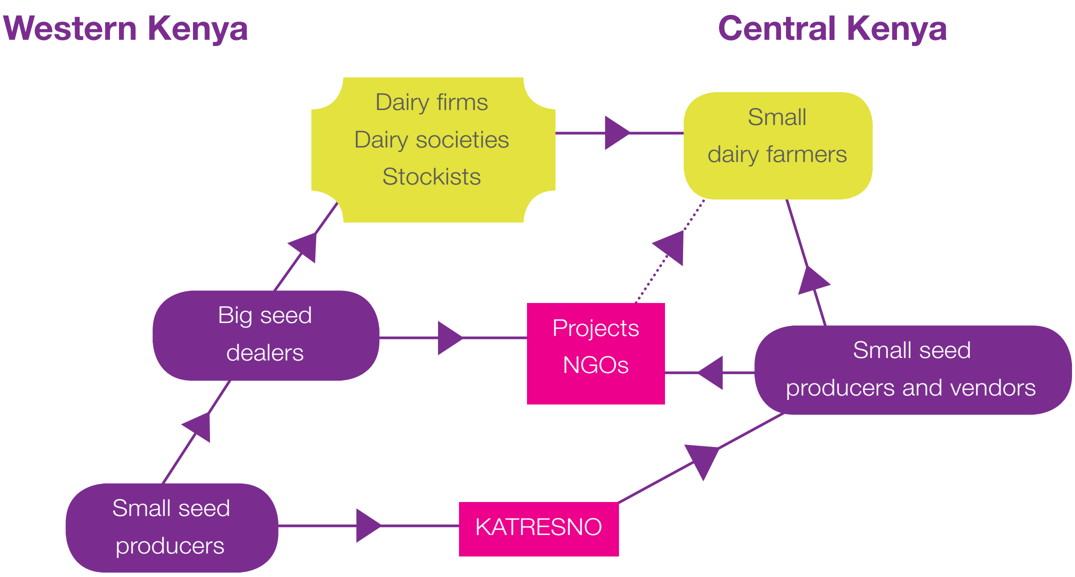
Another example of the costing of value chain steps, in this case for smallholder timber production in Kenya, is given in Box 5. In this case, VCA indicated group timber sales could provide scope for improved incomes for farmers.

Box 3

Mapping geographical flows for calliandra seed in Kenya: options for matching demand and supply

Calliandra (*Calliandra calothyrsus*) is a fast growing, nitrogen-fixing leguminous tree used for feeding dairy cows. Since dissemination began in East Africa in the late 1990s, over 200,000 farmers have planted it. The species is a shy seeder in central Kenya, and the supply of planting material can be a significant problem there. TechnoServe and ICRAF have explored the development of sustainable seed delivery systems in Kenya. The steps of seed production and supply were evaluated. This indicated that seed collectors and dealers were able to source calliandra seed in western Kenya, and that these actors provided seed to NGOs and other institutions that introduced seed into central Kenya. However, seed delivery from NGOs and others to smallholders in central Kenya was ineffective.

Interventions to improve the situation have included developing other channels for central Kenyan farmers to receive seed from western Kenya. This has involved bringing dairy societies and other, new actors into the seed value chain. One activity has been to promote small entrepreneurial seed suppliers. A network of seed vendors, the Kenya Association of Tree Seed and Nursery Operators (KATRESNO), has developed, in order to bridge suppliers in western and central Kenya, and has improved supply in the central region.



Taken from Wambugu *et al.* (2011).

Box 4

Mapping costs and returns for a trader of pygeum bark, Cameroon

The bark of pygeum (*Prunus africana*), a tree found in the highland forests of Cameroon as well as elsewhere in Africa, is used to treat benign prostatic hyperplasia in older men. The table below shows the net income earned by a trader of bark in Cameroon in 1995, when bark was processed and exported from the country by a French company, Plantecam.

Although the margin between the price traders paid to collectors and the price traders received from Plantecam seems high, traders' costs were also high. Traders also faced considerable risks: there was no easy way for them to assess bark quality, which determined the end price paid by Plantecam (see scenarios a and b below), and they had to pay considerable and variable 'fees' to government officers during transportation. Net returns as a percentage of capital invested, which ranged from 13 to 42% over the three months between purchase and sale, were probably not inordinately high, given the risks to traders and the scarcity of capital in rural Cameroon.

Costs and returns for a trader of pygeum bark Based on purchase of 16.5 tonnes of wet bark near Bamenda, Cameroon. After drying, this reduces to ~ 11 tonnes in weight, the quantity that can be transported in a single truck load from Bamenda to the Plantecam factory (costs in CFA, 1 USD ~ 500 CFA at the time of study)

Costs (CFA)	
Buy 16.5 tonnes of wet bark at 70 CFA/kg	1,155,000
Collection costs	
- 2 labourers for 1 month at 500 CFA/day	30,000
- Transport to organise collection (500 km at 200 CFA/km)	100,000
- Transport from collection site to Bamenda	75,000
Drying costs (1 labourer for 1 month, 500 CFA/day)	15,000
Transport from Bamenda to Plantecam factory (for 11 tonnes)	250,000
Tax (2 CFA/kg)	22,000
Miscellaneous fees (10%)	165,000
Interest on capital (10% for 3 months)	181,000
Total costs (all are variable costs)	1,993,000
Net Income (CFA)	
Scenario a) (high quality bark)	
Revenue earned from sale of 11 tonnes at 250 CFA/kg	2,750,000
Net income (revenue minus costs)	757,000
Net income as percentage of capital invested	42%
Scenario b) (medium quality bark)	
Revenue earned from sale of 11 tonnes at 200 CFA/kg	2,200,000
Net income (revenue minus costs)	270,000
Net income as percentage of capital invested	13.5%

Taken from Franzel *et al.* (2011).

Box 5

Costing value chain steps for smallholder timber producers in Kenya

A sample of more than 40 businesses involved in the timber trade around Mount Kenya were selected for VCA based on the hypothesis that current chains for sourcing timber from smallholders' farms are inefficient and deprive actors of profits. Eleven different types of timber related business were identified, of which furniture workshops and small sawmills were the most common. A variety of actors operating at various stages in the chain were also identified, including farmers, power saw operators, mobile saw bench operators and transporters.

VCA revealed that farmers received higher prices for timber when businesses visited farms to make purchases directly. These businesses then bore the cost of processing on farms, using power saws and mobile saw benches, or transported timber to town for sawing, activities that were either carried out by the businesses themselves or were contracted out to others. Businesses reduced their transport costs by purchasing in bulk from a number of farms in close proximity. The actual prices received by the selling farmers depended on the quality of the timber trees, which depended on the silvicultural management practices that had been applied by them, as well as on the particular species.

Overall, the chain with the least cost per board foot of timber was one in which a single business managed the length of the chain, rather than paying other service providers to conduct operations such as splitting and sawing. Analysis indicated considerable scope for improving the prices paid to farmers if they could sell in bulk through group sales. In addition, illegal harvesting of indigenous timber stands reduced the prices farmers obtained from selling legally produced timber. The enforcement of regulations protecting indigenous species in natural forest would enhance their conservation and support on-farm timber production.

Taken from Holding *et al.* (2011).

Tools for carrying out VCA

Many VCA are implemented using rapid market appraisal (RMA), which captures information and views from the actors along the value chain and from other interested parties (policy makers, extension services, scientists, etc.). RMA strives to give a first overview of products that have some market potential and to capture characteristics of their production-to-market system. Betser (2001) provides a detailed review of the approach. More formal surveys that use randomised sampling techniques and approaches to test the statistical significance of hypotheses may follow. Several of the studies described in the boxes above (e.g., Franzel *et al.* 2007, Holding *et al.* 2011) involved RMAs and then applied additional methods. Nang'ole *et al.* (2011) provide an overview of methods used to assess value chains, based on a review of 32 manuals on VCA.

RMAs and more formal, quantitative analyses have different strengths and weaknesses. RMAs can be completed quickly and at low cost, and can involve many different stakeholders. More formal surveys allow statistically-based estimation of critical parameters, but are more expensive to implement and are less flexible.

Developing recommendations for future action

VCA should lead to a number of technical, institutional and/or policy recommendations to improve the operation of a value chain. These recommendations relate to the following:

- Changes in input supply.
- Technical assistance and training needs.
- Marketing options (e.g., bulk sales, contracting).
- The establishment of market associations or producer groups/cooperatives.
- Improvements in market intelligence.
- Improvements in market infrastructure (e.g., transport, storage, processing).
- Improvements in financial services.
- Identification of new products and new markets.
- Opportunities for adding value.
- Policy and regulatory issues (taxation, subsidy, laws, price control, etc.).
- Needs for more in-depth research to better understand complex issues.

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Module 3

Evaluating variation

Unit 6 – Principles of field experiment design

Anja Gassner and Ric Coe

Unit objectives

After studying this unit, readers will be able to:

- Indicate why field experiment design is important in the context of agroforestry tree domestication.
- List and define the main elements of field experiment design.
- Understand how the objectives, design principles and knowledge of context can be brought together to give a valid and efficient design.
- State important considerations needed for the proper planning and management of field experiments.

Summary

Tree domestication research often involves the design and implementation of experiments in laboratory, nursery and field settings. Field experiments may be fully under researchers' control, or may involve both researchers and farmers. Field trials may be required for a number of reasons, for example, to select superior species or provenances, or to study interactions between species in agroforestry settings. Experiments are a key tool in research because they allow hypotheses of cause and effect to be tested. Decisions need to be based on sound evidence, and experiments are important in generating it.

It is therefore important that those involved in conducting trials and analysing the data they provide are familiar with the principles of experimental design, involving controls, randomisation and replication. This unit summarises important concepts related to treatments, layout and measurements. Scientists at ICRAF have produced several detailed learning resources related to experimental design, which are referred to here. Examples of design are also presented in Unit 7.

Key resources

- Roger JH, Rao MR (1990) Agroforestry field experiments: discovering the hard facts. 1. Statistical considerations. The World Agroforestry Centre, Nairobi, Kenya.
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Why are field trials important for tree domestication research?

Experiments are important in tree domestication in many different contexts. For example:

- In the laboratory, when studying germination processes.
- In the nursery, when developing vegetative propagation protocols.
- In the field in experiments controlled by researchers or farmers, as explored in this unit.

Making measurements in field trials, to draw statistical inferences and make informed decisions about differences between various 'treatments', is important in the tree domestication process for a number of reasons. This is best illustrated by a series of examples, as given below:

- In order to understand genetic differences and select suitable species, provenances or individuals (see Unit 7 for a definition of the term 'provenance', often used interchangeably with the term 'population'); for example, to identify trees that are high yielding and/or that meet specific market requirements for products such as timber, medicine and fruit. Clearly, this involves both between- and within-species comparisons.
- To understand the effects of a particular tree species or type on the performance of other components in a system (competition, synergy, etc.); for example, to test the influence trees have on soil nutrient levels, soil biology and crop yields (when intercropping).
- To understand the relationship between environmental conditions (e.g., temperature, rainfall, soil type) and the production of products and services by particular tree species and provenances, to establish recommendation domains/limits for use. The effects of these variables on tree health (e.g., pest and disease attack) may also be important, particularly in the context of climate change creating new environmental conditions.
- To devise cost-effective management methods (appropriate regimes for watering, pruning, coppicing, etc.) for the production of different products and services, and to evaluate the financial viability of different production systems.
- To understand basic genetic and physiological processes that control tree growth and performance.

The current unit discusses general principles of field experiment design. Unit 7 then refers specifically to field experiments that assess genetic variation within tree species, trials which can be particularly important in the domestication process.

A cautionary note

Field trials are costly and time consuming, especially when studying trees. Researchers should conduct a thorough review of the literature, to decide whether a field trial is the appropriate method to address the research question. For example, when studying the nitrification effect of nitrogen fixing trees it might be more efficient to carry out an observational study on existing tree stands rather than set up a field trial that will only yield interesting results after perhaps 15 years. However, an objective that requires investigating cause or change – such as finding out if different provenances of the tree fix nitrogen at different rates – will require a trial. In addition to field trials, simulation models of many different types are powerful methods to study the effects of climate, intercropping or disease on tree performance, if all relevant input parameters are known. Robinson (2000) is an excellent source when reflecting on whether an experiment is the best approach.

As experiments with trees are often long term investments, it pays to get every aspect of the design, management and assessment of a trial as good as possible before starting. Pay careful attention to these considerations and look at examples of successful experiments. Seek advice from experienced tree researchers and those with specialist knowledge in experimental design, and write it all down for sharing and review before commencing.

A common mistake is to confuse demonstration plots with field trials. Demonstration plots are visible, 'live' examples of trees and planting conditions, with the main purpose of showing how it is done – the possibilities and the techniques. The principles of good experiments are not the same as what is needed for effective demonstrations.

Elements of design

Despite the range of different contexts in which domestication experiments take place, their design depends on only a few principles. These are just the same as for other areas of experimental research and were elaborated as long ago as the 1920's by Fisher (1926), a brilliant statistician and geneticist. Coe (2009) gives a simpler story describing these principles. Here they are outlined briefly.

Objectives

The objectives must be clear and specific. Conclusions from an experiment are reached by comparing different treatments applied to units. It is important to think through exactly what comparisons are required to meet particular objectives, and this will help drive the rest of the design.

Experimental units

These are the plots where the trees are to be planted. Experimental units have to be independent of each other. Independence here means that changing the conditions in one plot will not influence the conditions in any one of the other plots. The units in field trials may be anything from single trees to large blocks of trees.

Treatments

Treatments are the conditions compared in the trial to answer a research objective; for example, different water or fertiliser conditions that influence tree performance, or a range of different species, varieties or provenances to compare for traits of interest. One or more of the treatments may be considered a 'control'. This is not necessarily a 'do nothing' treatment, but is a baseline against which other treatments are compared. The 'controls' needed in any experiment will be determined by the objectives.

Factorial treatment structures

These are defined by the combination of two or more treatment factors, each with two or more levels. For example, Akinnifesi *et al.* (2008) describe an experimental design with the objective to evaluate the effects of inorganic fertiliser, manure and dry-season irrigation on the early growth and survival of three priority miombo fruit trees (*Uapaca kirkiana*, *Sclerocarya birrea* and *Vangueria infausta*) and mango (*Mangifera indica*) in southern Malawi. The treatments consisted of a set of all combinations of inorganic fertiliser (with and without NPK fertiliser), manure (with and without) and dry-season irrigation (with and without), giving 8 treatments in total. (Note that full factorial designs are not always appropriate for testing two or more factors as they can use too many experimental resources; it depends on the objectives of the research.)

Replicates

Replicates are independent experimental units subjected to the same treatment. Replication is used in experiments to help answer the following question: are observed differences due to the treatment or due to inherent differences between the experimental units that would have been observed without applying the treatment? Inherent differences between experimental units depend both on the variability of the experimental site and the variability of the response of the tree under investigation. Thus, the more variable the experimental site or the planting material used in the trial, the higher the number of replicates needs to be. Since increasing the number of replicates multiplies the cost of the trial, but using too few replicates might result in its failure, it is very important to plan properly. This involves collecting as much information as possible about both the site for the trial and the tree species (planting material) under investigation, so that a proper experimental design can be developed. Guidance on the numbers of replicates needed in particular types of experiments is available in more detailed texts.

Site choice, site variability and blocking

Site choice will depend on many factors, such as where there is access to land and the conditions under which research needs to be undertaken. When studying the relationship between environmental conditions and tree growth, a range of different sites with different conditions will be deliberately chosen (see Unit 7). As already noted, fields may not be uniform entities and within individual sites there will often be known (or suspected) patterns of variation determined by water availability, soil fertility and other factors. Variability in soil fertility can arise from differences in underlying geology as well as different farming practices (important if undertaking on-farm research). A simple way to assess variability at a site is to plant a cover crop for one season and observe its performance. In experiments with trees, site variability may, however, only become evident after a considerable period of time, as tree roots go deeper into the soil than those of an annual cover crop. When experimenting in farmers' fields, farmers can be very good sources of information about variability, often providing information better than anything scientists can predict.

Within site variability can lead to large differences in performance at different parts of a site that are independent of any trial treatment. This can lead to erroneous conclusions, unless variability is dealt with properly. The best method to manage site variability is through 'blocking', which involves dividing the site into smaller areas for which each area (block) is as internally uniform as possible. The purpose of blocking is to reduce differences between units that are caused by site and thereby allow greater precision in the estimation of the source of variation under study. For example, if a site is sloped, then blocks should go along the contours, not across them. The principle of blocking is indicated in Figure 1. Blocks may be the same size, containing the same number of plots, or they may not. Again, each treatment of a trial may be applied to a block, or it may not; there are many ways by which blocking and the allocation of treatments can be undertaken.

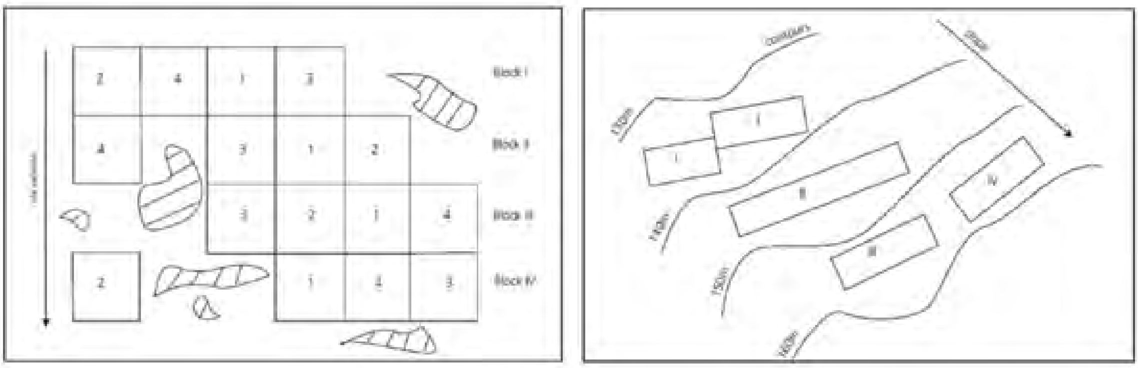

Figure 1 Examples of the distribution of four blocks in a field design. In the case at the left, the site varies along a uniform gradient in the direction shown. Rocky outcrops influence the positions of replicates within blocks. In the case at the right (blocks only shown), how blocks might be distributed along the contours of a slope is demonstrated (along rather than across contours; after Burley and Wood 1976).

Plot layout

The layout of a single plot (its size, shape, position and spacing of trees, etc.) will depend on the objectives of the trial. Plot size is determined by the requirement to provide information at a specified level of precision at minimum cost and subject to practical limitations. The area of available land obviously has an influence on the size of plots, as does the amount of planting material that is available (access to sufficient tree seed, seedlings, etc., for trial establishment, can often be limiting). Large plot sizes minimise the effects of abnormal individual trees on mean plot values and of tree-to-tree 'micro-site' abnormalities. Measurements are usually not taken from trees bordering the plots as substantial edge effects can influence the performance of these individuals. These trees are often referred to as 'guard rows'. Plot size is therefore dependent on the severity of these edge effects; as a rule of thumb, the larger the potential edge effects of plot-to-plot interference (see below), the larger the plot size.

Hierarchy

The layout of the trial describes both the 'objects' of the experiment and the way that treatments are allocated to them. In this description there is a hierarchy. At the top level are the sites where the trial is conducted, of which there may be one or several (e.g., to cover a range of environments). At the bottom level is the plot, the basic experimental unit to which a treatment is applied. If a trial has a number of sites, each treatment may be used at each site, although this is not an absolute requirement. When a farm is a site, the treatments applied may depend on the particular interests of the farmer.

Randomisation

A good experimental design will draw up the arrangement of the plots, after plot sizes, blocking structure and treatments have been decided. The treatments are then assigned to the individual plots at random. For example, to test the effect of different propagation techniques A, B, and C on the survival of tree seedlings, then each plot within each block should have the same chance of receiving either treatment A, B, or C.

The measurements to be taken

These include measurements that relate directly to the objectives of the experiment (e.g., tree growth), and those taken to help understand variation or patterns in other measurements (e.g., rainfall, which will influence tree growth).

Potential pitfalls in field trials

Plot-to-plot interference

As defined above, experimental units (tree plots) have to be independent of each other. Plot-to-plot interference is, however, a common problem in tree experiments. Potential sources of interference include the following:

- **Roots** When arranging plots in a small area it is important to remember that roots do not stop at the plot boundary. In Machakos, Kenya, roots of leucaena (*Leucaena leucocephala*) were found to reduce the yield of maize that was planted 5 m away after only 2 years of growth; in Hyderabad, India, the same tree was found to under-grow root barriers after only one season (Ong 1996). And in central Tanzania, roots of sesbania (*Sesbania sesban*) that had grown laterally to a distance of 9 m in just 3 months were observed.
- **Shade** When comparing trees with different growth rates, faster growing trees can overshadow slower growing trees in neighbouring plots. It is therefore important to consider sun direction, and sun movement throughout the day, when arranging plots.
- **Leaf litter** When soil fertility or soil carbon is the subject of research, it is important to consider potential 'leaf litter' contamination through strong winds.
- **Water** This may run off one plot and onto another.

The root problem is probably the most serious because it is hidden from casual observation. It can produced 'doubly biased' results – trees in the invading plot have access to more resources than they should, and hence grow better, while trees in the invaded plot are deprived of resources, and grow worse.

Pseudo-replication

While most researchers try to replicate their treatment units, even with the best of intentions they often don't. 'Pseudo-replication' occurs when treatments are not replicated but a statistical test is carried out anyway in which replication is incorrectly assumed for subsamples (Hurlbert 1984). A major factor that leads to pseudo-replication is a failure to define the correct experimental unit. Confusing subsamples from the same experimental unit with replicates will result in the use of an incorrect number of error degrees of freedom and the risk of claiming a treatment effect that is not real (a type I error).

A simple example illustrates the dilemma: suppose that one is interested in the effects of different pruning techniques on the performance of safou (*Dacryodes edulis*), the important indigenous fruit tree from Central Africa. The design of the trial is three different pruning techniques applied to three different rows of trees, each planted with 40 individuals. Within each row, trees are pruned exactly the same way; i.e., the pruning technique differs only between rows. Measurements are then taken from each tree.

The key question for the correct analysis of this experiment is: what are the treatment units? According to the definition of treatment units, each must have the same probability of receiving a certain treatment. In this example, however, neighbouring trees in a row were all assigned the same treatment, so they cannot be the treatment units; instead, rows are. Pseudo-replication would be the result if trees were considered to be the treatment units. Measurements from the same row are not independent samples, but subsamples. In order to have true replication, the researcher would have to increase the number of rows, not the number of trees. A quick check of whether one has true replicates or not is to calculate the degrees of freedom; if an experiment appears to have lots of degrees of freedom, it is probably pseudo-replicated.

Being too ambitious

Since field trials with trees are a big commitment, it is natural that researchers try to maximise their returns from each trial through complex nested (or hierarchical) experimental designs, with multiple factors at different levels of the hierarchy. While modern statistical software systems do allow the computational analysis of very complex designs, it is advisable to not over-complicate. It is better to include only the most important factors with respect to the research objective. For example, when studying the effect of various treatments on the performance of various cultivars of several fruit tree species, mixing the cultivars of all species in a single trial may not be advisable, as inter- and intra-species interactions may be difficult to untangle.

Loss of experimental units

Even the most carefully designed field trial can be influenced by events outside of the control of the researcher. Unforeseen extreme weather events such as droughts or floods, or an outbreak of a disease or pest, can result in partial loss of a field trial. If this happens early in the life of a trial, the researcher might replant losses with new seedlings. Environmental factors that interfere with the performance of trees can be included as covariates in the analysis of data, allowing both an estimation of the severity of the effect and a continued investigation of the effects of the original treatments. The most important thing to do is to record such events when they occur: which plots and trees were affected? Which seedlings were replanted?

The loss of a complete plot will result in an uneven numbers of replicates in a trial. Thanks to modern statistical software programs, these 'unbalanced' designs can however be analysed. Having more replicates than statistically required is a good insurance for the partial loss of a trial, although space and budget constraints may not allow this.

On-farm and on-station trials

The underlying principles in the design and analysis of on-farm and on-station field trials are the same. Different objectives, constraints and opportunities however give rise to differing problems in design and analysis. Some of the strengths and weaknesses of on-farm and on-station trials are given in Table 1. Coe *et al.* (2003a) describe three basic types of on-farm trial:

1. **Trials designed and managed by researchers (type 1)** These are essentially on-station trials that have been transferred to farmers' fields. They are good for assessing the 'biophysical' performance of a tree (e.g., fruit yield, growth rate, timber production, soil fertility improvement) under users' 'real' conditions.
2. **Trials designed by researchers but managed by farmers (type 2)** These are good for measuring inputs such as labour requirements and for conducting economic analyses of the profitability of technologies (particular species, management methods, etc.).
3. **Trial designed and managed by farmers (type 3)** These are good for assessing farmers' innovations and the adoption potential of different technologies.

These types essentially represent points on a continuum and often more than one type will be required, depending on the particular objectives of scientists and farmers. Regardless of the approach used for on-farm trials, it is important to share the results of an experiment with all the farmers that have been involved.

Table 1 Some strengths and weaknesses of on-farm and on-station trials

Approach	Possible strengths	Possible weaknesses
On-station	• Trials are managed by researchers in a uniform or controlled environment, reducing heterogeneity and experimental error • Typically better protected from damage (from fire, animal grazing, etc.) than on-farm trials • Typically have sufficient space to establish a complete trial with several replications • Access to trials is straightforward, so it is easier and less expensive to coordinate scheduled maintenance and evaluation	• There are only a limited number of research stations, which may cover only a narrow range of ecological conditions, limiting the scope of conclusions to a narrow environmental window • Results do not reflect the reality of farmers' management practices. Performance figures may well overestimate what can be achieved under farmers' conditions • Researchers miss out on the opportunity of using farmers' criteria in evaluation • It may be expensive to pay labourers to maintain trials that on-farm are maintained by farmers (where this may be done 'for free', as a 'co-investment')
On-farm	• Technologies are evaluated in the locations where they are designed to be adopted, so giving a realistic estimate of performance, profitability, acceptability • Can sample a broad range of ecological conditions by establishing trials on farms selected from different environments • Can take advantage of farmers' knowledge and experiences in identifying sites for establishment and in evaluating trials • Can take advantage of farmers' innovations in trial design and analysis • Direct farmer involvement can convince them of the value of a technology and increase the rate and level of adoption of results	• Highly variable environmental conditions and methods of management mean identification of genuine differences between treatments is harder • Typically farmers do not have enough land to establish a large trial with replications, or sometimes even one complete replication of a trial • More expensive to evaluate than on-station trials, if established on many farms over a large geographic area • Data management and analysis more difficult if have numerous small and perhaps incomplete replications on different farms

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Final considerations

Wherever and whenever a trial is established, it is important to give proper consideration to the below points.

Plan ahead

Start planning for a trial well in advance of the planting date. With adequate lead time, you can:

- Introduce a proposed experiment to your organisation and partners, ask them to review it, and get their approval.
- Choose the best collaborators to work with, seek their input, allow them to prepare for the work, and allocate the necessary resources.
- Investigate and characterise potential field sites

Budget realistically

Make a full and realistic budget that considers the following:

- Rental of land and equipment.
- Inputs (tree seed, fertiliser, etc.), laboratory analyses, office costs.
- Transport costs.
- Labour (professional and casual) costs.
- Awareness raising (signs, posters, local newspaper advertisements and mailings, especially for on-farm trials).
- Inflation, if it is a long-term project.
- Accounts for contingencies (perhaps 10% on top of estimated total cost).

Experience suggests that agroforestry researchers are notoriously bad at properly budgeting for tree seed procurement costs (inadequate funds allocated, see Unit 10)!

When the costs of research are borne by a number of partners, it is important to understand who will do what in advance.

Document properly

In order to understand the results of an experiment it is important to document the process of a trial from beginning to end. This starts with documenting the objectives of the trial, the treatments to be applied, the layout of the experiment and the measurements to be taken (see above). It is also essential to label experiments properly in the field: there are cases where field trial results have been rendered worthless because researchers failed to maintain the identities of the materials tested and treatments applied.

Field scientists should keep a notebook describing the progress of a trial, which should contain information on the following: the origins of inputs (e.g., for seed, the provenance or provenances and the suppliers' references), planting dates (including of any replacements for dead trees), pest and disease incidence, any interference outside of the experimental protocol (e.g., fire, wild animal grazing); and any new observations on site heterogeneity.

The measurements taken from the trial also need to be properly recorded in the field and kept as hard (paper) and electronic copy (once tabulated and checked for correct entry) in the office. Electronic spreadsheets should have been designed in advance to capture all relevant information from the trial and to identify obvious errors in input. The worksheets used to collect data in the field should correspond with electronic spreadsheets for row and column labels and layout. The use of Microsoft Excel is generally ideal for electronic data entry because it links seamlessly with analysis packages. The proper archiving of experiments, including printing paper copies of design, data and analysis, allows information to be revisited in the future when new interpretations may be possible.

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Unit 7 – Provenance and progeny trial approaches

John C Weber and Carmen Sotelo Montes

Unit objectives

After studying this unit, readers will be able to:

- Describe the difference between provenance and progeny trials and their value in the context of agroforestry tree domestication.
- Explain the relationship between phenotype, genotype and environment in selecting agroforestry trees for domestication.
- Relate examples of provenance and progeny trials that illustrate these concepts.

Summary

Many tree species can be found growing naturally in a wide range of environmental conditions. It is important to establish whether 'between-tree' differences in particular traits, both between and within stands, are due to the environment, to genetic differences or a combination of both. Provenance and progeny trials are field experiments that allow for an assessment of genetic variation and the selection of provenances, progenies and/or individuals with particular traits that are considered superior.

A provenance trial is used to compare the performance of germplasm from different geographical locations, while progeny trials are used to compare the performance of specific mother trees or families within a provenance. Sometimes the two are put together (a number of families from a number of provenances are tested in a single trial). This unit illustrates these trials with reference to two local species important for timber production in Peru. Such trials are costly and can require significant time to yield useful results; proper planning of their design (see Unit 6) is therefore essential.

Key resources

- Burley J, Wood PJ (1976) A manual on species and provenance research with particular reference to the tropics. Tropical Forestry Papers. No. 10. Oxford Forestry Institute, Oxford, UK.
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Provenance and progeny trials and tree domestication

In Unit 6, the general principles of field experiment design were discussed. In the current unit, field trials designed to study genetic variation, at provenance[1] and within-provenance levels, are considered. These trials are important for selecting superior provenances and/or individual trees with particular traits considered superior for domestication. They are also important for understanding the relationship between tree performance (productivity and quality) and environmental conditions. Such knowledge allows recommendations to be made on 'zoning' – that is, on which material should be planted in what environmental conditions to bring the greatest benefits to farmers.

Conducting provenance and progeny trials is costly. Testing a large number of trees means that a significant land area is required for experiments, with the associated costs of maintenance. In addition, several years may be required to properly evaluate trials; for example, fruit trees may not yield until a decade or more after planting, meaning these trees must be grown for at least this time before the level of production and quality of fruit can be evaluated. Similarly, the growth and stem form of a timber tree, which determine the quality and quantity of the timber that can be harvested from it, may not be evident for several years. Again, medicinal trees may not be ready for harvesting until 10 or 20 years after planting, and trials may need to be grown for this long to test for the level and composition of active chemical components. The expense and time involved mean that proper thought to the objectives, treatments, layout and measurement of field experiments, as outlined in Unit 6, is very important for provenance and progeny trials.

Provenance and (especially) progeny trials are often converted into seed production stands after research has ended (or, sometimes, this happens as part of the research process), perhaps through selective thinning of the trial (see more on seed production in Unit 11). Such planned transformations in function also have to be taken into account in the initial design of a trial.

The relationship between phenotype, genotype and environment

Many tree species can be found growing naturally in a wide range of environmental conditions. In the Peruvian Amazon Basin, for example, the important timber species capirona (*Calycophyllum spruceanum*) can be found in wild stands near the equator, where annual rainfall exceeds 3,000 mm, and much further south where the annual rainfall is only 1,400 mm. In the south, trees are notably shorter. The question arises as to whether the differences in tree growth observed between natural stands of capirona are due to environmental differences between sites, genetic differences between populations, or a combination of both? And, if the last, which is the greater effect?

[1] The term 'provenance' usually refers to a geographic location within the natural range of a tree species, from which seed or other germplasm is sourced. Because of genetic adaptation to distinctly different natural sites, seed of different provenances of a species can differ greatly in the way they grow when planted out at a common site. If a species has a continuous distribution across a wide natural range, we could denote many local provenances and the demarcation between different provenances is not self-evident. By collecting germplasm from different provenances from across a species' range, its intra-specific variation is captured for testing (see more in Unit 9 on collection issues). The term 'provenance' is often used interchangeably with the term 'population', and this is the case in the current publication, although strictly speaking the terms are not directly equivalent. From a reproductive biology perspective, 'population' refers to a group of individuals that can randomly interbreed with each other. In addition, various 'populations' of a tree species found as an exotic under cultivation across the world may come from the same original source – that is, they may be of the same 'provenance' – even though they are now considered as different populations based on their different 'secondary' locations.

To determine the extent of genetic differences within a species, trees originating from different locations need to be evaluated by growing them under common environmental conditions. This allows the total observed phenotypic variation (P, the way a tree looks) to be resolved into different components: the variation caused by genetic differences among the trees being tested (G, or genotype), the variation dependent on the environment (E), and the variation caused by the interaction of genotypes with different environments (GxE, genotype-by-environment interaction, which can only be determined when trials are planted across two or more contrasting environments). The relationships among these components are represented as P = G + E + GxE.

Tree domestication researchers are generally interested in variances, in particular the proportion of the total phenotypic variance (σ^2_P) that is due to the genetic variance (σ^2_G), the environmental variance (σ^2_E) and the genotype-by-environment interaction variance (σ_{GxE}). If genetic variance in a trait is high and environmental variance is low, then there are good opportunities to select genetically superior types. On the other hand, if environmental variance is high and genetic variance is low, then it will be difficult to improve the trait genetically. In this second case, rather than focusing on genetic selection, it may be better to focus on agronomic and silvicultural methods to improve the production of a species (see Unit 6).

In field-based tree genetic studies, typically objectives are to: (1) determine if there is statistically significant genetic variation in adaptive and commercially important traits, (2) estimate certain genetic parameters, such as the heritability of individual traits and the genetic correlations between traits that are useful for predicting genetic gain from selection and designing genetic improvement programs; and (3) identify the best performing germplasm for specific environments, such as areas with higher or lower rainfall. These and other aspects are discussed in the following sections.

Provenance trials

A provenance trial is used to compare the performance of germplasm from different provenances (geographical locations, see earlier Footnote). It may be used to select particular provenances that perform well at the trial site and in similar environments. An example based on bolaina blanca (*Guazuma crinita*), a timber tree identified by farmers as a priority for domestication in the Peruvian Amazon, is given in Box 1. This trial showed genetic differences between provenances. It also indicated that locally sourced seed from the watershed where the experiment was conducted generally grew better there when compared to seed sourced from outside the watershed, suggesting a local germplasm sourcing policy may be the best option in this case.

In the same trial, researchers took the opportunity to investigate phenotypic correlations between tree traits, which are a function of genetic and environmental correlations. In the first instance, two measurements are correlated because the same genes influence both traits, while in the second instance two measurements are correlated because shared growing conditions influence both in a similar manner. An understanding of correlations is important because they show whether an easy-to-measure trait can be used as a proxy for another important, but more difficult to measure, trait, making selection easier in a genetic improvement programme. In addition, possible conflicts that may arise in the selection of multiple traits may become evident; for example, are growth rate and wood density, both desirable characteristics for timber trees, negatively or positively correlated? Age-age correlations are also very important as they indicate the reliability of genetic selections made at an early age, and the optimum age for selection, an important consideration in domestication programs.

In the case of bolaina blanca, the data gathered from the provenance trial suggested a negative correlation between growth rate and wood density. In this instance, then, a decision may need to be made on whether to select for fast growing trees or for high wood density trees, as improvements in both traits may not be possible in a single selection. The choice of which trait to focus on will depend on the planned end use of the timber. In practice, breeders will often develop a multi-trait selection index based on end use, rather than exclusively focus on improving only one trait or another.

Box 1

A provenance trial of bolaina blanca in the Peruvian Amazon

Researchers wanted to know if there were genetic differences in performance among provenances of the timber tree bolaina blanca (*Guazuma crinita*) in the Peruvian Amazon, and to identify the best provenance or provenances for planting. In addition, they wanted to test the hypothesis that locally sourced provenances will grow better than 'foreign' provenances (from outside the area) in any particular watershed.

Researchers selected a large representative watershed (Aguaytía) as the location for the test and established a provenance trial composed of the local provenance ('Von Humboldt') along with 10 'foreign' provenances from other watersheds in the Peruvian Amazon. Each provenance represented in the trial was composed of seedlings grown from seed of 35 randomly selected trees from the provenance. The trial used a randomised complete block design and was established in three different parts (= zones) of the Aguaytía watershed: (1) a lower altitude zone with relatively low rainfall and very infertile soils, (2) a middle altitude zone with intermediate rainfall and soil fertility; and (3) an upper altitude zone with relatively high rainfall and fertile soils.

The trial had a total of 20 replicates (6 to 8 replicates per zone), each one placed on a different farm. Each replicate included 11 square plots (one for each provenance) that contained 36 seedlings. Tree growth, stem form and wood density were measured by researchers for the 16 trees in the interior of the plot (the other 20 trees formed guard rows to minimise interference in measurements from adjacent plots, see more in Unit 6).

Analysis of variance 30 months after planting showed statistically significant differences in tree growth and wood density due to provenance, indicating genetic differences among provenances. The level of the difference observed depended on the trial site where material was evaluated – it was greater in the lower zone for stem diameter but greater in the upper zone for wood density. A significant GxE (provenance x zone) interaction was also observed, with the performance ranking of different provenances varying across the three zones. The local Von Humboldt provenance did however generally perform well, so the researchers recommended it for small-scale plantations across the Aguaytía watershed.

Researchers also analysed phenotypic correlations between tree growth and wood density 30 months after planting. Comparisons were made for the lower and upper stems of trees, and for trees grown in the lower and upper altitude zones of the watershed. Analysis showed that the level of correlation depended on the stem position, the zone of testing and the provenance. Overall, however, data suggested a negative correlation between tree growth and wood density.

Based on Weber and Sotelo Montes (2008).

Box 2

A progeny trial of capirona in the Peruvian Amazon

Researchers wanted to know how genetic variation partitioned within and among capirona (*Calycophyllum spruceanum*) provenances, the heritability of important traits, and any correlations between different characteristics, in order to develop a domestication strategy for the species. Research was conducted in the Aguaytía watershed already mentioned (Box 1), and involved the same three zones for establishing trials: (1) a lower altitude zone with relatively low rainfall and very infertile soils, (2) a middle altitude zone with intermediate rainfall and soil fertility; and (3) an upper altitude zone with relatively high rainfall and fertile soils.

Progeny from 200 mother trees were collected from seven extensive natural populations (equivalent to local provenances) of capirona in the Aguaytía watershed. Seedlings raised in nurseries from the 200 trees were planted in a randomised complete block design with five replicates, each replicate on a different farm, in each of the lower, middle and upper zones of the watershed. In each replicate, the 200 families were randomly assigned to 200 experimental plots. Experimental plots consisted of two trees of the same family. This design was not the most efficient one to undertake genetic tests, but each farmer wanted each of the 200 families to be represented on their land.

Analysis of variation in stem diameter and wood density across the three zones at 39 months after planting indicated significant genetic variation between provenances, and between families within provenances, with a greater proportion of the genetic variance found between families within provenances, rather than between provenances. Provenances did not rank consistently across zones for stem diameter, but did so across replicates within zones. For wood density, ranking was consistent both across zones and across replicates within zones. Based on these data, researchers recommended a focus on selecting the best trees within provenances that showed consistent performance for diameter/density across the three zones. Furthermore, since analysis of the three zones indicated that the variation detected among families within provenances was found to be greater in the upper zone, this zone may be the best area in which to conduct trials to assess family differences.

Researchers also analysed individual tree heritability in the trial, based on the assumption that there was some degree of inbreeding within the open-pollinated families. Wood density at 39 months after planting had a higher heritability than tree growth variables. Heritability was identified to be higher in the upper zone of the watershed than elsewhere, corresponding with observations on variation among families within provenances. Researchers also assessed correlations between tree height, stem diameter and wood density 39 months after planting. Phenotypic and genetic correlations had the same sign in the trial, but differed in magnitude among the zones (i.e., due to the environment). There was a positive correlation between wood density and tree growth, suggesting measurement of either could be used to select superior material for both traits.

Based on Sotelo Montes *et al.* (2006).

Progeny trials

Progeny trials are experiments where the identity of the maternal parent of seed is maintained during testing; that is, during seed collection and the establishment of the experiment, materials from different mother trees are not bulked to form a 'provenance bulk seedlot', but are maintained as independent 'families'. The breeding system of the species and the pollination biology will affect the make-up of families. An open-pollinated family from a natural provenance may comprise a mix of offspring resulting from crosses with a few or many unrelated trees, offspring from crosses with closely related neighbours, and self-fertilised offspring, depending on the species' breeding system and the characteristics of the stand the family comes from. In advanced breeding programs, 'full sib' families may be produced for progeny trials by breeders who carry out controlled pollination between selected superior trees.

Progeny trials may involve families from a number of provenances, or they may be based on a single provenance only. They can provide more information about important genetic parameters than can provenance trials, for example in relation to the following questions:

- Does genetic variation occur primarily among geographical locations (provenances) or primarily among trees (among and within families) within individual locations? If the former, genetic improvement work may best focus on selecting the best provenances, based on a 'range-wide' sampling approach (see Unit 9 on collection). If the latter, it may be better to focus on selecting the best trees within a number of provenances. This is a crucial question for a domestication strategy; for example, see Unit 15 on the participatory domestication approach, which assumes local, within-population, selection is a viable option. (In practice, how variation is distributed among and within provenances will also depend on the traits that are under evaluation.)
- What is the heritability of a trait? Heritability is the proportion of the total variance of a trait that may be accounted for by genetic factors. If heritability is zero, then the phenotypic variance observed for a trait is entirely due to the environment and there is no opportunity to improve the trait by selecting superior trees. On the other hand, if a trait is under strong genetic control (high heritability), then there are good opportunities for genetic improvement. This is explained further by Falconer and Mackay (1996). The coefficient of additive genetic variation[2] is also needed when calculating the potential for gain from selection and breeding: if the coefficient of additive genetic variation is low, then the potential for gain is low, even if heritability is high.
- Are traits genetically correlated and, if so, what is the sign and the magnitude of the correlation? Correlations are discussed above in the context of provenance trials, but progeny trials provide more information.

In Box 2, an example of a progeny trial based on capirona, a timber species already mentioned, is presented. In this case, the trial showed greater variation between families within provenances than between provenances. This suggested a viable strategy for genetic improvement that focused on selecting the best trees within stands. A positive correlation between wood density and tree growth was observed, suggesting that improvement in both traits is possible by selecting for either (in contrast to the example of bolaina blanca given in Box 1).

Additional references

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[2] The coefficient of additive genetic variation is the square root of the additive genetic variance of the population under trial expressed as a percentage of the trait mean.

Unit 8 – Molecular marker characterisation

Ian Dawson, Alice Muchugi, Ramni Jamnadass and Joanne Russell

Unit objectives

After studying this unit, readers will be able to:

- Explain the importance of molecular marker characterisation in the context of agroforestry tree domestication.
- Describe the advantages and disadvantages of three different DNA-based molecular marker techniques for the characterisation of genetic diversity.
- Identify sources of information on laboratory protocols for molecular markers and approaches for data analysis.

Summary

In the last 20 years, there has been a significant increase in the use of molecular markers to characterise genetic variation in tropical trees. These methods can provide significant insights into the biology of species, information that can be used to define more appropriate strategies for tree management.

A range of different molecular markers are available for analysis; individual methods vary in the type of information they reveal and their cost. Whether a particular method is appropriate for a particular research project in a given setting requires careful consideration. Molecular markers may be relatively expensive to develop and use, and this cost must be weighed against the value of the results obtained and alternative research approaches such as greater investment in field trials to characterise the material.

This unit discusses the merits and limits of molecular marker approaches for characterisation, and the features of particular methods. A number of examples are given on how some common molecular marker techniques have been used to assess genetic variation in trees. The unit also outlines approaches for sampling material for laboratory research and techniques for analysing data. It also discusses why field-level application of results from molecular studies has been limited to date, and suggests ways to improve this situation.

Key resources

- Kindt R, Muchugi A, Hansen OK, Kipruto H, Poole J, Dawson I, Jamnadass R (eds. Dawson I, Hansen OK) (2009) Molecular markers for tropical trees, statistical analysis of dominant data. ICRAF Technical Manual No. 13. The World Agroforestry Centre, Nairobi, Kenya.
- Muchugi A, Kadu C, Kindt R, Kipruto H, Lemurt S, Olale K, Nyadoi P, Dawson I, Jamnadass R (eds. Dawson I, Jamnadass R) (2008) Molecular markers for tropical trees, a practical guide to principles and procedures. ICRAF Technical Manual No. 9. The World Agroforestry Centre, Nairobi, Kenya.

The potential and limitations of molecular marker methods for measuring genetic variation

Genetic variation can be estimated in tree species using phenotypic measurements made in natural stands and field trials (see Units 7 and 9), or by asking the people that use trees about the characteristics they observe and value (e.g., Unit 3). Such observations, however, only describe a portion of the genetic variation present in a species, and in any case many trees have not been properly evaluated in this way. Molecular markers provide a complementary method to evaluate genetic diversity. The results obtained are of particular value because they are more readily understandable in the context of the biological processes involved in shaping genetic structure than other measurements are (i.e., they shed light on population genetic issues, see Box 1).

At the simplest level, by using molecular markers to assess how genetic variation is geographically structured among tree stands, it should be possible to devise better strategies for sampling populations, so that collections are representative of the available diversity in a species. A simple application is also to work out the breeding system of a species under study by testing of parents and progeny arrays. In addition, since most tree species are preferentially out-crossing and can suffer from inbreeding depression (the loss of heterozygote superiority and the exposure of recessive deleterious mutations) if genetic variation is low, molecular markers can be used to identify highly diverse natural populations that are suitable for cultivation, because they are likely to avoid inbreeding in subsequent generations. (Note that high levels of genetic variation in populations may also be an important feature for providing an adaptive capacity to changes in pest and disease prevalence, the varying requirements of users, and an altering global climate.)

More subtly, studies on reproductive biology using molecular markers can result in a better accounting for the behaviours of pollinators and seed dispersers in devising farmland tree management strategies. For example, through a combination of field and laboratory work, it should be possible to determine appropriate densities and configurations for tree planting, find ways to manage pollinators that maximise productivity (e.g., to maximise fruit yields), and design suitable corridors for linking forest fragments in conservation initiatives. Molecular markers can also be used to compare natural, managed and cultivated tree stands to determine the impacts of logging, deforestation and past domestication.

Although they provide good opportunities for characterisation, molecular marker methods also have their limitations. Most importantly, molecular markers are not generally directly linked to the adaptive capacity or productivity of individual trees. This 'neutrality' is an important advantage in many population genetic applications, as it allows for the 'unbiased' estimation of population genetic parameters. The downside, however, is that field managers are ultimately interested in understanding differences in the physical performance of trees, not their molecular marker make-up. Molecular markers are thus no substitute for field evaluation, but provide data that can support the development and interpretation of field trials.

The features of different molecular markers methods

Most modern molecular marker methods are dependent on the polymerase chain reaction (PCR) for amplifying DNA and making genetic differences visible. There are many different PCR-based techniques, each of which varies in the properties of the markers that are revealed. Some of these techniques reveal incomplete genotypic information (dominant markers), while others provide complete data at a locus (codominant markers). In the first case, only one allele at a locus is visible, while in the second case, both are (in a heterozygous diploid).

Techniques also vary in the number of loci they can reveal at any one time, with some methods revealing many loci simultaneously, others only one locus at once. The cost of different molecular marker methods also varies widely, depending on the level of equipment and technical expertise needed. The reproducibility, labour intensity and development costs of different approaches are also different. In practice, this means there is no perfect 'one-size-fits-all' marker system as described in Box 2.

Box 1

Understanding population genetics

The discipline of population genetics is about assessing genetic variation and the way it is structured in an organism, and then using this information to help explain aspects of the biology of a species and thereby help determine appropriate management options. To design a molecular marker study properly, a basic understanding of the forces involved in structuring genetic diversity within and among populations is required. These forces are explained below.

A **mutation** is a permanent structural alteration in DNA and the ultimate source of genetic variation, which results in the development of new alleles (the variant forms of a gene at a particular locus). Mutations are generally rare, although they can occur more frequently in certain parts of the genome, such as at short simple sequence repeats (SSRs), a fact that is exploited in molecular marker analysis (see below). Mutations may have no effect on function, they may be deleterious, or they can occasionally be favourable and improve an organism's chances of survival.

Migration is the movement of any form of genetic material from one population to another. It can occur through the natural dispersal of seed and pollen, or it may be facilitated by humans (e.g., farmer dispersal of seed). Through the influx of new alleles, migration can improve the adaptability of tree stands; on the other hand, it may allow cultivated and natural stands to 'pollute' each other by causing the loss of co-adapted gene complexes in each, resulting in lower viability and impaired performance.

Recombination is the process of generating new mixtures of genetic diversity by exchanging parts of the chromosomes that make up the genome of an organism. It does not in itself create new variation, but shuffles chromosome sections into novel combinations that can affect fitness. Recombination occurs within as well as between genes, and is an important part of the process of the sexual reproduction of organisms, when chromosomes from maternal and paternal parents meet and pair.

Selection is a natural and human-induced process that occurs when the genetic variation in an organism influences its fitness (ability to survive and reproduce in a particular environment). Tree domestication involves processes of conscious human selection for particular features such as yield and quality. Unconscious human selection also occurs, through logging, forest fragmentation, and other human influences on the growing environment of trees. Human selection may decrease the genetic diversity found in cultivated tree populations, and this may lead to inbreeding depression and negative consequences for long-term performance.

Drift occurs when changes in allele frequencies are as a result of random or 'stochastic' sampling processes during regeneration. When populations are small, genetic drift can result in large losses in diversity and the loss of low frequency alleles, leaving loci in fixed (homozygous, one allele condition at a locus only) states. Drift is likely in tree planting programmes when seed is collected from only a small number of mother trees. Its extent depends not only on the census size of a population, but on factors such as the amount of gene flow in the landscape. Understanding the level of gene flow in agroforestry systems is crucial for understanding the sustainability of tree planting activities (e.g., for the prevention of inbreeding depression).

Taken from Muchugi *et al.* (2008).

Differences between techniques mean that information must be analysed and interpreted in different ways, and the molecular method used needs to be matched with the question at hand. The first consideration in planning a piece of research is what molecular approach is appropriate for collecting the type of data that is required, and then whether the technology is available to scientists within given constraints of time and budget.

AFLP, SSR, CAPS and other methods

The features of three PCR-based approaches – amplified fragment length polymorphism (AFLP), simple sequence repeat (SSR) (also known as microsatellite) and cleaved amplified polymorphic sequence (CAPS) (also known as restriction fragment length polymorphism-PCR) analyses – are shown in Table 1. Defining features as in Table 1 helps to make choices on the appropriateness of each method for addressing a particular research question. Descriptions of these methods and laboratory protocols for each are given in detail by Muchugi *et al.* (2008). Case studies where each of these approaches has been applied to tropical trees are given in Boxes 3 to 5.

Other more advanced methods now being used on a small number of (mostly temperate) trees, such as single nucleotide polymorphism (SNP) analysis and DNA chip technology (Gailing *et al.* 2009), will have application for a wider range of tropical trees in the future, though the equipment required can be expensive. The best way ahead for scientists in low-income nations is likely to be an 'outsourcing' approach, in which scientists collect material for testing and send it away to a commercial company for genotyping. This approach is already widely used by researchers in high-income nations, even though more resources are available for undertaking research in such countries, as it frees up scientists to focus on more interesting work, such as designing experiments properly and spending time interpreting the results.

Box 2

The characteristics of an ideal molecular marker system

An ideal marker system would have the following features:

- Be able to use DNA of all qualities, including very degraded and old samples, perhaps collected from small pieces of herbarium specimens as well as new collections.
- Reveal markers that distinguish between homozygote and heterozygote states (i.e., be codominant).
- Reveal many distinct loci at the same time, thereby reducing the costs involved in conducting multiple rounds of detection.
- Reveal markers that are evenly distributed throughout the genome, thereby providing a 'representative' indication of overall genetic diversity.
- Be cheap and technically simple, thereby not restricting use to only well-resourced laboratories.
- Reveal markers that are highly reproducible. That is, repeated use of the method at different times and in different laboratories produces the same results.
- Reveal markers that are easy to score. The different allelic states at a locus, and which alleles belong to which locus, should be clear.
- Reveal the right level of variation to address the question at hand. The variation revealed should be neither too low (impossible to identify differences) nor too high (no point of reference for comparison).
- Not be restricted in application by commercial or intellectual property considerations.

In reality, no single marker system is available that reaches our concept of the ideal and compromises are required. The choice of marker method will depend on the requirements of a particular study (see Table 1).

Taken from Muchugi *et al.* (2008).

Table 1 Properties and potential applications of three common molecular marker techniques

Technique	AFLPs	SSRs	CAPS
Description	DNA digested with two restriction enzymes, DNA adaptors fitted and products amplified using 'semi-specific' primers	Specific nuclear or organellar loci amplified by primers that surround previously characterised hypervariable repeats	Specific nuclear or organellar loci amplified. PCR products digested with restriction enzymes
Advantages	Very many loci can be revealed in single reactions. Can be applied to taxa for which specific sequence information is unavailable. Reasonably reproducible	Very high variation at individual loci. Nuclear SSRs are codominant. Possible to use lower quality DNA than for AFLPs	Many universal primers to organellar sequences are available. Nuclear CAPS are robust codominant markers. Possible to use lower quality DNA than for AFLPs
Dis-advantages	More technically complex than some other methods. Loci are generally scored as product presence or absence only (dominant markers). Quality of initial DNA needs to be reasonably high	Primer development for nuclear SSRs has traditionally been relatively expensive, though is now cheaper and easier. Interpretation of profiles can be difficult because of stutter and null alleles can be relatively common. Individual SSR loci can show too much allelic diversity for some applications. Normally, study of each locus requires a separate PCR	Primer development for nuclear CAPS has been relatively expensive, though is now cheaper and easier. Conserved primers to organellar regions show little variation. The technique is time-consuming. Normally, study of each locus requires a separate PCR
Normal applications	'Fast and dirty' species delimitations and population genetic analyses, excellent for 'fingerprinting' of specific types	The clear method of choice for detailed studies on gene flow, paternity and bottlenecks. Frequently misused in more general population studies where the approach generates too much variation for some applications	Phylogenetic studies, detailed population studies. Generally, however, direct sequencing now preferred for phylogenetic studies and SSRs for population studies

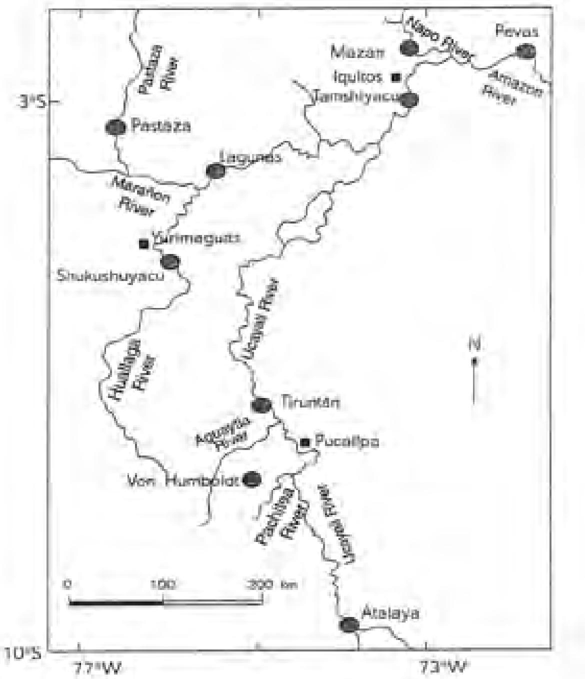
Box 3

AFLPs for assessing genetic variation in capirona in Peru

Laboratory researchers used AFLPs to assess genetic variation within and among nine natural populations of the timber tree capirona (*Calycophyllum spruceanum*), sampled along river tributaries of the Peruvian Amazon Basin (see figure below). According to an analysis of molecular variance (AMOVA), most variation occurred among individuals within populations (although variation between stands was highly significant). Similarity among stands depended partly, although not entirely, on their geographic proximity to each other.

Despite hypotheses suggesting it may be important, no firm evidence was obtained for unidirectional water-mediated seed flow (hydrochory) being a factor in determining genetic structure, as genetic diversity levels in populations downstream of river confluences were not significantly higher than in stands upstream, as might have been expected (Pevas downstream of Mazan and Tamshiyacu, Lagunas downstream of Pastaza and Shukushuyacu). Thus, researchers determined that there was no particular advantage in sampling seed from or below where rivers meet in order to capture diversity for improvement and *ex situ* conservation.

Distribution map of nine populations of capirona sampled from the Peruvian Amazon Basin along parts of the Amazon river system The major human settlements of Iquitos, Yurimaguas and Pucallpa are shown. Water flows from the Yurimaguas and Pucallpa regions toward Iquitos. Stands lower down the river system were not statistically more diverse than higher populations, as might have been expected if water was an important mechanism for gene flow.



Taken from Russell *et al.* (1999).

Box 4

SSRs for assessing genetic variation in inga in Peru

Researchers used SSRs to assess genetic variation in geographically matched planted and wild stands of the important cultivated fruit tree inga (*Inga edulis*) at five sites in the Peruvian Amazon Basin. The number of alleles present in planted stands was lower than in wild populations (see table below), supporting the notion that human intervention in the Amazonian rain forest is causing changes in the levels of population genetic diversity found in tree species. Allelic variation in planted stands was however still on average 80% of that found in natural stands. This indicated that planted populations should still be good targets for conserving genetic variation in the species, if they can be managed properly.

Data at five SSR loci for inga stands sampled from five sites in the Peruvian Amazon At each site, both natural and planted individuals were tested. Planted stands had lower allelic diversity than their neighbouring wild populations, though overall levels of diversity in cultivated material remained high.

Site	Number of individuals tested	Allelic richness (corrected to account for varying sample sizes)
Atalaya		
Wild	15	36.0
Planted	18	27.7
Genaro Herrera		
Wild	17	41.1
Planted	22	29.2
Pucallpa		
Wild	24	39.6
Planted	21	30.8
Ullpayacu		
Wild	16	41.1
Planted	22	34.4
Yurimaguas		
Wild	16	38.5
Planted	18	34.4
Across sites		
Wild	88	39.3 (mean)
Planted	101	31.3 (mean)

Taken from Hollingsworth *et al*. (2005).

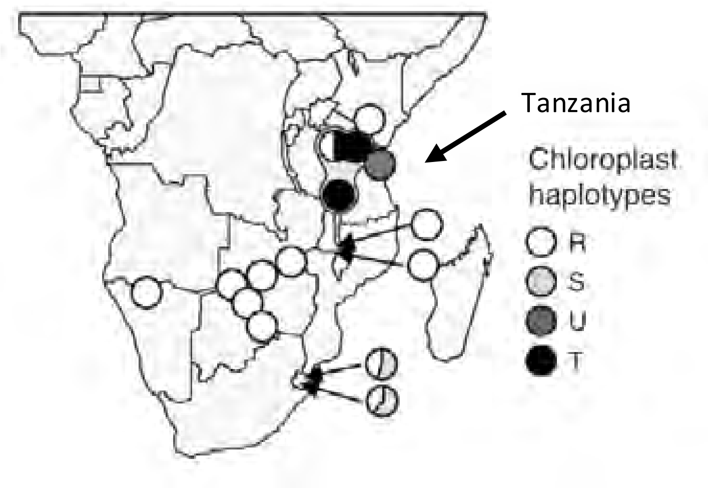
Box 5

CAPS for assessing genetic variation in marula in southern Africa

Researchers used CAPS revealed in chloroplast DNA (maternally inherited through seed) in combination with RAPDs (random amplified polymorphic DNAs, a type of nuclear marker) to assess genetic variation within and among populations of marula (*Sclerocarya birrea*), an important fruit tree that is currently under domestication in southern Africa. Consistent with other organellar-nuclear comparisons for trees, a much greater proportion of CAPS variation partitioned among stands than for RAPDs, suggesting a rather limited role for seed compared to pollen in mediating gene flow.

AMOVA of chloroplast CAPS revealed significant genetic variation among stands in Tanzania in particular. Tanzanian stands appear to contain a large fraction of the overall variation present within the species in the entire southern Africa region, suggesting this country should be a focus for domestication and conservation activities (see figure below).

Distribution map of four chloroplast CAPS haplotypes found in 15 populations of marula in southern Africa Of the four haplotypes identified across the region, three occurred in Tanzania, suggesting this country to be a centre of diversity for the species.



Taken from Kadu *et al.* (2006).

Field sampling for molecular studies

A meaningful molecular marker study requires that material be properly sampled in the field prior to analysis. Otherwise, the results of laboratory research will be inconclusive or, worse, misleading. (The same, of course, applies to other studies to evaluate genetic variation, such as the provenance and progeny trials described in Unit 7.) For molecular studies, designing a proper sampling approach depends on the species in question, the laboratory technique that will be applied later for analysis and the specific hypotheses that are being tested.

Ideally, an iterative approach to field collection should be followed, in which initial sampling at low intensity is followed by laboratory tests and then further, more detailed collection is based on initial results. With limited resources, however, it is often the case that only one round of field collection is possible. We must also recognise that field sampling for molecular studies may be an 'add on' to another activity, such as an ethnobotanical study (Unit 3) or a seed collection (Unit 9). In these circumstances, sampling for molecular studies must use a 'best bet' strategy based on the limited knowledge that is available on how variation is likely to be structured within and among populations. Practical protocols for collecting samples for molecular studies are given by Muchugi *et al.* (2008).

Taking the next step: analysing data

Once laboratory analysis has been undertaken, the data from it need to be compiled in an electronic spreadsheet. This spreadsheet should have been set up in advance to contain all the relevant column and row labels that describe data points. Labels should give information on the location that an individual comes from and provide a unique identifier for each tested individual. Data spreadsheets are the basic building blocks for all subsequent analyses of results and are essential for 'archiving' information. For this last purpose, as well as being backed up electronically, spreadsheets should be printed out and stored in a safe place.

Obviously, unless molecular data are analysed properly, there is no point in undertaking laboratory studies. The analysis of molecular data involves describing the variation revealed at various levels of collection hierarchy (e.g., individual and population) and based on whatever taxonomic, geographic or ecological structures have been sampled. It involves calculating the relationships between different levels of structure and expressing these clearly, both numerically and visually. In recent years, new geo-spatial methods of analysis have been devised, and these should be actively explored (Scheldeman and van Zonneveld 2010).

The type of measure that can be applied during data analysis depends on whether dealing with dominant or codominant markers, as some measures are more appropriate or only relevant for one or the other. As described by Kindt *et al.* (2009), there are a multitude of free software packages available for analysis; information on how to install and use a wide range of packages is given in this reference. Whatever the software used, there is no substitute for understanding the basic procedures involved. Rather than the complexity of the analysis, it is the interpretation of results in the context of the biological processes shaping variation that is fundamental in determining the relevance of molecular marker studies.

Seeking improvements in current limited practical application

Clearly, when undertaking laboratory research, it is essential to think beforehand how a study relates to the actual challenges faced by farmers. Is it likely that anything useful for farmers will come from a study? Despite the potential application of molecular markers for the better management of tropical trees in farmland and forest settings, the current literature reveals very few cases where potential has actually been realised in the form of practical management interventions. Reasons suggested for this 'disconnect' include a lack of knowledge on which molecular technique is really appropriate for addressing a particular question, and inadequate information on how to analyse molecular data once it has been obtained. The ICRAF manuals of

Muchugi et al. (2008) and Kindt et al. (2009) were published to help address these gaps.

Another reason given for practical application being limited is that laboratory workers are not integrated with other scientists who work on promoting the use of a species. This stems in part from the centralised nature of much laboratory work, which has led to research becoming disconnected from the actual practical needs of the people that use and manage trees. The same applies for other biotechnology methods that might be useful for promoting tree species. These issues are discussed by Dawson *et al.* (2009), who review the potential and challenges of biotechnology use for promoting currently underutilised plant species.

Establishing proper partnerships with the various people involved in promoting farmers' use of a tree will ensure the better integration of molecular marker studies with other research. Improved liaison is needed with forest ecologists, agronomists, social scientists, local and national policy makers, and those actually responsible for implementing activities at a field level. One effective method for promoting the better application of laboratory studies is to place emphasis on rewarding scientists for the publication of 'laboratory to field' management plans, as well as academic journal articles (the former backed up by the latter). Some institutions have already adopted this approach during staff performance evaluation.

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Module 4

Obtaining quality germplasm

Unit 9 – Field collection strategies

Ian Dawson, Joanne Russell and John C Weber

Unit objectives

After studying this unit, readers will be able to:

- List and describe key issues that need to be considered before, during and after a germplasm collection exercise.
- Explain the differences between a random systematic and a targeted collection approach, comparing advantages and disadvantages.
- Explain the advantages and disadvantages of collecting vegetative propagules compared to seed.
- Explain the value of 'range-wide' germplasm collection and describe its challenges.

Summary

The genetic quality of tree germplasm – seed, seedlings and clones – is a key input in determining the productivity of agroforestry ecosystems, but suboptimal material is often planted. The reasons for this include the inability of existing seed and seedling delivery systems to reach farmers with high quality planting material (as discussed in Unit 14), and a lack of attention to how germplasm is collected in the first place, before it is evaluated and/or distributed. This last topic is addressed here.

A number of common points should be considered in any collection exercise. Before commencing, a proper strategy for sampling (why, when, how, with whom, legal requirements?) should be devised. During collection, documentation is required for future reference, as sampled material may still be in use centuries from now. After collection, germplasm must be processed and stored properly.

Random systematic collection best represents a sampled stand genetically, allowing a full evaluation of its potential, while targeted sampling may allow genetic gain through superior genotype capture. Targeted collection, however, requires more resources to do properly, and expected genetic gains may not materialise.

Vegetative – as opposed to seed – collection has been applied when significant genetic gain through 'true-to-type' cloning is anticipated. However, vegetative sampling and subsequent multiplication require more resources – such as nursery propagators – when compared to seed collection. The approach has been applied to higher value species such as fruit trees, as described here by a case study based on *Allanblackia.*

Key resources

- Dawson I, Were J (1997) Collecting germplasm from trees – some guidelines. Agroforestry Today, 9, 6-9.
- FAO, Forestry Resources Division (1995) Collecting woody perennials. In: Guarino L, Ramanatha Rao V, Reid R (eds.) Collecting plant genetic diversity: technical guidelines. CAB International, Wallingford, UK, pp. 485-489.
- Kindt R, Lillesø JPB, Mbora A, Muriuki J, Wambugu C, Frost W, Beniest J, Aithal A, Awimbo J, Rao S, Holding-Anyonge C (2006) Tree seeds for farmers: a toolkit and reference source. The World Agroforestry Centre, Nairobi, Kenya.

Germplasm collection and tree domestication

Attention to germplasm collection methods is crucial if planted trees on farms are to fulfil their potential in providing the products and services that farmers require. Collection is an essential step in providing the raw material for analysis in trials, underpinning breeding programs and obtaining germplasm for direct distribution to users. When researchers or the extension services that support farmers collect germplasm, certain key issues should be addressed (Box 1). It is important to determine in advance the objectives of the collection and how this influences sampling. Logistical needs also need to be arranged properly, the process of collection documented and appropriate biological standards maintained.

Box 1

General issues of importance during germplasm collection

Construct a proper rationale for collection A well-developed written rationale describing the purpose of collection and the methodology that will be used during sampling is essential before any collection commences. In addition, the next steps in the use of collected material need to be clearly described.

Find out information about the species and where to collect from Prior research of herbaria, literature and key knowledge holders, combined with preliminary field work, are generally necessary to determine from where, when, and how to collect. These studies are also essential for understanding the taxonomy of a tree, and whether issues such as sub-species status need to be taken into account during collection. (When there are multiple sub-species, should one or more than one be sampled?) Understanding as much as possible in advance if the tree has a patchy or continuous distribution, and if the density of individual stands is high or low, are also important points in designing strategy.

Arrange logistics A team with the appropriate skills for collection needs to be assembled, with the necessary equipment for collection and field processing, as well as the necessary permissions for collection from the relevant authorities. If local people manage the trees from which sampling will take place, they need to be informed of the work and give their consent. It may be beneficial to involve them in the collection process. In participatory domestication (Unit 15), farmers are trained in collection methods and then take responsibility.

Document the process Good written documentation before, during and after collection is essential for an efficient domestication programme and for reference purposes. It may be necessary some years in the future to return to particular populations or particular trees for further sampling and evaluation. This is only possible if proper records have been kept. This is particularly important when collection involves targeted sampling (see more below). Proper documentation involves designing a form to collect all required data during sampling in the field and properly summarising this data in collection reports on return to base. Copies of collection sheets and reports should be maintained as electronic and paper copies. The last is important for 'archiving': in 50 years time, it may no longer be possible to access certain electronic file formats and electronic storage devices.

Box 1 continued

Maintain biological standards during collection Sampling of seed from a minimum of 30 trees, with a predetermined minimum distance between trees, is recommended in order to effectively 'represent' any population genetically. For the same reason, collecting fruit/seed from the entire crown is recommended rather than sampling it from only one or a few branches. In practice, it is frequently difficult to sample 30 trees from a site and a lower number may have to be deemed acceptable. If collecting clones, it is also important to sample a number of trees. If collections are to represent available genetic variation within a species or country, a number of sites need to be sampled; the definition of unique sites for collection may be based on the geographical distances between them (set a minimum distance) or variations in environment (see section on range-wide collection). Whether collecting seed or clones, they must be sampled at the right stage of physiological maturity.

Collection of associated materials When collection is part of a research process, it is important to sample more than just germplasm. Many tree species are now subject to molecular marker evaluation (Unit 8) and suitable material for laboratory analysis (normally, dried leaf samples) should be taken from parental trees. This allows the genotypes of parents to later be compared with their (seed) progeny. This is important in gene flow analyses and mating system studies.

Ensure efficient processing to feed into future use During and after collection, germplasm should be processed and then stored in a manner that optimally maintains viability and allows material to feed efficiently into the next stage of the determined use for sampled germplasm. When material is for research, germplasm (seed, clones) should normally be kept separate by individual trees during processing, to allow family-level analysis (e.g., progeny trials, see Unit 7).

Be flexible Every collection has unique features and problems. Collectors must be flexible and pragmatic, rethinking strategy in the field depending upon the conditions they encounter, and understanding where compromises can be made (and where they are not acceptable!).

For further information on collection guidelines, see Dawson and Were (1997). For practical information on processing and storing seed after collection – the next essential steps in its use – see Kindt *et al.* (2006).

Is a random systematic or targeted collection approach best?

One of the most basic decisions to make before collecting germplasm is whether to use a random systematic approach or if to undertake targeted sampling. The first involves the collection of germplasm from trees without reference to phenotype, while the second involves sampling of 'superior' individuals only. Random systematic sampling, ideally from at least 30 well-spaced individuals through a stand (though it may not be possible to collect this number with some species or populations), should maximise the genetic base of the germplasm collected. This limits the risk of inbreeding depression, a decline in vigour as a result of decreased levels of heterozygosity at individual loci and the exposure of recessive deleterious mutations, in future generations. (Note that important also for maintaining genetic breadth is how material is handled after it has been first collected; it is for example of little use to carry out wide initial sampling within stands if subsequently significant bottlenecks are introduced by scientists in the handling of material.) Targeted sampling, on the other hand, would at first appearances have obvious advantages for providing superior quality germplasm for testing and use.

Despite the apparent advantages of targeted sampling, it may not always be effective (Table 1), such that the extra time and energy involved in selecting the trees to collect from is not justified. Success depends on the heritability of the trait or traits that are being selected for: they should have at least moderately high heritability at the collection site, such that phenotypic differences observed in stands represent actual genetic differences between trees[1]. Heritability will however be lower in the non-uniform environmental conditions of natural forests and farmers' fields where collections take place than in field trials, making useful selection during sampling in the former two environments harder.

For many tree species important to small-scale farmers in the tropics, there is very little information on the heritability of key traits. Assumptions must often be made based on better researched temperate trees. However, the data that are available show that traits such as fruit (and nut) shape, size and yield are often – although are not always – of higher heritability than tree growth and form. Thus, when fruit and nut traits are important, targeted collections may be most useful. It is no surprise, then, that targeted germplasm collection has most often been applied to fruit trees. Also, the potential economic value of genetic gain is high for fruit trees, making investment in targeted sampling more worthwhile. Fruit trees are also often sampled vegetatively (see below), which increases the chances of securing gain.

The value of targeted sampling is supported by research on indigenous fruit trees (IFTs) by ICRAF and partners which has shown that large variation in yield, fruit size, shape and composition is often observed within natural stands (Box 2). For example, this has been seen in the important rainforest fruit tree *Allanblackia* that is being domesticated for edible oil production in Central, East and West Africa. IFTs therefore appear to be particularly good candidates for targeted collection.

Targeted collection has also sometimes been applied usefully to timber trees (Box 3). In this instance, the approach has been used because of the obvious high economic value of genetic gain in traits such as growth rate and stem straightness. This is even though these characteristics may be of rather low heritability, and actual gains during collection may therefore be rather modest. For trees used as fodder and fertiliser, targeted collection at the individual level is little practised; still important, however, is to select the right provenance or provenances, as there may be big differences in performance here.

When is it best to collect seed, when vegetative propagules?

Sampling vegetative propagules, such as stem cuttings, root cuttings or marcots, is an alternative approach to taking seed during germplasm collection. Each approach has particular advantages and disadvantages (Table 2). In general, vegetative collection has only been used with fruit trees and

[1] Environmental effects can only be properly accounted for in controlled field trials, see Units 6 and 7.

when in combination with targeted sampling. This is because of the relatively high heritability of important fruit traits in natural stands and farmers' fields, and the fact that cloning captures gain through the sampling of 'true-to-type' material that is genetically identical to the mother tree. In addition, a particular advantage of collecting fruit trees vegetatively is that, if done in the right way, it results in accelerated fruiting when compared to trees established from seed. Earlier fruiting means that faster evaluation in trials is possible and that farmers planting the tree receive quicker returns (see more in Unit 12). A further reason for vegetatively collecting fruit trees is that their seed are often recalcitrant and so cannot be easily handled and stored.

Although vegetative sampling approaches generally require more knowledge, resources and time to undertake when compared with seed-based collection methods, the issue is less of a concern when species are of high value and thus can merit the extra investment. Again, fruit trees, with their important revenue raising benefits for farmers, fit into this category. *Allanblackia*, with its high potential gain from targeted selection (see Box 2) and its poor seed handling characteristics, is being collected by vegetative means (Table 2).

Cloning has not normally been applied to timber, medicinal, fodder and soil fertility improving trees during initial germplasm collection. It is, however, sometimes used for multiplication later on in the domestication process for timber and medicinal trees. For example, it is sometimes used for timber trees when distributing planting material to growers, to maintain genetic gains that have been realised through breeding and selection (sometimes highly productive interspecific hybrid clones have been developed; these can only be deployed by vegetative propagation, for example hybrid acacia, eucalypt and poplar clones).

The participatory domestication method discussed later in this primer (Unit 15) seeks to use simple clonal methods of propagation that allow farmers to directly collect germplasm rather than rely on others to obtain material. Simple methods are based, for example, on the rooting of leafy stem cuttings in non-mist propagators that farmers can easily construct. Such vegetative propagation methods have been widely adopted by farmers in some locations for germplasm collection from wild stands.

Table 1 Advantages and disadvantages of random systematic and targeted approaches to germplasm collection (from a given tree population)

Strategy	Random systematic sampling	Targeted collection
Advantages	• Collection is representative of the population as a whole, allowing accurate comparisons of populations in field trials • Collection samples the widest possible genetic base, providing an adaptive capacity to varying farmer requirements and changing environmental conditions, and preventing future inbreeding depression • Re-collection using a similar strategy will result in material of approximately the same composition and performance, assuming that the population has not been degraded by environmental changes or human activities in the meantime • Because the sample is representative of a population, the approach is considered ideal for *ex* and *circa situ* conservation purposes	• If the heritability of targeted traits is at least moderately high, the approach is more likely to collect superior germplasm, which is important for improvement purposes • Targeted sampling based on traits important to local users provides good opportunities to get communities involved, and can help drive a participatory domestication approach
Dis-advantages	• A high proportion of collected material may be of low quality and have little value for use. Most of it may therefore be discarded from a domestication programme	• Phenotypic selection may not be effective in the field. The significant time and effort involved in targeting may then be wasted, resulting in so-called 'superior' trees that are in fact little different in performance from randomly sampled individuals • Collection may not be representative of a population, making future re-collections to obtain similar material difficult, unless excellent documentation is kept on the locations of individual trees (accurate geo-referencing) • Possible narrowing of the genetic base, with negative consequences for long-term sustainable management

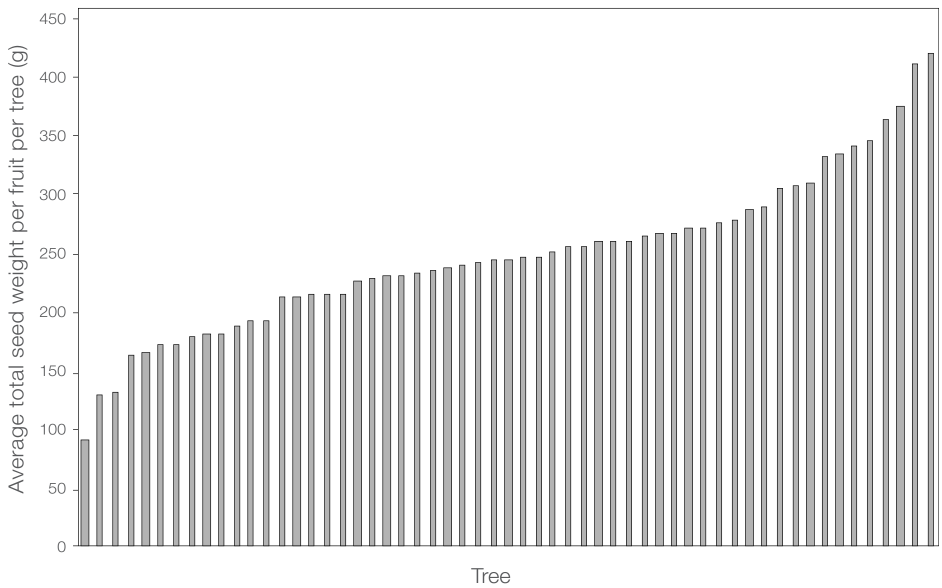
Box 2

Variation in important traits in natural stands of African fruit trees

Evidence collected from a range of African fruit trees shows that large variation in yield, fruit size, shape and composition, among other important characteristics, is found within natural stands. For example, in the important genus for edible oil production, *Allanblackia*, a more than four-fold difference in average seed yield per fruit has been observed between trees within wild populations in Cameroon (see figure below for *A. floribunda*, one of the nine species in the genus). This difference in yield is consistent with high molecular genetic variation in stands and the different fatty acid profiles of *Allanblackia* individuals.

Similarly, in the priority fruit tree safou (*Dacryodes edulis*) in Cameroon, it is estimated that local selection of the best types from within natural and/or farmers' stands could result in a five-fold increase in the economic value of material planted. Again, greater than two-fold variation between trees in the vitamin C content of fruit pulp has been observed in natural populations of the priority fruit tree marula (*Sclerocarya birrea*), an observation that corresponds with the high molecular genetic variation also noted in populations in southern Africa. A greater than two-fold difference in yield has also been observed between trees of the priority fruit tree wild loquat (*Uapaca kirkiana*) in Malawi. Based on these results, a targeted collection approach has been applied to all of these fruit trees, but how effective sampling from environmentally heterogeneous wild stands is in realising genetic gains needs to be confirmed by controlled trials (see Units 6 and 7).

Tree-to-tree variation in seed weight per fruit for *A. floribunda* trees Forty fruits were sampled from each of 57 trees from a single population in Cameroon during a single season. Variation in seed weight was high, suggesting merit for a targeted collection approach.



Taken from Jamnadass *et al.* (2011). See also Russell *et al.* (2009) and Atangana *et al.* (2011) for descriptions, respectively, of molecular marker and fat variation among and within *Allanblackia* populations.

Box 3

Random systematic and targeted collection of timber trees: the case of capirona

Very little research has tested the effectiveness of a targeted collection approach by directly comparing it with the alternative of random systematic sampling. An exception is the important timber species capirona (*Calycophyllum spruceanum*), which was sampled along river tributaries in the Aguaytía watershed of the Peruvian Amazon Basin (see also Unit 7). Capirona seed were collected from 132 trees growing on farms in seven locations in the lower, middle and upper parts of the watershed. Farmers visually selected 66 mother trees (approximately 20% of the trees present from the populations sampled) that appeared to have above-average growth rates and good bole form. In addition, 66 other mother trees were selected at random.

Seedlings of the 132 mother trees were grown in the nursery and planted in a field trial in a replicated, randomised experimental design to control for environmental effects. Trees were evaluated at 15, 26 and 38 months after planting. Mean tree height and stem diameter were greater in the selected than in the random group at all measurement ages, although the only statistically significant difference was in height at 15 months after planting. There were no significant differences in branching pattern and mortality between the two collection treatments.

Data from the trial suggested that, even at relatively low selection intensity (approximately 1 out of 5 trees) and in highly variable farm environments, it was possible in this case to obtain modest genetic gains through selection. This was even when the collection of seed was from mother trees of unknown and variable age.

Taken from Weber *et al.* (2009).

Table 2 Advantages and disadvantages of vegetative methods for the collection of tree germplasm, with specific reference to the sampling of *Allanblackia*

In general for trees	For *Allanblackia*
Advantages	
• Sampling takes an exact genetic copy of the collected tree, whereas with seed only the mother tree is identified (paternal parent generally unknown). Targeted vegetative sampling is therefore more efficient than seed collection in capturing and 'fixing' advantageous traits, especially in combination • The uniformity of cloned varieties may make them easier to register as farmer-derived, protected cultivars, meaning farmers are able to exercise, and benefit from, breeders' rights • The sex of the propagule is known for dioecious species (separate males and females), whereas individual seed collected from such trees may be either sex. For fruit trees, sampling females may be preferred because only they yield the required product (but collection of some males is still required for pollination) • Clones collected in the right way may demonstrate accelerated expression of important traits, e.g., time to fruiting. Germplasm can then be evaluated more quickly and bring earlier benefits to growers • Collection is possible when seed is unavailable or its handling is difficult (e.g., if recalcitrant). For some trees, the timing of seed production is hard to predict, making collection difficult. Isolated trees may never set seed or the seed they do produce may be of poor genetic quality due to inbreeding	• Cloning of targeted genotypes from phenotypically diverse natural stands may lead to significant genetic gains compared to seed sampling • As the species is dioecious, more female than male trees can be collected and planted to increase productivity • Trees established from seed will fruit after ~ 12 years, whereas material propagated vegetatively is expected to fruit after ~ 5 years • *Allanblackia* seed can take considerable time (sometimes more than a year) to germinate, with low absolute levels of germination
Disadvantages	
• Compared to seed sampling, vegetative collection is labour intensive: it takes more time to collect the same number of propagules. Research is needed for every species to develop efficient collection methods • Unlike (orthodox) seed, vegetative material is perishable and must be planted (or grafted) quickly after collection. Special nursery facilities for the establishment and growth of clones may be required. Special care must be given to healthy root development as otherwise plants will fail after field establishment • Regulations on the cross-border movement of vegetative material are stricter than for seed, due to the increased potential for pest and disease transmission. Establishing international clonal trials is therefore difficult • As vegetative collection is generally more time consuming than seed sampling, often a smaller number of trees are taken from any given population. This may lead to a narrowing of the genetic base of germplasm, which may make production more susceptible to pests, diseases, etc.	• Thousands of non-mist propagators are needed to provide sufficient rooted leafy stem cuttings for field planting by farmers. The collection of vegetative material requires the felling and coppicing of many mature trees • *Allanblackia* grows in a number of African countries. The exchange of germplasm and establishment of reciprocal field trials may only be possible via seed • Genetic narrowing is possible, although unlikely because of the very large numbers of propagules needed, which means cloning from many trees

The value of range-wide germplasm collection

When germplasm is being collected for evaluation in field trials as part of a genetic improvement programme, a range-wide sampling approach is best adopted, in which a number of different provenances or populations are collected for comparison. This is because considerable genetic variation in important adaptive and productive traits can exist among populations within tree species (see Unit 7). Range-wide collection aims to sample provenances from different ecological conditions, such as rainfall level, soil type and temperature range. An example of a range-wide provenance collection is given in Box 4.

Normally, the focus during range-wide collection is on sampling wild sources, although a few planted populations, if there is any cultivation history for the species, can also be collected for comparison during subsequent evaluation. (It should be remembered that many planted populations of a widely cultivated species may actually be of limited or common origin; for example, they may be of the same original provenance which has been distributed from site to site across the world. It may not make sense to sample cultivated stands very widely if this is suspected to be the case, as the differences between these stands may be small compared to the differences between wild provenances). As well as providing for the full evaluation of genetic variation within a species, range-wide collections also provide an important opportunity to conserve the genetic resource base of a tree, by placing material in seed or field genebanks. These genebanks ensure that material is available in the future for experimentation and use.

Despite its importance, the range-wide sampling approach has been adopted only rarely in the last two decades. In fact, most large, multi-country collections of agroforestry tree species – to the limited extent that such collections have been undertaken – were conducted in the 1980s and 1990s (see Stewart *et al.* 1996 for an example). Partly, this reflects the considerable expense involved in undertaking international collections.

Another factor, however, is that the cross-border exchange of germplasm for research in comparative field trials (and for laboratory analysis) has become increasingly difficult in recent years. This is due to legislation such as the Convention on Biological Diversity that places additional controls on research transfers. Where multi-country collections continue to take place for international trials, they generally occur among nations participating in regional trade and/or cooperation agreements. (Interestingly, the same restrictive controls on exchange often do not apply to the transfer of material for direct use [for planting by farmers], rather than for research).

Although the current rules on international germplasm exchange were devised with the best of intentions – for example, to protect the rights of communities who have traditionally used and managed species – their net effect has been to significantly restrict research that would benefit farmers and consumers (Koskela *et al.* 2009). The harmonisation of current legislation controlling international transfer, to remove unintended negative effects on research, while still providing the right level of protection to communities, etc., is crucial.

Range-wide collection and climate change

Because of the international nature of many of the problems that farmers face, the trend over the last 20 years to move away from regional germplasm collections, and to carry out fewer international trials, needs to be reversed. In particular, the impact of climate change on agroforestry practices requires range-wide sampling exercises, to conduct research to identify planting material that is suitably adapted to new environmental conditions. When carrying out this work, more attention in required to the physiological mechanisms underlying responses to environmental change; drought tolerance, water use efficiency and response to elevated CO_2 levels are all important characteristics for study (Box 5).

Box 4

Sampling strategy for a range-wide collection of grevillea

Grevillea (*Grevillea robusta*) is a an important timber tree for smallholders in the equatorial highlands of Central and East Africa, where it is widely planted and yields firewood and cash income from the sale of poles and saw-logs. The species is indigenous to eastern Australia, and was first introduced to Africa as a shade tree for tea and coffee at the start of the 20th century. Researchers suspected that the genetic base of these first unplanned introductions was narrow and sub-optimal, so they mounted range-wide seed collections of the species in 1990-1991 in Australia to provide additional genetic resources for domestication.

A first step in collection was to survey the natural distribution of the species. It was found to occur in two distinct habitat types: gallery forest along river valleys and vine forest on hillsides. Many discontinuous stands, well-separated from one another by kilometres of different forest types in which *G. robusta* trees do not occur, were found. Thus, there were many hundreds of natural occurrences that could each be designated as local provenances.

Although the natural range had been reduced by forest clearing, field reconnaissance identified many remnant populations where seed collections could be made. Many such populations, however, had relatively few adult trees and were of limited extent, such that standard recommendations on sample size (see Box 1) could not be applied. Provenances for collection were selected to satisfy the following criteria:

- Coverage of the full latitudinal range of the species.
- Both coastal (high rainfall) and inland (lower rainfall) sites to be represented.
- High, intermediate and low altitude sites all to be represented.
- Occurrence in both riverine and vine forest habitats to be represented.

Seed collections were carried out over two fruiting seasons, yielding 23 local provenances with four or more seed trees represented, and 19 provenances with ten or more trees represented. These genetic resources were used to set up breeding programs in several countries, and were also evaluated using molecular genetic methods. These studies confirmed that the planted African populations of the species displayed evidence of inbreeding and had much lower genetic diversity than was represented in the range-wide collections. Subsequent field trials in Kenya confirmed better performance of the newly-collected material from Australia.

Modified from Harwood *et al.* (1997).

Box 5

Matching genetic variation with new climate in the Sahel: smallholders' agroforestry and the SAFRUIT project

The current understanding of population-level environmental responses in indigenous tree species planted by small-scale farmers in Africa is limited. New trials have, however, been established to consider climate change effects. Under the Sahelian Fruit Tree project (SAFRUIT, see www.safruit.org), for example, trials on drought stress for important trees for smallholders, such as baobab (*Adansonia digitata*) and African locust bean (*Parkia biglobosa*), are being conducted in the semi-arid West African Sahel, a region that has become drier over the last decades.

In nursery experiments, populations collected from locations with different rainfall levels have been exposed to a range of watering regimes. Features being measured include photosynthesis, water use efficiency, water potential and chlorophyll fluorescence. The information being obtained on the effects of different treatments on root development, seedling vigour and other important adaptive characteristics will inform subsequent germplasm distribution strategies.

In some cases, climate change considerations for seed collection and distribution are already being taken into account in the region. One example is provided by prosopis (*Prosopis africana*), used by local people primarily for wood production. Based on field trials of 28 provenances measuring growth, survival and wood density in relation to rainfall patterns across seed collection sites, it has been recommended that germplasm transfers should only be undertaken in a single direction, from drier to (currently) wetter zones. A similar strategy was adopted for a recent International Fund for Agricultural Development agroforestry project in the same region.

Different global circulation models used to explain environmental changes vary in future predictions of rainfall for the Sahel, with some indicating drier and some wetter conditions. Given current uncertainties in projections, an emphasis in the region on matching seed sources to the more limiting scenario of a drier future climate would appear to be the most risk-averse option. Germplasm collected from drier locations may therefore be particularly useful for testing and possible future use, as well as for conservation purposes (such natural populations may be under particular threat as climate dries).

Taken from Loo *et al.* (2011) and Weber *et al.* (2008).

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Unit 10 – Seed procurement practices

Lucy Mwaura and Ian Dawson

Unit objectives

After studying this unit, readers will be able to:

- List and describe the steps involved before, during and after a seed procurement exercise.
- Develop a seed procurement strategy for a tree species of interest.
- Explain the importance and implications of international seed procurement.

Summary

Sampling germplasm directly from local (natural or planted) stands, as discussed in Unit 9, may be an effective means of obtaining tree planting material. Alternatively, farmers, NGOs and others will source seed, seedlings and clones from 'informal' small businesses that operate locally and aim to make a living through germplasm production and exchange (Unit 14). In other instances, as described here, material may be obtained from 'formal' germplasm suppliers that operate nationally and/or internationally.

During procurement, the most important points are to plan well ahead, and to consider the genetic and physiological quality of the material that is available. ICRAF's Tree Seed Suppliers Directory is a useful guide for procurement, giving information on more than 100 suppliers of seed for several thousand tree species. This unit describes key issues to consider before, during and after germplasm procurement, and illustrates the importance of international exchange for obtaining suitable material for smallholders to plant.

Key resources

- Dawson I, Were J (1998) Ordering tree seed – some guidelines. Agroforestry Today, 10, 8-11.
- Kindt R, Lillesø JPB, Mbora A, Muriuki J, Wambugu C, Frost W, Beniest J, Aithal A, Awimbo J, Rao S, Holding-Anyonge C (2006) Tree seeds for farmers: a toolkit and reference source. The World Agroforestry Centre, Nairobi, Kenya.

Seed procurement and tree domestication

Conducting a collection exercise is one approach to obtain planting material for research and for distribution to farmers (Unit 9). However, in many instances this is not a practical option for sourcing germplasm, because the necessary skills and equipment to make a collection are not available, because a species is not found growing locally, or because what is found locally is known or suspected to have poor performance. The cost of collection may also be prohibitive. If others have already collected germplasm, the best option may be to procure it from them. There are many 'formal' suppliers[1] of tree seed around the world who can provide planting material of particular quality characteristics and often of a range of provenances of a tree species. This unit describes how to source seed from these providers.

Guidelines for ordering tree seed

The normal procedure that should be followed when procuring tree seed from a formal supplier is indicated in Box 1. Key concerns are to plan ahead when sourcing seed, and to consider the genetic and physiological quality of the material that is available. As a rule of thumb, the more information that a supplier is able to give about the origin and handling of the material that is available for procurement, the more confidence can be given to any statement a supplier gives on quality.

The cost of initial investment in procuring germplasm of good genetic quality may be rewarded many times over in terms of the value of the products and services subsequently realised through tree planting. This is particularly so when germplasm is 'recycled' by farmers after it has once been introduced into the agricultural landscape. This happens a lot in smallholders' agroforestry systems: research shows that seed from initially established material is used for 'second generation' plantings and this for the next round of planting and so on. As a result, once germplasm has been introduced to farmers there may be only limited opportunity to 'reintroduce' it, even if the material being reintroduced is of better performance. The initial quality of germplasm is therefore crucial.

[1] The term 'formal' supplier refers to planting material providers that operate in the formal sector, such as research institutions, large-scale commercial seed suppliers and national tree seed centres. 'Informal' suppliers also play a key role in providing tree planting material, as related in Unit 14.

Box 1

Steps to take in ordering tree seed

Before ordering

- If possible, determine which species and provenances will best fulfil the purpose for which planting is required. This means considering the key end product – timber, fodder, medicine, etc. – that is needed.
- Consider whether an indigenous species could fulfil the needed function as well as an exotic species. If so, give preference to the indigenous species, as this is likely to provide a more sustainable option.
- Before procuring an exotic species from outside the country, check that it is legally permitted to import it, and survey the literature to investigate biosafety risks. The international exchange of several agroforestry trees is restricted because they are considered to be potentially invasive. If there are likely to be problems, consider an alternative species.
- Remember to consider the cost implications of seed purchase. Tree seed may be expensive, especially if the species or provenance required is in high demand. However, any extra cost associated with quality is likely to be worth it in the medium- to long-term.
- Search the literature to determine potential suppliers of a species (and of associated microsymbionts, if required). As far as possible, choose from those suppliers who provide the best documentation on the material provided, as this is generally a proxy for quality. ICRAF's online Tree Seed Suppliers Directory (TSSD) gives data on more than 100 suppliers of seed for several thousand tree species.
- Contact suppliers and provide them with as much information as possible to determine if they can fulfil your specific requirements. Indicate if a particular provenance or type of collection (e.g., family-based seed samples) is required. Give information on the proposed planting sites (geographic locations, altitudes, local climates, basic soil characteristics) and the objectives for planting.
- Ask the supplier to indicate if and when they will be able to meet an order, and what information they will provide with seed (e.g., on origin, collection strategy, purity, treatments applied to seed before or during storage or before dispatch, legal and ethical restrictions on the use or distribution of supplied germplasm, treatments needed to maximise germination).

Placing an order once a suitable supplier has been found

- Order seed well in advance of the anticipated planting time, as suppliers may not have sufficient seed in stock and may need to carry out further collections. Take into account the time that you will require to germinate seeds and raise plants in the nursery prior to field establishment.
- Provide practical details that will help the supplier process and ship an order. Indicate when material will be sown, how many seedlings are required (as opposed to seed weight, so the supplier can more accurately judge the quantity of seed that should be sent) and the preferred delivery date. If appropriate seed storage facilities are unavailable, the supplier may be able to delay dispatch until closer to the intended sowing date to ensure maximum viability of the seed.

Box 1 continued

- Obtain and sign any necessary documents for receiving seed, such as import permits (if material is being transferred from abroad) and material transfer agreements (which cover the conditions under which the seed can be used, e.g., to protect breeders' rights). If shipping from abroad, the supplier will generally have to provide a phytosanitary certificate to confirm that germplasm is disease free.

After the receipt of seed

- Confirm the receipt of seed with the supplier.
- Test the physiological quality of seed (viability) to know how much to use when the time comes to plant it.
- Store seed under the conditions specified by the supplier until sowing.
- At sowing, follow any instructions on seed pretreatment provided by the supplier.
- File and safeguard all documentation provided with seed for future reference (e.g., so that it is possible to order seed from the same source again [or to avoid this source]). Copy documentation to everyone that further receives seed.
- Keep the supplier advised about the performance of the germplasm and about any problems that occur with germination of seed or with pests and diseases. This is important for their quality control so that they can provide the best material to other requestors.
- Ensure that any agreement on the use and further distribution of seed are adhered to.

Adapted from Dawson and Were (1998). For practical information on what constitutes – and how to test for – seed physiological quality, see Kindt *et al.* (2006). The internet can be consulted for tree seed suppliers. Start with the TSSD, which is available at: www.worldagroforestry.org/Sites-old/TreeDBS/tssd/treessd.htm, and pay close attention to the level of information suppliers are able to provide.

The importance of international germplasm exchange

In recent years considerable emphasis has been placed on the development of a participatory tree domestication approach that relies on farmers' accessing genetic resources of indigenous species locally (Unit 15). Over the last centuries, however, the international exchange of 'exotic' tree germplasm has had a key role in the development of tree cultivation globally. In this respect, the planting of trees is no different from agricultural crops such as potato, maize, rice and wheat, all of which have been widely distributed around the world from their centres of origin. Some exchanges can be dated to ancient times; for example, incense trees, in seedling rather than seed form, were apparently transported from Somalia to Egypt 3,500 years ago (Fig. 1).

It is easy to illustrate the importance for smallholders of the international exchange of tree planting material by considering a case study based on 120 important agroforestry trees used for various purposes (Box 2). Survey indicated that each species had on average been distributed to 21 countries outside its native range. Survey also showed that the majority of formal germplasm suppliers were located outside the natural distribution range of the species they provided, and may be handling low quality material. Generally, suppliers located within the native range of a tree should be preferred during procurement.

Such transfers of tree germplasm around the world will continue to be important in order to respond to the global challenges facing agriculture, for example, in response to environmental shifts caused by anthropogenic climate change and in dealing with currently low farm productivity. An example of the last point is given in Box 3. In this case, germplasm procurement from Asia (of seed and vegetative propagules) for planting in Africa would boost the performance of a number of exotic fruit trees important to smallholders in the sub-Sahara.

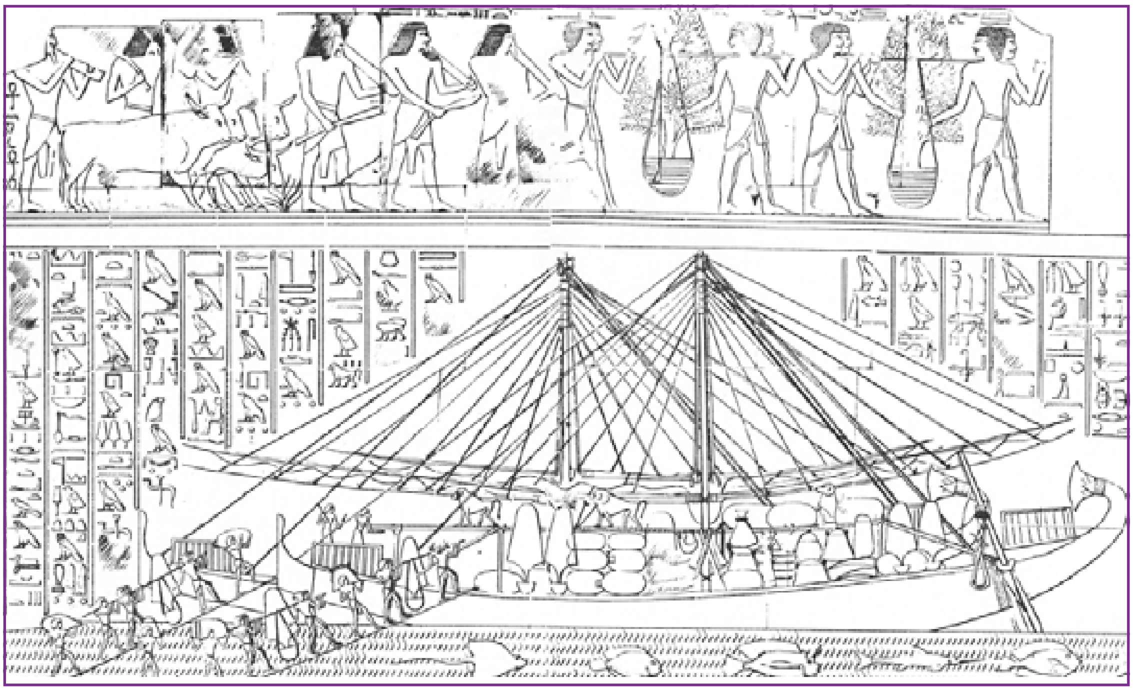

Figure 1 Potted incense trees (*Boswellia* spp.) being loaded onto ships for transport from the land of Punt (current day Somalia) to Egypt. Drawing on the walls of the temple of Deir El Bahari, dating from around 1,500 BC. This may represent one of the first government-sponsored international exchanges of tree germplasm.

Despite the benefits of such exchanges, there are also potential pitfalls. Some species can become weedy and invasive when they are introduced to new locations, and consideration of this should be given during procurement (see Box 1). Many countries have restricted the introduction of tree species that are known to have high invasive potential. In such cases, it may be possible to substitute an alternative, locally available species with a similar function. Local availability is however not always an indicator that a species will not become invasive: changing the management of a species (e.g., bringing it from the wild into cultivation) can cause it to become a weed.

Box 2

The importance of exchanging planting material internationally: a case study of 120 agroforestry trees

ICRAF's Agroforestree Database (AFTD) contains information on the native and exotic distributions of more than 600 tree species important to small-scale farmers. Researchers used the database to assess the international transfer of germplasm (of seed and possibly also seedlings and clonal material) of 120 tree species of importance to smallholders. In order to understand if transfer was more or less important for particular types of tree, 30 species of each of four different primary use groups – timber, fruit, medicine and fodder/soil fertility improvement – were considered in the survey. (Fodder and soil fertility uses were considered together, as many times the same species is planted for both purposes).

AFTD searches indicated high levels of past international transfer of germplasm for all use categories. On average, each species was recorded as having been distributed to a surprisingly high 21 countries outside its native range. Trees used for fruit and fodder/soil fertility improvement had been distributed to more exotic locations (both, on average, to 25 other countries) than timber and medicinal trees, with a greater proportion of the current total range (indigenous and exotic distribution) of the former two categories being exotic.

The same 120 species were then considered in the TSSD (see Box 1 for web address). On average across use categories, database searches recorded 11 suppliers of germplasm for each species, with a mean of four suppliers being located within the native range of a taxon and seven outside. The high proportion of suppliers recorded in exotic locations indicates interest in the further transfer of germplasm once a species has left its native range. These dealers may however be handling poor-performing landraces that contain genetic bottlenecks, if the germplasm initially introduced into exotic locations was poorly collected and not properly evaluated. The procurement of germplasm from these suppliers should therefore proceed with caution.

With such wide distribution of germplasm by all categories of tree use, the importance for smallholders of future procurement at an international level is evident, as new improved types are selected and developed for different functions. According to the database entries of the 120 taxa surveyed, *Casuarina equisetifolia* was the timber species distributed to most countries outside its native range, with *Azadirachta indica, Mangifera indica* and *Leucaena diversifolia* being the most widely distributed medicinal, fruit and fodder/soil fertility species, respectively.

Taken from Koskela *et al.* (2009). The AFTD is available at: www.worldagroforestrycentre.org/resources/databases/agroforestree

Box 3

Increasing exotic fruit yields in sub-Saharan Africa through the 'south-south' transfer of cultivars

Exotic fruit trees such as avocado, mango and orange are often mentioned as priorities for cultivation by smallholders in sub-Saharan Africa (see, e.g., Table 2 in Unit 4). Often, these species were introduced into the sub-continent many centuries ago, through seed transfers and sometimes through the carriage by sea between maritime ports of whole potted plants (similar to the ancient transfer of incense trees to Egypt, see Fig. 1). Exotic fruits trees were probably transported into the sub-Sahara by traders in slaves and manufactured goods. For example, mango and banana from Asia were already widely distributed in sub-Saharan Africa in the 14th Century, according to the Arabian traveller Ibn Battuta. These fruits may have formed important foods for slaves in their transit to the coast, before they were shipped to Arabia, the Americas and elsewhere.

Many of the fruit tree cultivars now grown by African smallholders are derived from these ancient introductions, but they do not perform well when compared to more modern varieties developed elsewhere. For example, several local mango landraces in Kenya are considered stringy in texture and are not well matched to current consumer preferences. Much better varieties are grown by smallholders in other parts of the world such as India, from where the species originally derived.

To revitalise sub-Saharan smallholder production of these long-present but exotic fruit trees, two approaches are possible. The first is to breed new varieties within the sub-Sahara based on the existing landrace gene pool, while the second is to renew 'south-south' linkages to bring in superior varieties developed elsewhere in the tropics. Taking advantage of new cultivars developed elsewhere appears a cost effective approach. This is because local landraces in Africa may have a narrow genetic base anyway, with limited potential for gain, and there seems little benefit in duplicating breeding efforts that have already been undertaken in other locations.

A recent example of the success of south-south transfer has been the introduction of new varieties of ber (*Ziziphus mauritiana*) from Asia into Sahelian countries. In this case, the species is in fact indigenous to both the sub-Sahara and Asia, but varieties developed in Asia perform significantly better when introduced into West Africa and tested against local types. There is also great potential for renewed transfers of fruits such as guava (*Psidium guajava*), tamarind (*Tamarindus indica*), pomegranate (*Punica granatum*), papaya (*Carica papaya*), custard apple (*Annona squamosa*) and jackfruit (*Artocarpus heterophyllus*). To facilitate such south-south procurement, the regulations that control international exchange need to be harmonised.

Taken from Jamnadass *et al*. (2011)

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Jamnadass RH, Dawson IK, Franzel S, Leakey RRB, Mithöfer D, Akinnifesi FK, Tchoundjeu Z (2011) Improving livelihoods and nutrition in sub-Saharan Africa through the promotion of indigenous and exotic fruit production in smallholders' agroforestry systems: a review. International Forest Review, 13, 338-354.

Koskela J, Vinceti B, Dvorak W, Bush D, Dawson I, Loo J, Kjaer ED, Navarro C, Padolina C, Bordács S, Jamnadass R, Graudal L, Ramamonjisoa L (2009) The use and movement of forest genetic resources for food and agriculture. Background Study Paper No. 44. The Commission on Genetic Resources for Food and Agriculture, Food and Agriculture Organization of the United Nations, Rome, Italy.

Unit 11 – Seed production methods

Anne Mbora and Ian Dawson

Unit objectives

After studying this unit, readers will be able to:

- Explain the importance of seed production in the context of agroforestry tree domestication and illustrate through examples.
- List and describe the steps in establishing and managing a tree seed production stand.
- Illustrate the need for research on tree seed production using an example from the genus *Leucaena.*

Summary

Collecting germplasm directly from natural populations (Unit 9) or procuring it from formal suppliers (Unit 10) may be effective means of obtaining tree planting material. When the demand for seed of a particular tree species or provenance is particularly high, however, it is often necessary to establish multiplication stands to supply sufficient quantities of good quality germplasm. Otherwise, lack of supply can become a major constraint for farmers' planting targets.

This unit describes the key steps to take, and factors to consider, when establishing and managing 'formal' seed production stands planted specifically for the purpose of meeting the seed requirements of a planting project. During seed stand establishment, it is essential to determine the area that needs to be planted to meet the likely volume of demand. Maintaining genetic quality during production, such as by avoiding contamination, is also an important concern. Some simple tips on how to harvest quality seed from trees available on farm are also given.

By considering a case study based on *Leucaena trichandra*, the unit illustrates some of the issues important in tree seed multiplication research. This case shows that there can be large genetic differences in seed production on a family-by-family basis (i.e., progeny from different mother trees vary in their seed production ability). Careful consideration therefore needs to be given to the collection strategy applied to production stands, if effective population sizes are to be maintained. Where possible, the maintenance of family structure in production stands is useful to allow balanced sampling.

Key resources

- Dawson I, Were J (1998) Multiplication, that's the name of the game. Guidelines for seed production of agroforestry trees. Agroforestry Today, 10, 19-22.
- Kindt R, Lillesø JPB, Mbora A, Muriuki J, Wambugu C, Frost W, Beniest J, Aithal A, Awimbo J, Rao S, Holding-Anyonge C (2006) Tree seeds for farmers: a toolkit and reference source. The World Agroforestry Centre, Nairobi, Kenya.

Seed production and tree domestication

The demand for tree seed of species and provenances particularly suited for specific agroforestry practices can be very high, often outstripping the supply available by collection from natural stands and by procurement from formal dealers or other sources (Units 9 and 10). When this happens, farmers plant whatever seed is available, even if it is of inferior quality, is not very productive and is not well adapted to the planting site (see Box 1 for case studies), or they do not plant trees at all. Once inferior material has been planted in farmland it is often difficult to replace it with better sources.

Proactive seed production of good quality sources is often therefore an essential step in successful tree domestication. This involves anticipating the future demand for seed and establishing at an early stage multiplication stands of genetically superior material. Then, when the demand for seed arises, good quality germplasm is available immediately, facilitating adoption and maximising impact in current and future generations of tree planting.

Sometimes, it may not be clear at the start of a project which is the best source of germplasm that should be multiplied, because provenance and progeny evaluation is still ongoing. In this situation, proactive multiplication of a number of provenances may be worthwhile, even if only one of these will subsequently be distribution to farmers. This is because the benefits of early availability of high performance material can outweigh the extra costs associated with the 'wasted' multiplication of a wider range of possible sources.

Guidelines for seed production

The steps to take when establishing and managing a tree seed production stand are given in Box 2. Key concerns are to choose a site suitable for production and to consider likely seed yield and the magnitude of probable demand, to determine the extent of the area to be planted. Contamination by pollen from other stands of the same species may be a problem in maintaining genetic quality, as the pollen dispersal distance of some trees can be high (see examples of dispersal distances in Table 1). Contamination is likely to be a greater concern if other stands of a species are large and/or very close; 100 m is normally considered the minimum separation distance.

Sometimes, provenance trials are later used as seed production stands. If this is done, the seed obtained will be contaminated through inter-provenance mating within the trial, unless all except one provenance in the trial are prevented from flowering. This means either removing or cutting back (to prevent flowering) all trees in the trial except for the one provenance that is required for seed production. The cutting back of trees rather than their removal can be a good option if seed from a different provenance might be needed at another time (one can later allow only that provenance to flower and seed). However, continued cutting back is labour intensive and prevents land from being 'freed up' for other purposes.

Box 1

Limited tree seed supply results in suboptimal planting: the cases of three leguminous species

Calliandra *Calliandra calothyrsus*, originally from Central America, has been promoted in East Africa over the last two decades for use as a fodder shrub to support dairy production (see Unit 5). International provenance trials have revealed genetic variation in the quality and quantity of fodder produced, with particular natural stands found to have superior qualities. Natural populations are however generally small in size and calliandra is often a shy seeder, meaning that the quantity of seed that can be collected from wild stands is limited. The lack of availability of superior germplasm has meant that most of the more than 200,000 farmers in East Africa that have planted calliandra trees have used seed which is believed to be suboptimal in performance. Most seed appears to have been sourced from introductions made into the region over the last century for the purpose of fuelwood production. This was before provenance trials had been undertaken to define superior material, before the importance of wide sampling to capture genetic diversity and prevent inbreeding was recognised, and prior to the widespread use of calliandra as a fodder.

Gliricidia *Gliricidia sepium*, from central America, is planted throughout the tropics for fodder, firewood and green manure, among other uses. It has been widely collected and tested in provenance and progeny trials. One particular provenance, Retalhuleu from Guatemala, has consistently performed significantly better than the others across a range of environments. Its superiority has been widely advertised, resulting in a demand for seed of several tonnes yearly for this one provenance. However, the small natural stand of gliricidia found at Retalhuleu has yielded only limited seed and its location on a riverbank is also under threat due to erosion. Many farmers across the tropics have had to use inferior seed collected from poorly performing gliricidia landraces of undocumented origin that over the centuries were established by Spanish colonists and others outside the native range. For example, landraces from South East Asia appear to have been the first to be introduced into Africa.

Sesbania *Sesbania sesban*, a species with a wide natural distribution across Africa, has been promoted in the sub-Sahara for enhancing soil fertility through improved fallow technology. Molecular marker studies (Unit 8) have shown that the genetic composition of germplasm from East and southern Africa is very different. This has raised concerns about the effects of transferring seed across countries within the subcontinent on performance and conservation status, due to mixing/ hybridisation and possible outbreeding depression, and lack of local adaptation. Nevertheless, the expansion of the improved fallow technology to thousands of farmers in the 1990s in Zambia relied heavily on sesbania seed imported from a single stand in Kenya (Kakamega). This was because there was insufficient seed available in southern Africa of local, well-performing stands.

In each of the above cases, the deficiency of seed was eventually recognised, which led to the establishment of multiplication stands of important provenances. This development came too late, however, to prevent the widespread distribution to farmers of suboptimal germplasm.

Box 2

Steps to take in establishing and managing a tree seed production stand

Obtaining the seed needed for establishment

- Find out the species and provenance (if known) that is best suited to fulfil the function for which tree planting is required. Look at local species and provenance trials; ask for recommendations from seed suppliers, national forestry and agriculture services; contact organisations involved in trials in other countries.
- Look at the current sources of seed supply to establish whether or not there is a need for multiplication stands to meet demand. For tree planting activities that have reached the adoption phase, it is likely that specific production stands will be necessary.
- Obtain founder seed for stand establishment from a well-reputed supplier, even if it costs more than from elsewhere (see Unit 10). If collecting rather than procuring seed, follow standard sampling guidelines (Unit 9). A seed production stand should ideally be established from seed from at least 30 mother trees, to maintain adaptive capacity and prevent inbreeding depression in future plantings. When family structure is available, maintain family identities in the field layout of the seed production stand.

Choosing a planting site

- Choose a site with suitable ecological conditions for seeding. Factors such as temperature (influenced by altitude), fluctuations in day length, annual rainfall, length(s) of dry season(s), soil fertility and pollinator availability, all determine whether a species will flower and fruit well at a particular site. Generally, fertile well-drained soils, an abundance of appropriate pollinators and dry conditions after flowering all help seeding. Also, most species will seed under ecological conditions similar to their native environments, as they have evolved to regenerate under such conditions.
- Arrangements should be made so that it is easy to gain access to the site, while potential labour supply, the ability to irrigate, protection from livestock browsing, informal harvesting, and possible pest and disease problems should also all be considered.

Stand design and management

- *Tree spacing and tree management.* Trees need to be widely spaced so that light can penetrate crowns to stimulate flowering, pollination and seed ripening. Wide spacing also allows easy access for seed collection. Actual spacing will depend on the biology of the species (e.g., tree form, age before flowering and fruiting, pollination mechanism). Trees may be planted at high density to maximise early seeding and then thinned as the stand develops. Thinning can be systematic (e.g., remove every second tree) or selective, retaining trees that are of superior quality for desired traits, such as growth, tree form, fodder quality and fruit characteristics. Trees with poor flowering and low seed yields may also be removed during selective thinning. Selective thinning may result in higher performing germplasm (depending on heritability, see Unit 7 on provenance and progeny trials). It may however also have negative consequences for the genetic base of the material collected (see *L. trichandra* case study in the current unit). For some

Box 2 continued

species, coppicing can increase crown density, leading to more flowering and fruiting branches. Coppicing also limits tree height, which can make collection easier. To increase flower and seed production, the application of a multi-nutrient fertiliser prior to the flowering season may be effective.

- *Pollinator management.* If it appears that there are problems with pollination at a site, it may be possible to introduce the relevant animal vectors, e.g., through bee keeping activities.
- *Number of trees.* Annual seed yield per tree can be roughly estimated for most species. This will give a figure for the number of trees that need to be planted to fulfil the predicted demand for seed. To ensure a wide genetic base, a 'formal' seed production stand should consist of at least 100 trees, though normally many more individuals will anyway be required to meet the predicted demand for seed.
- *Isolation distance.* To ensure genetic purity, a multiplication stand should be isolated from any other stands it might cross with. 100 metres is a minimum separation distance, but depending on the species it may need to be greater, especially if pollination is possible over long distances (see Table 1).

Harvesting seed

- *Seed maturity.* Seed should be collected when mature, as immature seed has low viability and storage life. For most species, seed is mature when it can no longer be crushed between thumb and forefinger. Seed can be cut to check on the presence of a mature embryo and endosperm.
- *Seed harvesting method.* Seed can be harvested directly from trees by picking fruit, or for some species it can be collected when fallen from underneath trees. Direct harvest is generally better for seed quality because pest and disease attack is less likely, but it may be more expensive to undertake.
- *Seed harvesting interval.* Individual trees produce mature seed at different times and, within trees, seed maturation varies through the crown. Mature seed should be collected more frequently if a species sheds seed easily. The aim of harvesting is not necessarily to collect all seed, but to collect a reasonable proportion in a cost-efficient manner, while ensuring quality standards are met.
- *Seed harvesting conditions*. Collect during dry weather as seed is then less susceptible to pest and disease attack during the time between collection and processing.
- *Ensure that seed of high genetic quality is harvested.* Unless there are specific reasons to carry out selection, collected seed should as nearly as possible represent the constitution of the material used to establish the stand initially. To do so, collect approximately the same quantity of seed from individual trees and sample throughout the crown. In practice, the quantity of seed produced by, or the ease of harvesting from, individual trees may vary greatly and this causes biases that influence effective population size. In large stands, biases are less of a concern because of the high overall number of trees sampled. One way to control bias is to maintain family identity in stands (see the *L. trichandra* case study).

Guidelines adapted from Dawson and Were (1998). For practical information on how to process and store seed after it has been collected from multiplication stands, see Kindt *et al.* (2006). For information on the ecological conditions suitable for the establishment of production stands of particular species, see the Agroforestree Database, available at: www.worldagroforestrycentre.org/resources/databases/agroforestree

Table 1 Pollen dispersal distances of some Latin American trees, showing the large distances that can be involved. These determine the isolation requirements for tree seed production stands

Tree species	Pollinator	Gene flow observed
Calophyllum longifolium	Variety of small insects	62% of pollen moved more than 210 m
Ceiba pentandra	Bats	Several matings over 5 km, longest dispersal 18.6 km
Dinizia excelsa	Small insects, stingless bees, *Apis mellifera* in disturbed habitats	Mean pollen dispersal 212 m in undisturbed forest, 1,509 m in forest fragments with *Apis* pollination
Gliricidia sepium	Large bees	6.1% of pollen moved more than 75 m, longest dispersal 275 m
Spondias mombin	Variety of small insects	~ 6% of pollen movement over 300 m
Swietenia humilis	Bees, moths, thrips	Pollen dispersal up to 4,500 m between forest fragments

Taken from Ward *et al.* (2005); estimates obtained by molecular marker studies.

Research on seed production: a case study in the genus *Leucaena*

Research on tree seed production has involved exploring the effects of thinning, both systematic and selective, and the impacts of coppicing and other practices. One important concern is to understand tree-to-tree or family-to-family (family = seed collected originally from a single mother tree, see also Unit 7) variation in seed production. Although such effects have not been explored widely in agroforestry trees, the genus *Leucaena* is an exception (see Box 3). More such research is required because of the important consequences for the genetic diversity and future performance of seed collected from production stands. In addition, more research is needed on the reproductive biology of agroforestry trees, since knowledge in this area is a basic requirement for devising effective seed production strategies.

Seed production on farms

Rather than planting special seed production stands, most farmers collect seed from trees they have planted for other reasons. This ‘informal’ method of seed sourcing is discussed in Unit 14. Some simple tips to share with farmers to ensure the harvest of better quality seed from such trees include:

- Do not make seed collections from one or two isolated seed-bearing trees that have no seed-producing neighbours of the same species, as they will likely produce highly inbred seed that perform poorly.
- Harvest equal amounts of seed from a number of trees, not just a large amount of seed from the tree with the most seed.
- Exchange seed with neighbouring farmers to help keep a wide genetic base in planting material.
- Only harvest seed when it is mature, as this seed has the best viability and storage life.
- Harvest seed by hand-picking directly from trees and not from the ground, to minimise pest and disease attack.
- Dry seed as soon as it is collected and store it in dry, shaded conditions to maintain the highest viability.
- If trees are normally coppiced, or managed in other ways that prevent seed production (as, e.g., occurs with trees whose branches are lopped for animal fodder), allow instead a few trees to grow normally and produce seed.

Box 3

Research on seed production: a family-based trial of *Leucaena trichandra*

Method *Leucaena trichandra* is a leguminous tree used for fodder, soil fertility improvement and firewood that is native to Central America but is grown throughout the tropics. Researchers planted a family-based (progeny) seed production trial of the Los Guates provenance of the species at two sites in Kenya with different altitude, rainfall and temperature profiles. The purposes of the trial were to evaluate variation in seed production in relation to maternal origin, tree growth and under different ecological conditions.

Twenty families were established at each of the two sites, with either 10 or 20 replicates of each family as 4-tree line plots (so each family was represented by 40 or 80 trees, depending on the site). The trial was assessed at regular intervals for growth and seed production on an individual tree basis. For seed production, this involved collecting seed every two weeks from each tree during the pod ripening and seed shedding season. Averages for growth and seed production were then calculated on a family-by-family basis.

Results Considerable variation in seed yield was observed across families (Fig. 1a). A correspondence in the family variation in seed yield was observed across the two planting sites – high yielding families at one site tended also to yield well at the other (see also Fig. 1b). Overall levels of seed production varied by site, with production at the lower altitude, drier, warmer site about twice that at the other location. The growth performance of trees also varied across families and sites (data not shown), although in both cases the variation observed was less than that seen for seed production. There was no obvious correlation between family averages for seed yield and tree height (Figs. 1c and d).

Interpretation A number of important practical conclusions can be drawn from these results. The high variation observed among families in seed production (Fig. 1a), and the correspondence in seed yield by family that was observed across sites (Fig. 1b), suggest strong genetic control. Data therefore indicate that when bulking seed from production stands, there may be a significant bias to individuals with genetic traits associated with high seed yield, which will reduce the effective population size (N_e) of the seed collection.

This may have significant implications for the future performance of seed after it has been distributed for planting and as it passes through future regenerations on farms, due to effects such as inbreeding depression. To counter likely negative impacts, maintaining family structure in seed production stands and sampling approximately equal amounts of seed from each family would help to maintain genetic diversity. This would, of course, mean that some seed from the highest producing trees would be ‘wasted’, as it cannot be used in the collection.

On the other hand, suggestions by some researchers that high seed producing trees may be those that grow poorly (as energy is expended on seed production rather than growth) appear to be unfounded for *L. trichandra* (Figs.1 c and d) in this trial. Thus, in this instance, the collection of seed from the highest producing trees from each family in a structured stand should not reduce overall tree performance, if the seed from each family is then combined to ensure N_e.

Box 3 continued

Finally, the difference in performance between sites observed for *L. trichandra* indicates the value of proper site selection when establishing seed stands. Seed production was greater at the site that is more matched environmentally to the location from which seed was originally collected in Latin America. The same effect has been observed for other members of the *Leucaena* genus, as well as in many other tree species. Site matching is therefore essential for good seed production.

Taken from Were *et al.* (1998).

Figure 1 Results of a family-based seed production trial of *L. trichandra*. The trial was established at two sites in Kenya (see Box 3). Data based on 20 families are shown (average values by family given). Seed data are totals 24 months after planting, height data are 17months after planting.

Additional reading

Ward M, Dick CW Lowe AJ (2005) To self, or not to self… A review of outcrossing and pollen-mediated gene flow in neotropical trees. Heredity, 95, 246–254.

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Unit 12 – Vegetative propagation techniques

Zac Tchoundjeu, Ebenezar Asaah, Jules Bayala, Antoine Kalinganire and Simon Mng'omba

Unit objectives

After studying this unit, readers will be able to:

- List and explain the reasons to multiply plants vegetatively.
- Describe common vegetative propagation techniques for agroforestry trees.
- Present the case for research to compare different vegetative propagation techniques for agroforestry trees.

Summary

The most commonly used vegetative propagation techniques are rooting leafy stem cuttings, different types of grafting and budding, and air-layering (or marcotting). Micropropagation in a laboratory is also a possibility, but requires special facilities and cannot be carried out by farmers themselves in the field.

When domesticating a new agroforestry tree species, it is important to compare different vegetative propagation techniques, in order to determine which one is the most appropriate for a specific situation and tree service or product. The unit gives several examples of the vegetative propagation of agroforestry tree species.

Key resources

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Vegetative propagation and tree domestication

Vegetative propagation, the multiplication of plants through clonal means, is an approach widely adopted in agroforestry for the propagation of certain tree species. As already mentioned in Unit 9, it can be applied during the initial collection of tree germplasm from the wild. It can then also be used during the subsequent multiplication of trees in the nursery. The practice is not new but has a history that dates back millennia; for example, the Romans propagated olives and grapes this way 2,000 years ago.

As already noted in Unit 9 (see especially Table 2) in the context of germplasm collection, vegetative propagation has particular advantages and disadvantages in comparison to seed-based propagation of trees. To summarise again here briefly, advantages include the ability to multiply genetically identical individuals with particularly favourable combinations of traits, the avoidance of problems related to recalcitrant seed handling, the ability to propagate individuals of known sex for dioecious trees, and the ability to reduce the time between planting and fruiting (see Box 1 for examples of this last point). Vegetative propagation can also be used to control the architecture of trees so that they are easier to grow and harvest. At the same time, vegetative propagation methods often require more specialised knowledge and more resources and extra time to undertake, when compared with seed-based propagation methods. In addition, there are dangers that the genetic base of material under cultivation will become too narrow, unless deliberate action is taken to maintain a diverse set of clones for farmers to plant.

Whether or not clonal propagation is appropriate therefore depends on balancing a number of considerations. It is widely used for high value fruit trees, occasionally for timber and medicinal trees (Tchoundjeu *et al.* 2002), but rarely for 'lower value' species. As noted later in this primer (Unit 15), the development of simple vegetative propagation techniques that can be used by local people to capture variation from the wild, and then multiply it for planting in their fields, is an important part of the participatory domestication method.

Vegetative propagation techniques

The most common approaches promoted for vegetative propagation have been the rooting of leafy stem cuttings, grafting and air layering. In addition, micropropagation protocols have been devised for a few agroforestry tree species. Each of the four above clonal propagation methods is discussed here (see Jaenicke and Beniest 2002 for further information on these and other methods).

Rooting stem cuttings

Propagation by cuttings is a relatively easy method and can efficiently provide a large number of rooted propagules in a relatively short time (3 to 4 weeks after cuttings are set under a simple, non-mist propagator). Single or multi-node leafy stem cuttings are usually placed into a suitable rooting substrate and kept under high humidity in propagators until roots and shoots are formed. The rooting of cuttings depends on whether material is juvenile or mature. In the former case, rooting ability is high, in the latter case low. Rooting is also influenced by factors such as cutting volume, rooting substrate, humidity, plant hormones, leaf area, light, temperature and plant hygiene.

Rooting juvenile stem cuttings in non-mist propagators is an approach developed successfully for a range of important timber species (such as *Khaya ivorensis*, *Lovoa trichilioides*, *Triplochiton scleroxylon* and *Terminalia superba*). The success rates range from 60 to 90%, depending on the species and the skill of the practitioners. For fruit trees such as bush mango, njansang, safou and *Allanblackia*, good results have also been achieved. For further information on the rooting of cuttings of tropical trees, see Longman (1993).

Grafting

Grafting is the science (and art!) of joining parts of two plants together in such a manner that they will successfully unite and continue to grow as one plant. The upper section of the plant is called the scion and the lower part the rootstock. The scion will frequently have superior production characteristics, while the rootstock may be a genotype with a stronger rooting ability. Grafting is frequently used to multiply mature plant material that is difficult to root from cuttings. For successful grafting, the following are important requirements:

- The stock and scion should be compatible, i.e., they must be capable of uniting. Usually, but not always (cross-species grafting can be successful for some species), the more closely plants are related, the more likely they are to be compatible.
- The grafting operation must be done at a time when the rootstock and the scion are both in an appropriate physiological state. It is often desirable for the rootstock to be actively growing, and for the scion to be in a dormant condition.
- At least some of the cambial region of the scion must be in contact with that of the rootstock, through the cut surfaces being held tightly together. Rapid healing of the graft is necessary so that the scion may be supplied with water and nutrients from the rootstock. Immediately after the grafting operation is completed, cut surfaces must be carefully protected from desiccation.
- Plants should be carefully managed for a period of time after grafting. Generally, shoots coming from the rootstock (below the graft) should be cut back, as they will otherwise compete for resources with the scion.

As well as being widely used for exotic fruits, suitable grafting protocols have been developed for a range of economically important indigenous fruit trees such as *Allanblackia*, marula (*Sclerocarya birrea*), safou, sheanut and wild loquat. Examples of protocols for sheanut, to demonstrate the types of procedures that are involved in grafting, are given in Box 2.

Air layering (marcotting)

Layering involves the development of roots on a stem while it is still attached to the mother plant. Once roots have formed, the marcot is detached and planted independently. Common layering techniques include air layering – root induction on a shoot in the aerial portion of the tree – as well as simple layering, and stooling, of which we discuss only the first here because it plays the most important role in tropical fruit tree propagation.

Box 1

Reducing the time between planting and production through the vegetative propagation of fruit trees

The time taken between planting and fruiting is a key factor determining the profitability of fruit tree planting and farmers' interest in it. Vegetative propagation techniques can result in accelerated fruit production compared to tree establishment from seed, as illustrated by the examples in the table below, all of which are priority fruit trees for cultivation.

Data on possible reductions in time to first fruiting through vegetative propagation
Information on seven important species is given

Species	Planting to first fruiting, from seed	Planting to first fruiting, vegetative propagation
Allanblackia	12 years	5 years
Baobab (*Adansonia digitata*)	> 10 years	4 years
Ber (*Ziziphus mauritiana*)	2 years	6 months
Bush mango (*Irvingia gabonensis* and *I. wombolu*)	7 years	3 years
Safou (*Dacryodes edulis*)	5 years	2 years
Sheanut (*Vitellaria paradoxa*)	20 years	< 5 years
Wild loquat (*Uapaca kirkiana*)	12 years	4 years

The level of acceleration in fruiting of vegetative propagules depends on the level of ontogenetic maturity of the material being propagated. This is determined by the origin of the scion or cutting from within the tree/stockplant. The crown is ontogenetically most mature, such that cuttings or scions taken from crown shoots develop flowers and fruits more quickly than cuttings taken from shoots from lower branches or basal coppice. Cuttings taken from the crown may, however, not root well; taking scions from the crown for grafting purposes can be a more successful approach.

Adapted from Jamnadass *et al.* (2011).

In the air layering technique, a ring of bark of about 1 to 5 cm is stripped from a section of stem or a lateral branch of the mother plant by making two encircling cuts and removing the intermediate ring. It is important that a large enough ring is removed to prevent callus from closing the wound. Cutting into the wood should be avoided as it may interrupt the water supply and also increases the risk of breakage of the shoot. The wound is then covered with moisture-retaining material such as moist sawdust, moss or coconut fibre, which is secured in place with plastic wrap and eventually covered with aluminium foil, to preserve moisture and prevent overheating. Soil from under established trees can be added to rooting substrate to help in the rooting process, especially for species that require microsymbionts. Root promoting substances, such as auxins, may also be added. Wrapping can be removed periodically to check for root development and to moisten the rooting substrate. When sufficient rooting has been obtained, the marcot can be cut from the tree and transplanted into the nursery.

Air layering is often used on species that are particularly difficult to root by other means, but is not generally appropriate for mass propagation because of the low multiplication rate. The technique can be particularly useful for the initial collection of elite genotypes, which are established in the nursery and then propagated by other vegetative methods. This approach has for example been used with the important African fruits bush mango and safou.

Micropropagation

The ability to establish tissue cultures of forest trees dates back to the 1930s. In recent years, tissue culture techniques have been used to produce large quantities of propagules of horticultural crops such as bananas, pineapples, citrus and several ornamental plants, as well as plantation trees such as eucalyptus, rubber and oil palm. Common techniques used include organogenesis (callus culture), embryogenesis (the production of somatic embryos), micrografting, and meristem proliferation.

Generally, micropropagation methods require a substantial investment in infrastructure, equipment, materials and training. The capital investment to set up a laboratory may be anywhere between 15,000 and 250,000 US Dollars, depending on particular requirements. Plant material must be kept in sterile conditions and be provided with the necessary macro- and micro-nutrients (energy, vitamins, amino acids, etc.) and plant regulators. Application is therefore often not appropriate in a low-income nation setting. In addition, the centralised production of propagules, which does not involve farmers directly, means that it may be difficult for smallholders to obtain micropropagated germplasm. Careful thought needs to be given to delivery mechanisms (see Unit 14); otherwise, smallholders may be excluded from access when compared with plantation owners and large-scale growers.

Particular reasons to micropropagate include when there is a lack of success of other vegetative methods and when there is a need to eliminate viruses and other diseases from material, to distribute pathogen-free germplasm to growers. In addition, micropropagation provides the ability to 'rejuvenate' older trees (e.g., through repeated micrografting) and to avoid maturation of valuable clones that would occur through serial cutting propagation. For example, rejuvenation by repeated recapture into tissue culture has been important for acacia and eucalypt hybrid clones; some are still in use without loss of vigour 20 years after initial selection. The large numbers of clonal hedges required are established from weaned, tissue-cultured plants and not by serial cutting propagation. Micropropagation also allows for a very high multiplication rate.

Safou is one locally important fruit tree for which callus and adventitious root formation from seed cotyledons has been observed, although results have never been applied so far to actually supply planting material for use outside the laboratory. The same applies for micropropagation methods developed for wild loquat.

Box 2

Grafting protocols for the sheanut tree

The sheanut tree (*Vitellaria paradoxa*) is a key species for communities in the traditional agroforestry parkland systems of sub-Saharan Africa, which extend from Senegal in the west to Ethiopia and Uganda in the east of the subcontinent. The tree yields a variety of useful products but is primarily important for the fat extracted from the nuts, which is used in the food and cosmetic industry worldwide, as well as locally.

Although sheanut is a major commodity, the species is not yet widely cultivated. To domesticate it, the development of vegetative propagation methods that multiply superior genotypes and yield fruit more quickly than trees that are raised from seed (which is recalcitrant and therefore difficult to handle) is a major concern. The main clonal methods developed for the propagation of sheanut involve grafting. Success has been achieved with side cleft, whip and tongue and top cleft methods, and with bark grafting. The methods for whip and tongue and bark grafting are described below.

Collecting scions (both grafting methods)

- Trees to collect scions from are selected with farmers based on the appearance of the fruit and the absence of disease.
- Scions are collected from trees after they have recently flushed. Scions that are 5-10 cm in length are cut from green shoots from the crowns of selected trees early in the morning or late in the afternoon, to minimise physiological stress.
- Scions are placed in black polythene bags containing wet saw-dust and transported to the location where grafting will take place. Grafting onto rootstocks should take place as soon as possible, certainly within 24 hours.

Whip and tongue grafting

- Choose rootstocks and scions that when cut for grafting will have an equal diameter, so that the cambial tissues of both are juxtaposed. The diameter of scion and rootstock should preferably not be more than 1.5 cm.
- Prepare the rootstock and scion by cutting both diagonally with a single draw of the knife, so that both have smooth surfaces. The cut should be four to five times longer than the diameter of the rootstock/scion.
- Place the blade of the knife across the cut end of the rootstock, halfway between the bark and pith. Use a single knife stroke to draw the blade down at an angle through the wood and pith. Stop at the base of the initial diagonal cut. This second cut must not follow the grain of the wood but should run parallel to the first cut.
- Prepare the scion in the same way and fit it into the rootstock so that they interlock whip and tongue. Be certain that the cambia are aligned.
- Secure the graft by wrapping the junction with grafting tape or twine, and seal it with grafting wax or grafting paint.

Box 2 continued

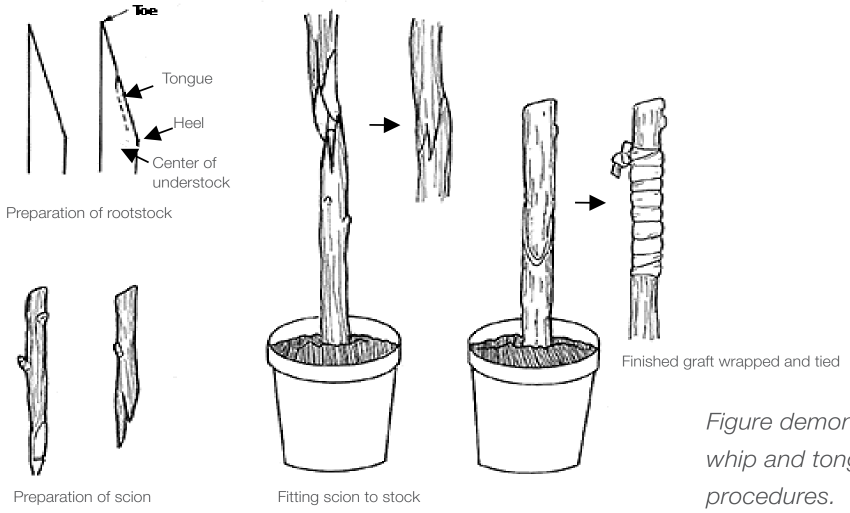

Figure demonstrating whip and tongue grafting procedures.

Bark grafting

This technique is normally carried out during the hot dry season in the Sahel, when the bark slips easily from the wood of trees but before major sap flow. In this case, the rootstock is a mature tree in the field that is being 'rejuvenated' and/or genetically improved by grafting:

- Fell the tree with a sharp saw that leaves a clean cut across the trunk.
- Make two vertical slits through the bark of the trunk around 2.5 cm apart and 5 cm long, allowing a flap of bark to be pulled back for the insertion of a scion. By making similar cuts spaced every 7 to 10 cm around the trunk of the rootstock, the insertion of multiple scions is possible.
- Prepare scions by cutting the base of each to a 4 to 5 cm tapered wedge on one side only.
- Insert scions by loosening the bark slightly, such that the wedge-shaped tapered surface of the scion is against the exposed wood under the flap of bark. Push the scion firmly into position, replace the bark flap, and nail the scion in place.
- Secure the graft by sealing all exposed surfaces with grafting wax. Once the scions have begun to grow, prune away all except the most vigorous one.
- Bark grafting tends to form weak unions and trees usually require staking or other support during the first few years.

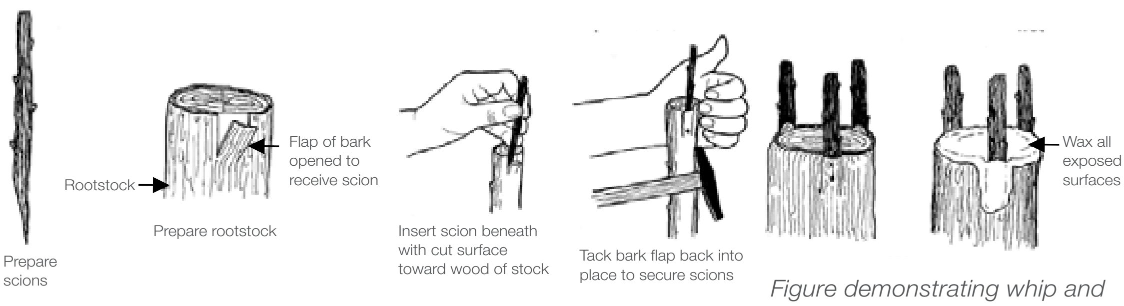

Figure demonstrating whip and tongue grafting procedures.

Taken from Samaké *et al.* (2010) and Sanou *et al.* (2004).

Table 1 Relative growth parameters (mean values) for wild loquat (*Uapaca kirkiana*) derived from grafts, marcots and saplings eight years after planting at ICRAF-Makoka field station. Taken from Akinnifesi *et al.* (2009)

Growth parameter	Marcots	Grafts	Trees from seed	Probability
Tree height (m)	3.8 ± 0.14	3.5 ± 0.17	3.6 ± 0.27	NS
Bole height (m)	0.41 ± 0.06	0.32 ± 0.04	0.61 ± 0.09	NS
Root collar diameter (cm)	12.7 ± 0.5	11.4 ± 0.6	11.3 ± 1.1	NS
Crown depth (m)	3.3 ± 0.13	3.2 ± 0.15	2.9 ± 0.31	NS
Crown spread (m)	3.8 ± 0.23	3.1 ± 0.18	2.8 ± 0.35	NS
Primary branches	19.4 ± 1.5	22.8 ± 1.2	15.3 ± 1.7	$P < 0.05$
Secondary branches	42.0 ± 4.6	30.3 ± 2.5	19.6 ± 4.2	$P < 0.05$
Tertiary branches	36.4 ± 4.1	20.3 ± 2.6	8.1 ± 2.7	$P < 0.05$
Fruit weight (g)	13.0 ± 0.35	12.2 ± 0.28	0	NS (marcots v grafts)

NS = The given means are not significantly different from each other.

Comparing propagation methods

There are only a few examples where different propagation methods for agroforestry trees have been formally compared. In the case of wild loquat, however, the relative growth parameters of trees derived from grafts, marcots and seed were compared eight years after planting at a field station in Malawi. The main difference observed was in the branching pattern of trees, which may at a later date influence yield. Saplings had not fruited in the time period, while both grafts and marcots had (Table 1). In another example, Asaah *et al.* (2010) compared the root morphology of five year old trees of safou of seed and vegetative (cuttings and marcots) origins in Cameroon. Trees of seed origin had a tap root system, whereas trees of vegetative origin had developed prominent adventitious roots. Different root structures may have implications for the later performance of trees.

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Module 5

Germplasm delivery to farmers

Unit 13 – Tree nursery practices

Jonathan Muriuki, James M Roshetko and Isaac Nyoka

Unit objectives

After studying this unit, readers will be able to:

- Explain the importance of tree nurseries in the context of the agroforestry tree domestication process.
- List and describe three types of community nursery.
- Describe the characteristics of quality tree planting material.
- List and describe good nursery practices that need to be implemented, to provide good quality planting material.

Summary

Delivering high quality planting material to farmers through good nursery management practices and networks of nurseries is an essential part of the tree domestication process. In agroforestry, tree nurseries are often of a communal type and can be project-managed community nurseries, farmer-managed group nurseries or small-scale commercial nurseries. This unit describes their characteristics and lists some commonly experienced community nursery constraints.

The physiological qualities of planting material are important. Nursery plants must have a well-developed root system, hardened foliage, the right shoot-to-root ratio, good carbohydrate reserves, and be pest and disease free. Where required, nursery plants should also be provided with the right symbionts for further growth and development. This unit describes good nursery practices as they relate to seed germination, seedling handling, the use of containers and substrates, phytosanitary problems, and the proper planning of nursery activities for timely delivery of planting material to farmers.

Key resources

- Jaenicke H (1999) Good tree nursery practices: research nurseries. The World Agroforestry Centre, Nairobi, Kenya.
- Wightman KE (1999) Good tree nursery practices: practical guidelines for community nurseries. The World Agroforestry Centre, Nairobi, Kenya.

Tree nursery practices and domestication

Adopting good nursery management practices and the development of tree nursery networks are essential steps in producing high quality planting material and thus are key components of the tree domestication process. Many of the species that are emerging from tree domestication programmes have not been widely planted before, and sharing information on how to raise these trees in nurseries is particularly important.

Farmers may obtain planting material from different types of nurseries, although generally the most important are those that operate at a local level within communities (as described in Box 1). Information vital to tree domestication strategies can be obtained through interaction with community nursery operators. The diversity of trees in these nurseries gives an indication of the demand for particular species, which is an important factor in determining which trees to focus promotion efforts on. The problems faced by nursery operators in growing plants indicate domestication bottlenecks that should be the focus of biological research. Nurseries also provide a forum for discussion on, and the dissemination of, new species and technological options.

The importance of physiological and genetic quality in nursery planting material

Regardless of the type of nursery involved, attention to quality is of paramount importance in determining the success of tree planting initiatives. A farmer's primary concern is to be able to plant healthy material (of high physiological quality), so that trees will establish successfully and thrive on their land. On the other hand, poor quality trees waste space and resources, grow slowly, and lead to low productivity, reducing the farmer's returns. Quality planting material leaving the nursery is defined by having:

- A well developed root system that is able to anchor in the ground and start assimilating nutrients and water quickly after planting out. Root deformities are the hidden curse in seedling production; sometimes, problems become more acute as the tree grows, as roots that became coiled in the nursery grow until they eventually strangle each other and the tree.
- Sun-adapted foliage. This is obtained by gradually reducing the shade over plants in the nursery.
- The right balance in the shoot to root ratio. This depends on the conditions where a tree will be planted: material for dry sites may need deep roots, while for humid sites with strong weed competition, more above-ground growth may be required.
- Good carbohydrate reserves to provide a buffer during new root development and adaptation to new conditions.
- The right associations with any symbionts, such as nitrogen-fixing bacteria for leguminous trees, which are required for proper growth.

Genetic variation in traits such as yield, seasonality and other production characteristics is important in addition to the physiological state of planting material, though these qualities will in general not be evident to farmers from the appearance of seedlings in nurseries. For example, it is impossible to assess the quality of the fruit a tree will produce until it has matured in the field (unless one knows it is a recognised, tested cultivar). Genetic quality also determines whether a plant is ecologically well adapted to its chosen planting site, which may not be evident in a nursery where watering, shading, soil/substrate, etc. conditions are different from the field. Genetic quality may also relate to the genetic diversity present in the planting material used in nurseries; diversity in planting stock may be low if nursery managers collect their own seed. For example, Lengkeek *et al.* (2005) found that nurseries in Kenya, Tanzania and Uganda collected seed from on average only six mother trees to establish nursery lots. This is too few.

Although aspects of genetic quality are difficult for farmers to evaluate at the nursery level, labelling in the nursery to identify the cultivar/provenance/other source is a useful approach for providing guidance. Performance can then be related to that of mature trees of the same source under growing conditions similar to those on smallholders' farms. How to source good quality seed for nursery planting was outlined in Unit 10, while further information on what constitutes quality seed is provided by Kindt *et al.* (2006).

Addressing community nursery constraints

Common problems mentioned by nursery operators in producing plants, especially for farmer-managed group nurseries and small-scale commercial nurseries, include the following:

- Lack of a reliable water supply.
- Poor quality or lack of nursery equipment.
- Lack of access to germplasm, meaning that the range of species available in nurseries is limited
- Poor physiological and genetic quality of available germplasm sources.
- Lack of technical knowhow on plant production.
- Lack of a market for nursery plants.

Box 1

Different types of community nurseries

Project-managed community nurseries These are established and managed at the community level by research, development, governmental and/or non-governmental organisations for specific tree planting projects. They have specialist staff employed to run them, may have large capacity of hundreds of thousands of plants per year, and have the resources to invest in nursery equipment and infrastructure. They provide training for local nursery operators and may have an important role to play in the introduction of new tree species, especially those that are difficult to propagate. They provide a means of measuring the level of progress in a tree planting project. Although at times farmers may be charged a (generally nominal) fee for planting material (so that the value of germplasm is appreciated), these nurseries are rarely commercially self-sustaining. Most depend on external support and last only for the length of a particular project, perhaps three to five years.

Farmer-managed group nurseries Farmers form groups to share information and resources in order to meet the various challenges they face. Development projects encourage the formation of group nurseries in order to build the technical and leadership capacity of farmer members, as well as to make planting material available, perhaps of thousands of plants per year. The success of group nurseries depends on good relationships between the members. However, disbanding of groups should not necessarily be seen as failure but rather can indicate success: once farmers have built their capacity in groups, they may then choose to operate alone. Group nurseries can be a good venue for raising seedlings that will be used for establishing on-farm trials (See Unit 6), since there is continuity: the same farmers that produce nursery plants are then involved in managing and evaluating field experiments. Group nurseries sometimes have an income generating objective, based on selling surplus planting material that goes beyond group farmers' immediate needs (in which case there is an 'overlap' with the small-scale commercial nurseries described below).

Small-scale commercial nurseries These are established and managed as enterprises for selling planting material to growers that can afford to purchase trees. They vary greatly in size and production capacity, often have higher species diversity than group nurseries, and are more likely to apply technological improvements during propagation (such as clonal, vegetative methods) in an appropriate and cost-effective manner. The quality of the planting material they produce is generally higher than group nurseries and their distribution networks spread further. These nurseries may rely more on purchasing seed and scions for the establishment of stock than group nurseries do, which rely more on self collection of germplasm. Individual operators of small-scale commercial nurseries frequently have had experience as employees of development projects or were previously members of group nurseries.

Adapted from Roshetko *et al.* (2010).

Some constraints can be addressed through training in good nursery practices (e.g., see below; also see Jaenicke [1999] and Wightman [1999] for further information), while others require the development of an improved infrastructure to provide the necessary inputs. The constraint of germplasm supply is a common one for all farmers' tree planting activities, and is discussed in Unit 14 of this primer. Projects can supply 'starter kits' of seed of newly introduced species and/or of improved cultivars to nurseries, but care needs to be taken that this does not discourage the development of nascent small-scale commercial tree seed dealers that could ultimately provide germplasm to nurseries more sustainably.

Although lack of technical knowledge on nursery management can be a major constraint, in many communities nursery operators are enthusiastic to learn. The recommended approach is to train the basic principles behind production technology rather than provide specific 'recipes', so that operators can then experiment and innovate. Successful innovations can be spread further through nursery networks. This promotion of self-reliance is similar to the philosophy adopted when disseminating the participatory domestication approach (Unit 15). Marketing of seedlings by small-scale commercial nurseries is also essential for their success and this requires business training. It may also involve the formation of groups of nurseries to share access to starter germplasm and information, and deal with bulk demands by buyers for nursery plants.

It is very important to understand community dynamics when engaging in the support of group nurseries. The coalescing factors that lead to group formation will vary widely. For example, a youth group and a woman's group in the same locality may gather for completely different reasons, but both may end up establishing tree nurseries. Depending on the group, the evolution of the nursery will be different and the most important interventions required for support will vary. Projects should as much as possible work with already existing nurseries rather than start new ones, as the former are likely to be more sustainable.

Good nursery practices

Proper seed germination and seedling handling

Most orthodox seeds are dormant until they come into contact with sufficient moisture to start the germination process. Some seeds need special treatments to break dormancy or to speed up and synchronise germination. Often, soaking seed in cold or warm water overnight is sufficient; if special treatments are required, such as nicking or chilling, this information is usually given by the seed supplier (see Kindt *et al.* [2006] for further information on seed treatments).

The development of seedling roots determines the performance of trees when they are planted out. To avoid root damage, the physical handling of plants should be reduced to a minimum during their time in the nursery. Poor practice in pricking out (the transfer of young seedlings from seed beds to containers) is a common source of root deformities. For example, seedlings are often pushed into holes that are not deep enough for their root system. Pricking out should therefore, where possible, be avoided by sowing seeds directly into containers. Depending on the expected rate of germination (which can be determined in advance by testing, see Kindt *et al.* [2006]), two or three seeds may be sown per container. In cases where pricking out is unavoidable, it is important that it is done as early as possible and carefully, so as not to bend or overexpose roots to drying conditions.

Another common cause of root damage is when the roots of nursery plants have grown through the base of containers into the ground below. Such plants can suffer severely when removed from the nursery and may not survive in the field. This problem can be avoided by regular root pruning in the nursery using a wire, which is pulled under the bottom of plant containers to sever the protruding roots. Pruning in this way also stimulates lateral root development. A better approach is to place plants on raised nursery beds that circulate air underneath open-bottomed containers. This prevents roots from growing outside containers (by 'air pruning') and improves drainage, reducing pest and disease incidences in a humid environment.

In a dry environment, placing a plastic sheet beneath plant containers can help conserve water and at the same time prevent roots from growing into the ground.

The way plants are transported from the nursery to the field is important but is often done carelessly, resulting in high mortality. Potted plants should be kept upright and under a moist cover to prevent them from drying out. If planting bare-rooted seedlings, bundle them carefully and wrap bundles in damp paper, cloth, leaves or moss before transport. After transport, potted plants should be kept under shade and planted within a few days, bare-rooted seedlings as soon as possible.

Use of appropriate containers

Containers for plant propagation come in various shapes, sizes, and in different materials, such as polystyrene, polyethylene, fibre or paper. New forms and materials are constantly being developed and tested, with the latest being biodegradable cellulose-based polymers. The type of container that should be selected depends on the particular species being raised and how and when material will later be planted. Plants with a long nursery production period and seedlings being raised as rootstocks for grafting (see Unit 12) are usually grown in larger, more durable pots. The size of the container should also depend on the growth substrate (the mix of soil, sand, compost, etc.) being used within it (see below).

The most commonly used containers in the tropics are polythene bags. They are usually locally made, relatively easily available and fairly cheap to purchase. However, these can cause roots to grow in spirals once they hit the smooth inner surface of bags, leading to restricted growth and reduced tolerance of the tree to stress. As the tree grows, dieback can result from ensnarled roots. 'Root trainers' are rigid containers with internal vertical ribs that direct roots downward to avoid spiralling, and have a large drainage hole at the bottom to allow air root pruning on raised nursery beds. These are more expensive to purchase, however, and less readily available than bags, although they are reusable.

Biodegradable cellulose materials also allow air root pruning as they have porous walls. They minimise seedling damage and labour requirements at field planting, since trees are planted within their containers. This also ensures less environmental pollution, as happens when polythene bags are removed from seedlings at planting and are discarded. Where water availability is limiting, however, porous biodegradable containers can prove inefficient as plants require more frequent watering. Locally available containers, such as used milk or juice cartons, detergent containers, bamboo segments or rolled banana leaves are cheap and can be used by small nurseries. However, they are usually not durable enough for plants that need to stay in the nursery for longer periods.

The right type of growth substrate

The substrate used to raise a nursery plant is one of the most important influences on its growth, as it provides the nutrients, water, air and other components (such as nitrogen-fixing bacteria for leguminous trees) required for good development. The use of an unsuitable substrate leads to root deformities, pathogen attack and retarded development. The physical properties of substrate that influence plant growth include how much water it can hold, porosity, texture, and bulk density (weight per container). Important chemical properties include the amount of nutrients the substrate contains and how easily available these are to the plant. Water holding capacity and porosity are related characteristics. The substrate needs to hold sufficient water for good plant development and needs to be sufficiently porous to allow good gas exchange in the root zone. With too much water and without sufficient oxygen in the root zone, roots rot and die. Containers that do not have holes for drainage are more likely to result in waterlogging.

Local soils may be inappropriate for seedling production if they contain large amounts of clay (increasing waterlogging and weight) or if they lack the necessary plant nutrients. To lighten a substrate, provide the right texture and supply macro- (e.g., nitrogen, phosphorus and potassium) and micro-nutrients (e.g., iron, manganese and zinc), the incorporation of organic matter (in the form of animal manure, compost, rice husks, etc.) and/or inorganic materials (such as sand and inorganic fertiliser) is often recommended. Depending on the nutrient composition of available substrate and the length of time in the nursery, the use of additional fertiliser may be required later in the nursery production cycle. The type and quantity of the materials incorporated in the potting substrate and applied in later fertilisation depend on what is locally available and what is needed by the particular species. For trees newly entering domestication, experimentation is required to come up with the right approach. Being able to recognise the visual appearance of stressed nursery plants, including the symptoms of particular nutrient deficiencies and imbalances, is clearly important.

Ensuring nursery health

Nurseries experience problems with plant health due to damage caused by abiotic factors, such as excessively high or low temperatures, strong winds, drought, waterlogging and injury due to chemical use, and/or damage caused by pest and disease attack. Abiotic damage can be reduced by choosing an appropriate nursery site with the right growing conditions and by designing a nursery layout that protects plants. Shading for young plants and regular watering are good nursery practices. Shade can be provided by nets or cloth (available in various densities), grass thatch, banana leaves or other local materials, although local materials may harbour pests and diseases. As plants grow, they should be exposed to more light by the gradual removal of shade. Nursery beds and shade cover should be oriented so that plants are shaded from harsh, direct midday sun.

A proper watering regime is essential, neither too little nor too much. Water is often a limiting resource, but when it is available there is often a tendency to over-water, leading to waterlogging and the death of plant roots. In dry areas, drip irrigation, in which water is delivered directly to pots rather than sprinkled from above, can be used to minimise water loss through evaporation. Toward the end of the nursery period, plants need to be prepared for the field by hardening off. This is done by withholding water from time to time and by removing shade.

In managing pests and diseases, rather than relying on the use of pesticides and the like, preventive actions to minimise build-ups are preferable when possible. Diseases may enter and be harboured in the nursery on equipment, in irrigation water, in growth substrate, on seed and on plants when they are first brought into the nursery, and on the shoes and clothes of nursery staff. Nursery areas should be kept free of weeds because these may be alternate hosts of common nursery pests. Growth substrate may be treated by solarisation or steam sterilisation to remove pathogens. Alternatives to synthetic chemicals for treating diseased plants include hand removal of infected plant parts or pests, and the use of tobacco, chilli pepper, neem or pyrethrum extracts. Diseased plant material should be burnt rather than composted. When unsure of the identity of a pest or disease, if possible take samples or photographs and consult local experts, for example within the ministry of agriculture.

Proper planning and time management

Good nursery management requires proper planning. The most important factors to consider are when planting material will be required by farmers, and the number of plants that will be needed. A common nursery practice is to leave plants in the nursery well beyond the time when they should be planted in the field. These left-over, overgrown plants often have severe root deformities and will thus not perform well on farms: it may be better to ‘start from scratch’ for the next planting season. If it is known in advance that plants will not be required in the short- to medium-term, however, then they may be transplanted into bigger pots before roots become overgrown, so that they can be kept healthy in the nursery for longer. More inputs in tending the plants will however then be required, until the next planting season.

The information on when plants will be required and in what numbers best comes from asking growers. Tools that can be used to plan nursery operations include a calendar to set dates for necessary activities such as seed purchase and planting (Box 2), a book in which to collect specific protocols for raising plants of particular trees species, and an inventory of the species present in the nursery and their numbers. Training nursery operators in the use of these tools may be required.

Box 2

An example of a nursery calendar

In the first half of the year In central Kenya, the best time for farm planting is usually between 1 April and 15 May. Farmers plant fodder trees from mid-April onward, once the demand for labour for crop planting has eased. On this basis, the calculations below can be made for raising three fodder tree species in the nursery. Activities should begin with *Leucaena diversifolia*, then *Calliandra calothyrsus* then *Leucaena trichandra*. Seed needs to be at hand to facilitate timely sowing, and sufficient time needs to be given to undertake a repeat sowing, in case of initial failure to germinate.

Calculating the sowing date for three fodder tree species

	Calliandra calothyrsus	***Leucaena diversifolia***	***Leucaena trichandra***
Days needed from germination to planting out	100	110	90
Days needed from sowing to germination	10	10	10
Safety margin in case of repeat sowing	15	15	15
Total days needed	125	135	115
Required sowing date	Mid- December	Early December	Late December

Adapted from Jaenicke (1999).

Additional references

Kindt R, Lillesø JPB, Mbora A, Muriuki J, Wambugu C, Frost W, Beniest J, Aithal A, Awimbo J, Rao S, Holding-Anyonge C (2006) Tree seeds for farmers: a toolkit and reference source. The World Agroforestry Centre, Nairobi, Kenya.

Lengkeek AG, Jaenicke H, Dawson IK (2005) Genetic bottlenecks in agroforestry systems: results of tree nursery surveys in East Africa. Agroforestry Systems, 63, 149-155.

Roshetko JM, Tolentino EL, Carandang WM, Bertomeu M, Tabbada A, Manurung GES, Yao CE (2010) Tree nursery sourcebook: options in support of sustainable development. The World Agroforestry Centre, Southeast Asia Regional Office, Bogor, Indonesia and Winrock International, Arkansas, USA.

Unit 14 – Sustainable germplasm distribution strategies

Jens-Peter Barnekow Lillesø and Lars Graudal

Unit objectives

After studying this unit, readers will be able to:

- Compare the advantages and disadvantages of existing germplasm supply strategies to provide small-scale farmers with tree planting material.
- List and describe the three major components of the germplasm supply chain to farmers, and explain the relationship between these and the agroforestry tree product value chain.
- List five common germplasm source types used in agroforestry.
- List and describe three major models of germplasm supply, and discuss the innovations needed to improve germplasm delivery systems.

Summary

This unit deals with the mechanisms by which tree planting material reaches small-scale farmers. There are several strategies aimed at achieving this, but most have not succeeded. This is for a variety of reasons, such as the relatively small quantities of planting material that are required by any one farmer, production disincentives caused by the 'for free' distribution of germplasm, and conflicts of interest of producing and regulating entities. Lessons can be learned from strategies to deliver agricultural seed to small-scale farmers in the developing world.

There are three major components of the germplasm supply chain to farmers: sources of reproductive material, procurement or initial collection; and distribution of seed and seedlings. Who is in charge and how information flows determine the efficiency of the germplasm delivery system for each of these three components.

There are five germplasm source types used in agroforestry. Four are from seed: natural forest, farmland, plantations and seed production stands; the fifth is from vegetative propagation. Germplasm sources can be characterised by the time it takes to produce material for distribution and by their genetic quality. Characterising sources helps to explain how tree domestication processes take place in agroforestry.

Germplasm delivery systems can be grouped into three major models: the 'Government model', the 'NGO model'; and the 'decentralised model' (with two variants for the last). Innovations in agroforestry tree germplasm delivery systems are sorely needed in order that planting material reaches farmers in more effective ways. Required are a change in the functions of, and in the relationships between, the various actors/stakeholders involved in delivery.

Key resources

- Graudal L, Lillesø JPB (2007) Experiences and future prospects for tree seed supply in agricultural development support – based on lessons learnt in Danida supported programmes, 1965-2005. The Ministry of Foreign Affairs of Denmark, Copenhagen, Denmark.
- Kindt R, Lillesø JPB, Mbora A, Muriuki J, Wambugu C, Frost W, Beniest J, Aithal A, Awimbo J, Rao S, Holding-Anyonge C (2006) Tree seeds for farmers: a toolkit and reference source. The World Agroforestry Centre, Nairobi, Kenya.

Germplasm distribution strategies and tree domestication

Lack of access to high quality planting material of a wide range of tree species is a frequent refrain of small-scale farmers when they are asked about the constraints that face them in adopting agroforestry practices. Improving the ways by which growers gain access to planting material is therefore crucial in bringing trees into cultivation on farms, and thus is an essential consideration in tree domestication strategies. 'Top down' approaches to germplasm delivery, such as those based around national tree seed centres (NTSCs), were heavily supported by donors in the 1980s and 1990s. However, it has been estimated that, although NTSCs are appropriate for supplying large-scale tree plantation industries, they have delivered less than 10% of the smallholder demand for tree planting material. One reason for the failure of this approach is that small-scale farmers are widely dispersed and require only small volumes of particular species, making them expensive to reach (Graudal and Lillesø 2007).

A trend in the 1990s to provide donor support to non-governmental organisations (NGOs) to carry out delivery appears in general to have not fared much better than NTSC-based approaches, due to the restricted timescale of projects, the lack of attention to the promotion of genetically superior material, and insufficient technical knowledge in handling germplasm and raising seedlings, leading to poor physiological quality.

Local, small-scale entrepreneurial suppliers, who may ultimately be able to operate on a more sustainable basis, have been discriminated against by NTSCs that hold both 'productive' and 'normative' functions in supply (that is, by NTSCs that provide planting material commercially, competing with other suppliers, and yet also have a unique role in regulating the sector, resulting in conflicts of interest). In addition, small-scale market-based suppliers have been disadvantaged by the common NGO practice of providing germplasm for free or under heavily subsidised conditions of sale. In a survey of NGO distribution to smallholders in Uganda, for example, 71% of beneficiaries obtained material for free, proving a significant disincentive to the involvement of private suppliers (Brandi *et al.* 2007).

In many parts of the tropics, poor delivery of tree planting material to smallholders mirrors the situation observed in the annual crop sector, where the majority of small-scale farmers use their own saved seed for future plantings. For crop seed systems, there has been heated debate over recent decades in how to improve smallholder access to good planting material, and the new concepts from these discussions provide an insight into what innovations may be possible for agroforestry tree germplasm delivery systems. A starting point in improving existing systems is to have models that help describe current practices, in order to define constraints and identify opportunities for intervention. The next sections of this unit provide systems that can be used for classification. These should be applicable to almost any situation concerned with delivering tree planting material to smallholders.

Defining components and actors in agroforestry tree germplasm delivery systems

The three major components of the germplasm supply chain to farmers can be identified as follows:

Sources of reproductive material

Sources can be categorised into five types (Table 1), each of which imposes various biological and logistical constraints on the supply chain; for example, natural forests produce seed now, while seed production stands will only do so a number of years after establishment. An understanding of germplasm sources helps explain the processes involved in tree domestication, and where interventions to improve genetic quality and management can be made. The optimal use and 'blending' of sources requires cooperation between different public and private actors (or stakeholders), which governments and development agencies should seek to promote.

Procurement/initial collection Which actors are involved in collection depends on who owns and/or controls germplasm sources, and their capacity and willingness to make use of material. The actors involved in the germplasm delivery chain can be classified as either 'formal', including NTSCs and large-scale commercial seed suppliers, or 'informal', including NGOs, small-scale commercial nursery owners and seed vendors, and farmers themselves. Research shows that informal actors currently supply the vast majority of the germplasm planted by farmers.

Distribution of germplasm
Some actors are able to afford to give away material during distribution, others makes an income from it. The efficiency and reach of distribution is linked to the extension and marketing methods applied to species, varieties and provenances, and the information given to receivers on germplasm use and quality.

The three above components of the supply chain are qualitatively different from each other, in the sense that a source is something physical, while procurement/collection and distribution are 'actions'. The definition, design and establishment of sources are, however, also actions that determine the quality of planting material that is available to smallholders. The relationship between these three components, and the link with agroforestry product outputs, is described in Figure 1.

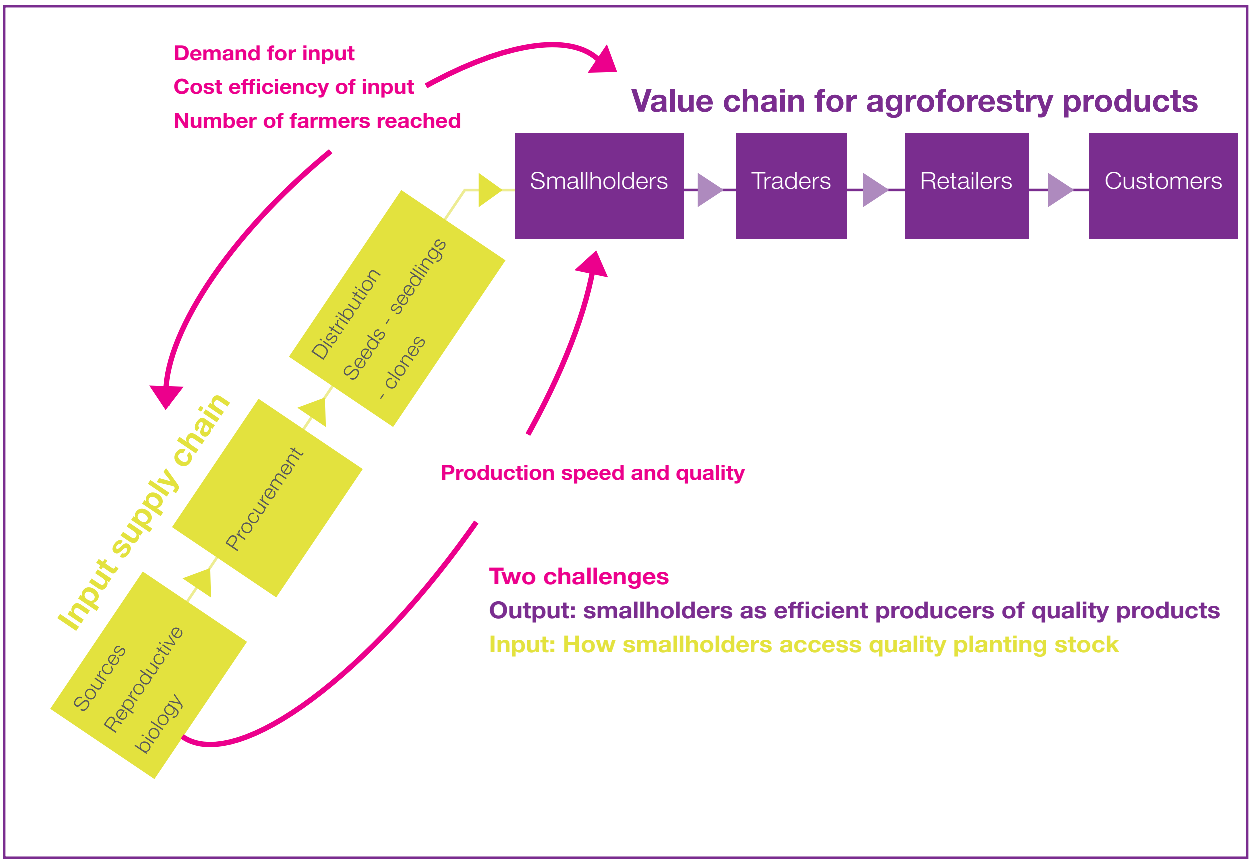

Figure 1 The relationship between components of germplasm supply (the 'input supply chain') and the value chain for agroforestry tree products.

Table 1 The five germplasm sources used in agroforestry

Source type	Brief description	Current use	Timing of production/ further notes
Natural forest (seed)	Natural vegetation, ranging from high forest to woodlands, material of local origin	Underutilised, a reservoir of a wide range of little planted, under-researched, indigenous trees	Producing now. Higher collection cost than other sources. High within-species variation provides a good genetic base and opportunities for selection
Farmland (seed)	Trees on farms, planted or remnants of natural vegetation, may be local or non-local (often unknown) origin	Readily available, widely used by NGOs, small-scale nurseries and farmers. A limited number of indigenous and exotic species only	Producing now. Seed yield may be a trade off with farm function, such as lopping branches for fodder/reducing competition with agricultural crops. Quality criteria generally not applied during collection. Genetic base may be narrow
Plantations (seed)	Trees planted in a plantation or woodlot, origin not always known	Limited range of species, mainly ‘industrial’ trees	Producing now. Quality depends on origin and diversity of the base population
Seed production stands (seed)	Trees planted specifically for seed production, often of superior performing material (including ‘seed orchards’)	Limited use, mostly for a few exotic species for which large seed demand	Producing only after a number of years. Quality good and may be improved further by selective thinning
Vegetative propagation	Grafts, cuttings, marcots, etc., propagated from selected clones, may be local or non-local (potentially unknown) origin	A few exotic fruit trees, also applied in the participatory domestication of indigenous fruit trees	Vegetative multiplication protocols generally take a few years to develop and adopt. Genetic diversity often narrow because only a few clones used

Adapted from Lillesø *et al.* (2011).

Defining models for agroforestry tree germplasm delivery systems

In order to understand how various actors participate in the germplasm supply chain, a useful approach is to consider whether control of a component is ‘centralised’ or ‘decentralised’. A ‘centralised’ actor is defined as one of only a limited few that exist in a chain, while a ‘decentralised’ actor is one of many that are present. Since each of the three components in the ‘source-procurement-distribution’ germplasm supply chain can be managed by either centralised or decentralised actors, a map of possible input supply approaches includes eight (2 x 2 x 2) configurations.

In practice, these eight configurations can be grouped into three major models, the ‘Government model’, the ‘NGO model’ and the ‘Decentralised model’, that differ mainly with respect to: (i) who controls germplasm sources, (ii) the type, availability and use of technical knowledge on germplasm management; and (iii) how transaction costs are supported (Box 1).

Box 1

The three major models of germplasm supply

The 'Government model' A central authority (most often a NTSC) controls all three components of the chain. Sources (e.g., natural forest, plantations) are most often located on land controlled by this (or a sister, government) authority. Good technical knowledge on handling germplasm is held by the same institution, and the transaction cost of bringing seed from source to smallholders is covered by government funds or development assistance. Sales of germplasm are predominantly to other centralised actors.

The 'NGO model' Planning of activities is centralised by NGOs, but they do not manage the germplasm source, which is often on farmers' land. Technical knowledge on germplasm handling and quality is often unavailable. Transaction costs are mainly covered by an NGO through project funds. Sales of germplasm are predominantly to other centralised actors, while material is provided free of charge to the NGO's clients (e.g., farmers, nurseries). This model is the most common in agroforestry.

The 'Decentralised model' All three components of the chain are handled by decentralised actors. There are two variants, one non-commercial and the second commercial. Non-commercial, 'farmer-to-farmer diffusion' of tree germplasm, is limited to species and populations that have already been in agricultural landscapes for some time, or to new introductions of early maturing species. Technical knowledge is limited to farmers' experiences and large scale diffusion is restricted by transaction costs. This model is conceptually similar to farmer diffusion of agricultural crop seed, although for trees it is generally a slower process because of the longer time period between planting and seed production. In the commercial variant, small-scale local entrepreneurs procure and distribute germplasm. These entrepreneurs have higher technical knowledge than farmers, while transaction costs are supported by the sale of planting material. Conceptually, this variant corresponds to the approach that is now being strongly promoted to deliver annual crop seed to small-scale farmers in many parts of the tropics.

Adapted from Lillesø *et al.* (2011).

Innovations to improve current delivery systems

Profound change is required in the roles played by different actors in agroforestry tree germplasm supply chains if they are to operate effectively for small-scale farmers. The role of NGOs should be to support existing small-scale entrepreneurial seed dealers and tree nurseries rather than unfairly undercutting them through short-term free handouts of germplasm. This support could come through providing business training and developing networks of producers and distributors of planting material.

To prevent unfair competition, NTSCs should not be both suppliers of germplasm and regulators of the sector as this introduces a conflict of interest. Rather than providing seed to farmers themselves, it is better if NTSCs are knowledge brokers of technical information to producers on all aspects of germplasm quality, production and procurement, which involves a strong training role. NTSCs should also be involved in supplying high quality 'starter' germplasm to nursery operators and for the establishment of seed production stands or 'mother blocks' for vegetative propagation.

Suggested innovations for collaborative models that ensure germplasm of good genetic quality of a wide range of species is distributed efficiently to smallholders from relevant sources are listed in Box 2. Interventions relate to divisions of labour between actors based on their comparative advantages.

Box 2

Interventions required for specific tree germplasm source types (as described in Table 1)

Seeds from **farmland sources** are best collected and distributed by small-scale enterprises. Collection and distribution can be organised at a decentralised level, but require knowledge of practices to ensure genetic quality that can be provided by NTSCs (Unit 9). Special care should be taken to widen the genetic base though support for the development of networks of producers for exchange and pooling of material.

Natural forest sources contain a large number of underutilised indigenous species. To mobilise the genetic potential of these species for farmers requires skilled collection of relatively large amounts of seed. This can only be justified on economic grounds if material is distributed to many users. NTSCs should coordinate collection together with several NGOs and networks of small-scale nurseries. An alternative approach to using natural forest sources is that of participatory domestication (Unit 15).

Seed collection of species in **plantations** can be carried out by NTSCs or private specialised small-scale collectors for distribution to networks of small-scale nurseries. Quality can be ensured by applying common sense norms.

Production of high genetic quality seed in **seed production stands** should be scaled up to more sources and species supported by NTSCs. Collection and distribution can be organised at a decentralised level, but distribution requires efficient networks to ensure volumes are reached in order to provide a return on the long term investment required (time between stand establishment and seed production).

Wider use of **vegetative propagation** requires the development of new and more effective methods of propagation. Clones may be developed centrally, but multiplication should be organised at a decentralised level to save the costs of transportation and to support entrepreneurial nurseries. Support by research institutions, NTSCs and NGOs is required to ensure a return on investment. The participatory domestication approach (Unit 15) is a special means to use vegetative material sourced from natural stands.

Modified from Lillesø *et al.* (2011).

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Unit 15 – The participatory domestication approach

Zac Tchoundjeu, Ebenezar Asaah, Ian Dawson, Roger Leakey

Unit objectives

After studying this unit, readers will be able to:

- Understand the advantages and disadvantages of different approaches to tree domestication.
- Describe the participatory tree domestication method used by ICRAF and its partners in Central Africa.
- List the various functions and activities that can be offered by rural resources centres (RRCs).
- List positive as well as negative impacts that the participatory domestication approach can have.

Summary

A centralised approach to agroforestry tree domestication allows advanced methods to be used to produce improved genetic material, but can be expensive as well as disconnected from the requirements of small-scale farmers. This approach is normally implemented on research stations and the outputs are research publications and improved germplasm for mass production by others.

Using experiences with indigenous fruit trees (IFTs) gained in Central Africa, ICRAF has developed a decentralised approach to domestication that is implemented by farmers on their own farms, with mentoring by scientists and extension agents. Experiences make clear that there are many benefits to this participatory approach, including relevance for farmers and the speed of adoption of research. A limitation however is that it can only be applied when the trees of importance to farmers are already found in local landscapes.

Key to the participatory domestication approach is the establishment of RRCs that play a central role in addressing the production and market constraints experienced by communities. RRC activities include germplasm production and distribution, providing training, making available farm management services as well as grading and processing facilities, and the provision of market information.

Key resources

- Leakey RRB, Akinnifesi FK (2008) Towards a domestication strategy for indigenous fruit trees in the tropics. In: Akinnifesi FK, Leakey RRB, Ajayi OC, Sileshi G, Tchoundjeu Z, Matakala P, Kwesiga FR (eds.) Indigenous fruit trees in the tropics: domestication, utilization and commercialization. CAB International, Wallingford, UK, in association with the World Agroforestry Centre, Nairobi, Kenya, pp. 28-49.
- Tchoundjeu Z, Asaah E, Anegbeh PO, Degrande A, Mbile P, Facheux C, Tsobeng A, Atangana AR, Ngo-Mpeck ML (2006) Putting participatory domestication into practice in West and Central Africa. Forests, Trees and Livelihoods, 16, 53-70.

Formal and informal approaches to tree domestication

As illustrated in Figure 1, tree domestication can proceed along two basic pathways, either using a centralised approach or using a decentralised strategy (Leakey and Akinnifesi 2008). The first involves field trials, controlled crosses and, in some cases, biotechnological breeding methods to carry out genetic improvement. It has been employed for a few dozen 'industrial' trees (mostly timbers/wood-producing species), as well as for a small range of temperate and (fewer) tropical tree fruits (such as avocado, orange and mango) (refer back to Unit 1).

This centralised strategy is relatively easy to coordinate and allows advanced methods to be used to combine multiple important traits into improved material. It has been applied for developing quality planting material for tree species that are of interest to large-scale producers, such as plantation owners. The approach can be expensive and time consuming, however, and improved material does not always or often filter down to small-scale farmers. The approach has the added problem that the traits improved may not be those that are most important to smallholders.

The second, decentralised approach applies a participatory strategy that involves local people. A method has been developed that builds on the existing knowledge of communities on the importance and use of the tree and its products, and its cultivation and marketing. In the last decade or so, a specific strategy has been tested, refined and adopted, especially for indigenous fruit trees (IFTs); the same approach can be applied to other high value tree products. It is this method that is described in this unit.

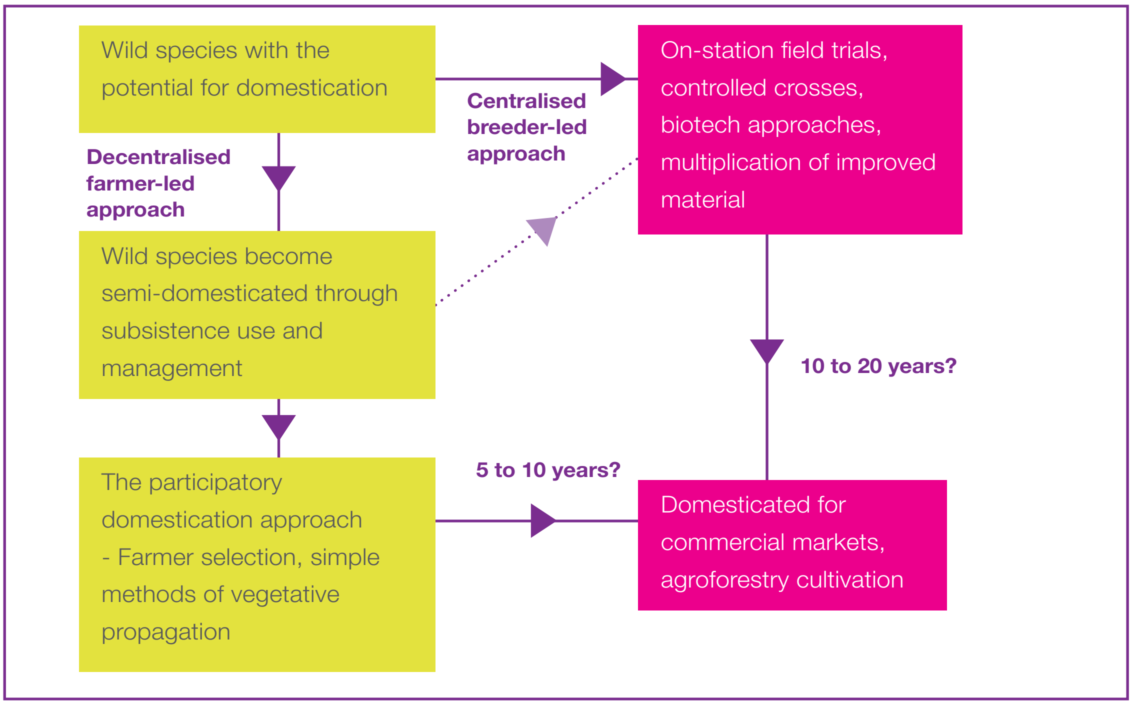

Figure 1 Two approaches to tree domestication.

The participatory domestication method

The participatory domestication method, as developed by ICRAF and partners, involves combining communities' traditional knowledge on tree use and management, and their priorities for cultivation, with scientific advances in germplasm collection, selection, propagation and farm management, and with industrial advances in product processing and use. Farmers are trained by extension staff, who themselves have been trained by scientists, in appropriate techniques for handling germplasm. Farmers are then encouraged to apply these newly-acquired skills to the trees that they find in the landscapes that they inhabit, bringing new types of trees into cultivation and testing them in their farms.

A key advantage of the participatory domestication approach is that it empowers communities to manage local resources themselves. In addition, it promotes greater and more rapid adoption because it is immediate and does not depend on the slow dissemination of information and germplasm to farmers that is typical of centralised approaches. Furthermore, it provides farmers with the strategic skills they need to domesticate a range of different species and therefore supports diversification that buffers production and market risks, increasing the resilience of farming systems.

The participatory domestication approach has been widely applied when farmers can still gain relatively easy access to natural populations of tree species that are important to them; where such stands are harder to access, for example, due to extensive deforestation and agricultural intensification, the method may not be appropriate at all. In this second situation, a more formal approach based on the introduction of germplasm from outside may be the only possible method. Difficulties in participatory domestication can also be encountered when working with colonist communities who are not familiar with the indigenous tree species found around them, or simply when farmers do not consider any local species to be important (as indicated by priority setting Unit 4). One of the regions where the participatory approach has been widely practiced in the last decade is in the humid forest margins of Central Africa, especially in Cameroon; here, IFTs are highly valued in the local economy and natural stands are often still found in close proximity to farms. The same ideal conditions apply elsewhere where the approach has not yet been applied.

The time taken between planting and production is a key factor determining the utility and profitability of tree planting and farmers' interest in it. An important part of the participatory domestication approach therefore has been to emphasise the use of simple vegetative propagation techniques, such as grafting, to accelerate production from indigenous fruits. The rooting of leafy stem cuttings in simple, non-mist propagators that can be built from locally available materials has also been promoted (see Unit 12 for a discussion of different vegetative propagation methods). Vegetative methods are used by farmers to multiply superior genotypes and thereby maximise yield and quality gains. Whether or not farmers can successfully carry out their own selections to realise gains depends on how much genetic variation is found within tree populations in the local landscape. Fortunately, research suggests that variation is typically high at this level for important yield and quality characteristics in many indigenous fruits (as described in Unit 9, see especially Box 2). There appear therefore to be significant opportunities for local selection.

Rural resource centres

To promote the participatory domestication approach in Central Africa, rural resource centres (RRCs), managed by local communities, have been established with the assistance of government extension agencies and international development funds. These carry out production and market functions to address constraints in both of these areas (Fig. 2). Centres train farmers in how to collect and propagate superior germplasm, host small field trials to demonstrate effective horticultural methods, hold stockplants of selected trees for wider vegetative propagation, and link with smaller nurseries to provide germplasm and knowledge at a wider range of locations.

RRCs also provide processing facilities to add value and increase storage life for tree products, deliver business training, and act as venues for farmers, wholesalers and service providers (e.g., of fertiliser, credit) to meet, so that they can share market information and undertake transactions including group sales. In this way, RRCs link with market value chains (see Unit 5) and facilitate fair returns to farmers. In addition, trials established at RRCs allow communities to gather the data they need to gain future Plant Breeders Rights over their best cultivars. This is an important issue for protecting farmers' interests, if varieties are to be more widely disseminated or adopted in formal improvement programmes (Lombard and Leakey 2010).

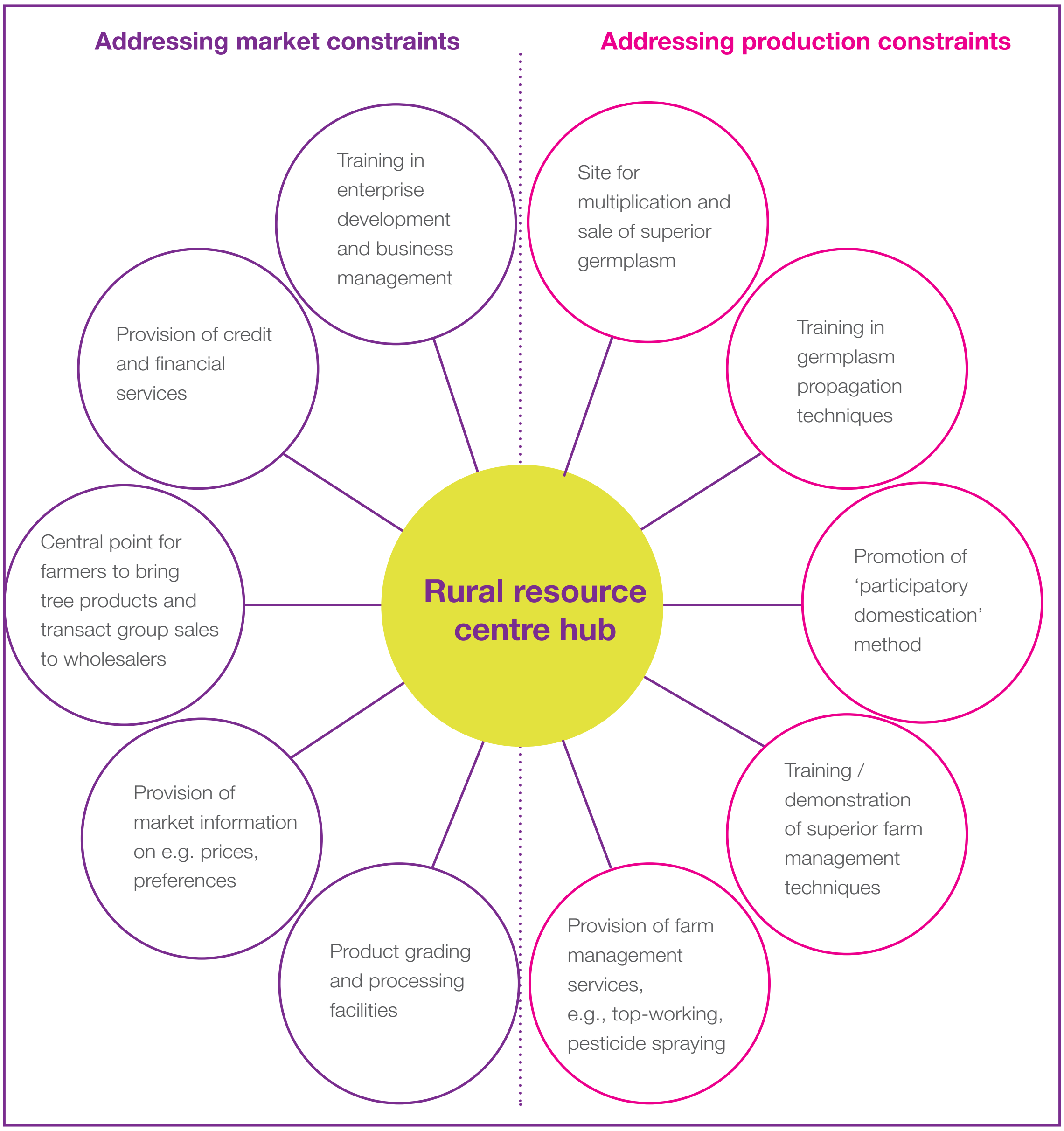

Figure 2 The market and production functions of rural resource centres (RRCs).

The impacts of participatory domestication

The impacts of the participatory domestication approach as applied in Cameroon have been measured and have been shown to be positive for the incomes and nutrition of local people (Box 1).

The participatory domestication approach as practiced in Cameroon and other sites in Central Africa now needs to be adapted and replicated at greater scale in Africa and more widely in the tropics.

Box 1

Impacts of the participatory domestication approach in Cameroon

The effectiveness of a programme promoting the participatory domestication of indigenous fruit and nut trees in Cameroon was surveyed under the following categories of impact: (i) productivity and product quality, (ii) household income, (iii) farmers' health and nutrition, (iv) cultural and social well-being, community life and cohesion; and (v) environmental benefits. Negative impacts were also determined by interviewing both adopters and non-adopters of the approach.

Positive impacts included the following:

- Smallholders achieved increased incomes from the sale of fruits from locally selected, clonally propagated cultivars of species such as safou (*Dacryodes edulis*) and bush mango (*Irvingia gabonensis* and *I. wombolu*), and from selling nursery stock of selected trees to other growers. Incomes were used to pay for school fees, health care and basic household needs. Some income was invested in developing other small enterprises.
- In one survey, around 50% of local adopters had included more fruit in their own diets, thereby having a direct impact on their own nutrition. Participatory domestication had also contributed to a reduction in human migration from rural to urban areas, as young people stayed in villages to engage in new farming activities and benefit from new business opportunities.
- Tree nurseries in Cameroon that had received support from the participatory tree domestication initiative supplied a wider range of fruit trees, propagated in more appropriate ways, and with higher purchaser satisfaction, than those nurseries that had not received assistance.
- Tree nurseries applying participatory domestication methods were generating thousands of US Dollars through plant sales annually (depending on the size of the nursery and the length of time of operation).
- The propagation methods taught as part of the participatory domestication approach were now also being applied to exotic fruits, such as avocado (*Persea americana*), mango (*Mangifera indica*) and apple (*Malus domestica*).
- Farmers involved in tree domestication had gained more respect in their communities and had been asked to take on other responsibilities. Many had been able to develop links with farmer groups in other parts of the country, and with research institutions, schools, local authorities and/or business people, thanks to better communication skills and exchanges supported by the programme.

Box 1 continued

Negative impacts included the following:

- Conflicts between tree planters and livestock owners arising from the damage to young trees by animal grazing.
- Jealousy by those who were not involved in the programme, sometimes resulting in the theft of plants from nurseries, and of fruit from orchards.

For further information, see Tchoundjeu *et al.* (2010) and Asaah *et al.* (2011).

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ANNEX – A short learning event on agroforestry tree domestication

Introduction

For many years, ICRAF has been organising and implementing seven-day introductory learning events on *Agroforestry Tree Domestication* for a broad variety of audiences. In support of these workshops, resource persons from ICRAF and collaborating institutions have produced a series of learning resources based on the five modules and fifteen units contained in this publication, reflecting a possible structure of such a course. After going through the various modules and units of this publication, teachers and learners should have a good idea of what is important to know about agroforestry tree domestication when embarking on research, development or teaching on the subject.

In order to facilitate teaching, ICRAF has produced a publication[1] that provides more details on how to go about planning, organising and implementing agroforestry learning events. The purpose of this annex is to give some suggestions on methods to those who are interested in teaching on the topic of agroforestry tree domestication, based on the content of the current primer. The units of this primer provide basic information on key learning points that should be covered on a specific subject, but it is up to future resource persons to enrich this content by making it relevant to their specific audiences and the learning context. This may require the inclusion of additional content, learning activities and resources. In particular, new case studies relevant to learners may be required.

Overall learning purpose

When organised by ICRAF, the overall purpose of a short, introductory learning event on agroforestry tree domestication is described in the following way:

To expose participants interested in embarking on an agroforestry tree domestication 'research for development' programme to the complex and multi-disciplinary character of the subject, as well as to new concepts and experiences, so that they can conceptualise, implement and manage such a programme, leading to the successful adoption of agroforestry tree species by farmers.

Course content and curriculum

The curriculum developed by ICRAF for a short learning event on agroforestry tree domestication has evolved over the years to incorporate new information and methods on domestication research. A course always remains a 'work in progress' and any curriculum and programme can be expected to continue changing as new knowledge becomes available. As domestication activities are multi-disciplinary, participants should be constantly reminded about the interconnectedness of the content of different training modules and units.

The most recent version of the course, as reflected in this publication, is structured in the following modules and units:

Module 1 – Tree domestication in context explains what 'domestication' entails in the context of crops, industrial and agroforestry tree species. It links the concepts of agroforestry and tree domestication to global challenges faced by agriculture, and outlines key principles for an agroforestry tree domestication programme, to serve as a basis for domesticating a new tree species.

[1] Taylor P, Beniest J (2003) Training in agroforestry – a toolkit for trainers. The World Agroforestry Centre, Nairobi, Kenya.

Module 2 – Choosing the right tree provides information on how to go about selecting agroforestry tree species that address farmers' identified needs, opportunities and constraints. This requires knowledge and skills related to 'participatory rural appraisal' and how to make sure that farmers and other stakeholders, being the ultimate beneficiaries of agroforestry innovations, are involved in the tree domestication process. A good knowledge of the indigenous tree and shrub vegetation of a region through ethnobotany studies and vegetation mapping will facilitate agroforestry tree selection. The module provides an approach for setting priorities among species for tree domestication and covers the concepts and principles of agroforestry tree 'value chains', since in many cases farming communities will be primarily interested in cash returns on their investment when choosing what tree species to plant.

Module 3 – Evaluating variation. This module looks at some of the ways by which tree species can be characterised in order to make informed decisions in the choice of what to cultivate, and then how to manage plantings. Quite often it will be necessary to evaluate tree germplasm so as to determine which is the best material for a given biophysical and socioeconomic situation. This can be done in an 'on-station' or an 'on-farm' context and those conducting research must be thoroughly familiar with the approaches that can be used. One unit focuses on field experiment design for agroforestry tree domestication trials. Another discusses the kind of practical information that tree domestication researchers can obtain from provenance and progeny trials. A final unit looks at some of the molecular marker methods that can be used to characterise genetic diversity in agroforestry tree species.

Module 4 – Obtaining quality germplasm. Once the right trees have been identified, care must be taken to collect high quality tree seeds or vegetative propagules of the species being domesticated. The module describes advantages and disadvantages of different germplasm collection approaches as well as the key issues that need to be considered before, during and after collection, ultimately leading to the development of an appropriate germplasm collection strategy. It is also possible to procure germplasm from various sources, which requires a defined strategy if farmers are to have access to good quality planting material. It can also be important to establish seed production stands, using either collected or procured tree germplasm, to cope with high demand for quality material. Finally, the module describes vegetative propagation as an alternative to seed-based propagation, the former often applied to fruit trees.

Module 5 – Germplasm delivery to farmers. Farmers must be able to gain access to quality tree germplasm for planting, but this can be a major limitation. If seed is not directly sown in the field, the establishment and management of tree nurseries will be required and the first unit in this module describes good nursery practices. Another unit here focuses on how germplasm can reach individual farmers and farming communities in a sustainable manner, while the last unit pays particular attention to the participatory domestication approach that has been developed by ICRAF and partners in West Africa.

The following table gives an example of how the curriculum for a seven-day domestication course can be structured into a programme.

Day 1	Welcoming the participants
	Participant and resource person introduction
	Introduction to the course, programme overview, monitoring and evaluation procedures
	Practical arrangements
	Unit 1 – Tree domestication for small-scale farmers (keynote presentation)
	Coffee/tea break
	Introduction to a participant assignment (to continue through the course) – working groups on the development of tree domestication strategies for specific types of species (e.g., timber, fruit, medicinal species; one tree function for each of the groups)
	Lunch break
	Participants present their tree domestication activities in a poster session, combined with coffee/tea break (posters prepared before the course)
	Summary and discussion session on participants' poster presentations – links to the course units
	Welcome drink
Day 2	Participant feed-back and evaluation of day 1
	Unit 2 – Participatory rural appraisal
	Coffee/tea break
	Role play exercise – skit on 'do's and don't's' when interviewing farmers
	Unit 3 – Ethnobotanical methods
	Lunch break
	Unit 4 – Species priority setting procedures
	Coffee/tea break
	Practical exercise – using online tree databases to obtain information for domestication
	Working groups continue on tree domestication strategy assignment
Day 3	Participant feed-back and evaluation of day 2
	Discussion on a species priority setting case study – fruit trees in Cameroon
	Coffee/tea break
	Unit 5 – Value chain analysis
	Role play exercise – modelling of different value chain actors and discussing their constraints and requirements
	Lunch break
	Unit 6 – Principles of field experiment design
	Coffee/tea break
	Unit 7 – Provenance and progeny trials
	Working groups continue on tree domestication strategy assignment

Day 4	Participant feed-back and evaluation of day 3 **Unit 8** – Molecular marker characterisation *Coffee/tea break* Visit to a molecular marker laboratory facility *Lunch break* **Unit 9** – Field collection strategies Practical exercise – break into groups to design a field collection strategy for a particular species, compare results *Coffee/tea break* **Unit 10** – Seed procurement practices Working groups continue on tree domestication strategy assignment
Day 5	Participant feed-back and evaluation of day 4 Visit a tree seed physiology laboratory/seed processing facility *Coffee/tea break* **Unit 11** – Seed production methods *Lunch break* Visit to a tree seed production stand Working groups continue on tree domestication strategy assignment
Day 6	Participant feed-back and evaluation of day 5 **Unit 12** – Vegetative propagation techniques *Coffee/tea break* **Unit 13** – Tree nursery practices *Lunch break* Practical demonstrations/exercises – vegetative propagation and tree nursery practices (in a nursery) Working groups continue on tree domestication strategy assignment
Day 7	Participant feed-back and evaluation of day 6 **Unit 14** – Sustainable germplasm distribution strategies *Coffee/tea break* **Unit 15** – The participatory domestication approach *Lunch break* Presentations by working groups of their tree domestication strategies, as developed over the week *Coffee/tea break* Final course evaluation and participants' feedback Closing session and awarding of course certificates to the participants

Target audience

Agroforestry tree domestication is a multi-disciplinary field requiring the knowledge, skills and experiences of a broad variety of biophysical and socioeconomic specialists. When organised by ICRAF, the target audience for this type of short learning event mostly consists of scientists, research technicians, and development and extension specialists. Most participants will at a minimum have a BSc degree, preferably an MSc, in an agroforestry related discipline, or have substantial experience in tree domestication. Modules and units can also provide information for university and college teaching staff, students and policy- as well as decision-makers interested in knowing more about the various subjects.

One important criterion of selection for course participants is that they have relevant experience to share in a 'peer-to-peer' teaching environment. By sharing information and expertise, participants and resource persons alike will make sure that what is being learnt remains relevant and firmly grounded in experience.

It is important if possible to conduct a needs assessment exercise in advance of the course with the potential participants in order to help model content. This can be done through sharing of a draft curriculum and asking interested possible participants what they see as priority activities. At the same time, candidates for attendance can be asked to describe how the course should be useful in their day-to-day work. This description can serve as both a motivation and justification to attend the course, and facilitates the selection of participants by the organisers. A well-designed 'application form', filled out by interested applicants and endorsed by the employing institute of the candidate, will facilitate the selection process.

Resource persons

When this type of learning event is offered through ICRAF, resource persons for the course are scientists and technical staff at the Centre who are experienced subject matter specialists. Their primary role at ICRAF is to conduct research in their specific field, but they also contribute to the Centre's capacity building activities; this provides participants with up-to-date information on a particular topic. National, regional and international partners to ICRAF also often contribute resource persons. Since course participants are also required to be agroforestry and tree domestication practitioners, they too become important resource persons contributing to the learning event. It is up to the course facilitator to make sure that participants' experiences are properly used in the course.

Teaching and learning methods

Quite often, resource persons teaching this type of course are tempted to use a theoretical presentation, supported by visual aids such as slides, as the main method to present a unit. Such 'talk and chalk' types of presentations are however unlikely, in isolation, to provide the best way to teach or learn. Resource persons must be able to constantly and actively engage learners through using a wider range of methods. The four main factors to consider when selecting methods are:

1. *Learning objectives and outcomes:* list all possible methods that can be used to allow the achievement of the objectives or learning outcomes.
2. *Content:* narrow down this list to make sure that the content is adequately covered.
3. *Learners:* consider their needs, capabilities, etc.
4. *Resources:* choose only methods that can be realistically implemented using available logistical support.

The following textbox gives some commonly used methods that can be used to enhance teaching and learning. The main point is that the theoretical content of presentations should be supplemented by as much participatory activity as possible. Courses such as this must be based on adult learning concepts and on participants' experiences.

Box 1

Teaching and learning methods

- ***Lectures and presentations.*** Pure lecturing is a 'one-way' process. Despite this limitation, a well prepared and presented lecture can be an effective and economical method of training when there is a need to present a large amount of information to a big group in a short period. It is unsuitable to teach skills on detailed issues. Lectures (supported with visuals) are best combined with other teaching methods to make them more effective.
- ***Case studies.*** Several units in this publication contain case studies which are very useful elements of a learning event. Case studies provide an opportunity to bring different situations into the training room and expose learners to the real world when resources, time or opportunity are not available to take participants on field trips. The main benefit of case studies is in encouraging learners to think and interact with a subject. They can be used as experiences for reflection and as practical examples in which learners can test out theories and concepts. Case studies can be presented as a written document, a video or aurally.
- ***Poster session.*** A learning event must ground the subject matter in the expertise and experiences of the learners. It is therefore important that participants are given an opportunity to share their own knowledge with other learners and resource persons alike. One way this can be done is by requesting all participants to present some of their work in a poster. Resource persons should attend poster sessions and use the information provided to enrich the content of their units and presentations. Careful thought it required by the course organisers in choosing a poster format, in order to challenge presenters to think about and present their work in ways relevant to the course. Posters are made and printed in advance of the start of the course.
- ***Group work.*** Teaching sessions should actively involve learners through making them work together in small groups on specific assignments (questions, experiments, role play, brainstorming, etc.). Quite often, participants can be asked to read the text of a unit for themselves and can then be given exercises that will allow a resource person to see if the subject matter is properly understood, and which content requires more explanation. This method requires the resource persons to actively engage with groups throughout an exercise and during plenary presentations by participants of the outcomes. Clear instructions need to be given prior to such exercises.
- ***Field visits.*** Depending on the unit or subject, participants will learn more by seeing than by listening. Field visits to case studies can contribute to this and are often worth the time and expense that may be involved. Again, clear instructions and proper preparation are needed to make visits relevant and effective. Constant reference to concepts and principles as taught in the classroom are required.
- ***Practical demonstrations.*** Skills and techniques such as vegetative propagation or nursery practices are best learned by doing. These can be quite time consuming activities that need to be properly prepared and implemented to make best use of the available time. In some cases it will be necessary to simulate the final outcomes of practical activities, since time may not allow for participants to experience the results directly.

Learning resources

The World Agroforestry Centre and other agroforestry research and development organisations have produced numerous learning resources related to agroforestry and tree domestication that can be used in support of this type of learning event. The units as presented in this primer have been developed by scientists and technical staff at ICRAF and by its partners. The 'fast track summaries' of these units provide the following information as a starting point:

Unit objectives are statements of what learners should be able to do after successfully completing the unit of instruction. They should indicate a measurable change in behaviour. They contribute to the broader purpose of the learning event and guide resource persons in the preparation and implementation of a unit.

The summary provides an overview of the topic being addressed. It highlights the important learning points of a unit that absolutely need to be covered, and that can then be topped up with 'nice to know' information.

Key resources are the sources of information that a reader of the unit should cover to obtain basic information. These can be publications such as scientific papers, books and book chapters, manuals and models, and may be e-learning (online) materials.

Evaluation and assessment

To determine if effective learning has taken place during a course, the organisers should monitor and evaluate what happens during and after the event. Evaluation with resource persons and trainees is an integral part of the curriculum development cycle, as it allows future improvements in content and methods. Assessment is also to determine if changes in knowledge lead to changes in attitudes and approaches in learners.

There are many methods of assessment. Some are formal (tests, examinations) and aim at measuring whether learning objectives and outcomes have been obtained, others can be informal, allowing individual learners to self or peer assess if learning has taken place. The following box gives some approaches that have been used by ICRAF to evaluate and follow-on with this type of learning event.

Box 2

Evaluation and assessment: approaches and tools

- ***Benchmark and final testing.*** A benchmark test at the beginning of the course will allow the organisers and resource persons to get an idea of what learners already know about the topics that will be taught. This can be either through multiple-choice tests, open response questioning, or practical skill testing. At the end of the course, a similar test can be organised to determine what change (wanted and unwanted!) has taken place.
- ***Daily evaluations.*** Learners can be requested to provide feedback on a daily basis to course organisers and resource persons. Each day, two volunteers can collect feedback from all participants and this can then be presented in a plenary session at the start of a new day or module. Points to be addressed can be: 'what went well?', 'what did not go well?'; and 'how can we improve for the future?'. During the course, participant can also provide individual feedback on a 'mood-o-meter', to express their feelings and sentiments.
- ***Final evaluation.*** At the end of the course, there can be a formal evaluation using a questionnaire, an evaluation 'dartboard' or a 'spider's web'. Covered can be the participants' views (perhaps on a 1 to 5 scale) of: the opportunities provided to participate; the methods used; the overall organisation of the course; the content of the course; and the preparation and skill of the resource persons.
- ***Action planning.*** At the end of the course it is important to know if learners will apply what they have learned. This can be explored by requesting course participants to develop a concrete action plan related to something that was taught on the course and how this means they will do things differently in the future. Such an action plan can describe a specific activity, the resources available or needed to do it, the time frame to implement the activity, the people involved and the means of verification. Ideally, such an action plan should not require new resources to implement, but sometimes the course may be able to give grants to support new activities that a trainee determines to be important. The trainee should be asked to report back on the changes they have made after a six month period.

Conclusion

These brief guidelines describing how to organise a learning event on agroforestry tree domestication are an indication of how this primer can be used to teach its various modules and units. It is up to the training organisers and resource persons involved to make adjustments based on their own needs and opportunities, and based on the requirements of their target audience. Teaching and training are all about actively engaging learners in the process; this cannot be achieved only by reciting written texts such as those presented here.

Agroforestry is all about using trees on farms and in landscapes for the benefit of rural communities and other land users. At the centre of agroforestry innovation and adoption is the agroforestry tree that provides products and services such as fruit, fodder, firewood, timber, medicine, soil fertility, shade, erosion control and carbon sequestration. People have noticed tree-to-tree variation within individual species and have taken advantage of this by selecting, propagating and bringing into cultivation superior types with a view to optimising products and services for human benefit. We know that the processes of domestication started thousands of years ago for some tree species, but more recently modern knowledge has enabled scientists to work in collaboration with farmers to continue and expand these activities.

The purpose of publishing *Agroforestry Tree Domestication: a Primer* is twofold. First, it provides an opportunity to synthesise basic information about important agroforestry tree domestication issues, using recent research results obtained by ICRAF and its collaborating partners. Second, it provides a resource for learners and teachers to use and contextualise for their own purposes. Our intention is to update this primer regularly, so that readers will have access to the latest information on the subject.

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WORLD AGROFORESTRY CENTRE
United Nations Avenue, Gigiri, PO Box 30677, Nairobi 00100, Kenya
worldagroforestry@cgiar.org - www.worldagroforestrycentre.org