African Journal of Biotechnology Vol. 7 (25), pp. 4677-4686, 29 December, 2008
Available online at http://www.academicjournals.org/AJB
ISSN 1684–5315 © 2008 Academic Journals

Review

A decision support tool for propagating Miombo indigenous fruit trees of southern Africa

Simon A. Mng'omba[1]*, Festus K. Akinnifesi[1], Gudeta Sileshi[1], Oluyede C. Ajayi[1], Sebastian Chakeredza[1] and Weston F. Mwase[2]

[1]World Agroforestry Centre, Southern Africa Programme, P.O. Box 30798, Lilongwe 3, Malawi.
[2]Bunda College of Agriculture, University of Malawi, P.O. Box 219, Lilongwe, Malawi.

Accepted 9 September, 2008

Indigenous fruit trees (IFTs) contribute to the livelihoods of rural households as sources of food, income and medicine. Conservation and domestication of IFTs involve germplasm selection, collection, multiplication and evaluation. In addition, biodiversity and genetic improvements have been realized through propagation. However, there are numerous challenges when propagating indigenous trees and the choice of appropriate propagation techniques determines the success of domestication programme. In this paper we synthesize different propagation methods used for indigenous fruit trees, and propose a decision support tool based on desirable attributes of individual IFT, technical requirements, expertise of the propagators and relative cost of implementing the technology in addition to field performance and tree management. Depending on circumstances, this decision support tool can be used to quickly choose a propagation method for a given fruit tree so as to maximize on germplasm collection, multiplication and evaluation without compromising field performance and management of the fruit trees.

Key words: Biodiversity, fruit traits, genetic variation, propagation, wild fruit trees.

INTRODUCTION

Many countries in southern Africa are experiencing increasing environmental and development challenges including rapid deforestation, land degradation, poverty and hunger (The World Bank, 2004; Akinnifesi et al., 2008a). Malnutrition is widespread because many rural communities rely on cereal-based diets, which are deficient in vital nutrients (Ham et al., 2008). The poor nutrition aggravates the dwindling health plight of sick people, especially for HIV/AIDS infected farming families (White and Robinson, 2000). Despite these challenges, southern Africa has abundant renewable natural resources, which could be utilized to address poverty, food insecurity and environmental degradation problems. Africa has a diverse array of indigenous fruit trees which could be utilized to improve nutrition and health of its people. In the last two decades, efforts have been made to domesticate and commercialize priority indigenous fruit trees (IFTs) in order to improve rural livelihoods (Akinnifesi et al., 2008a).

There has been a wide range of germplasm collection and characterization of priority IFTs for domestication in southern Africa (Akinnifesi et al., 2006). Their diversity, role on farm and market opportunities have been exploited (Maghembe and Seyani, 1991). According to Akinnifesi et al. (2006), lack of knowledge on reliable propagation methods has slowed down domestication of many IFTs. In addition, the overexploitation of natural stands due to their high importance is endangering the species. This exacerbates the problem for species which have poor seed viability or meager distribution.

While some breakthroughs have been recorded in propagating some IFTs of southern Africa (Akinnifesi et al., 2006), there is still information gap on the impact of different propagation methods on field performance and management of the trees. Furthermore, availability of many propagation options for trees suggests a need to develop a decision support tool which could be used for selection, evaluation and multiplication of indigenous fruit tree germplasm in the domestication or conservation pro-

*Corresponding author. E-mail: SMngomba@cgiarmw.org. Tel: +265 1 707 319. Fax: +265 1 707 319.

grammes. Tree propagators often use routine methods with the lowest risk of failure, but there is little or no consideration on field performance and management of trees given that each propagation method has both positive and negative effects on field performance and management of trees. Based on two decades of research and development on indigenous fruit trees by the World Agroforestry Centre and its partners in southern Africa (Akinnifesi et al., 2006, 2008a), the objective of this paper is to develop a decision support tool for propagation of IFTs based on desirable fruit traits of individual tree, field performance and management, technical requirements, relative cost of implementing the technology and level of skills or expertise required.

THE ROLE OF PROPAGATION IN TREE CULTIVATION AND ECOLOGICAL RESTORATION

Propagation has been one of the key factors for successful cultivation and sustainable management of IFTs (Akinnifesi et al., 2008a). Although not widely applied in Africa, propagation methods could also aid in ecological restoration of ecosystems and conservation of endangered species (Ray and Brown, 1995; Wala and Jasrai, 2003). Ecological restoration is the recovery of an ecosystem that has been degraded, damaged or destroyed. Many ecosystems in Africa have suffered from demographic growth and external pressures of various kinds, and are in need of restoration. For instance, the Miombo wood-lands of Southern and Central Africa have been deforested and the plant biodiversity is being lost (Sileshi et al., 2007). The restoration of ecosystems and conser-vation of endangered species involves the recovery of indigenous species, propagation and the deliberate reintroduction of species that would have been lost. Propagation plays a crucial role in the reintroduction of such species and macro- and micro-propagation techniques could be useful for mass multiplication of species for restoration.

As illustrated in Figure 1, propagation methods can be used to multiply germplasm so that collection and evaluation can be carried out and these are the key steps in domestication and conservation of indigenous trees. Simple and low-cost propagation methods are important factors that can drive adoption of improved IFTs at farmer level (Akinnifesi et al., 2008a). As more IFTs are being selected from the wild and evaluated for domestication or conservation, there is a need to consider suitable propagation methods since each method has an effect on tree field performance and management. It is envisaged that propagation has a direct impact on tree field survival, growth, productivity and management. It is also a key factor in genetic improvement of wild fruit trees (Ngulube et al., 1997). Application of appropriate propagation methods is expected to lead to improvements in the quality of germplasm and sufficiency in supply. Furthermore, there is a need to develop a database on how individual indigenous fruit and medicinal trees should be propagated.

Sexual and asexual propagation techniques are the commonest methods used for trees as illustrated in Figure 1. Vegetative propagation takes various forms including cutting, budding and grafting, marcotting, and tissue culture. Vegetative propagation involves the asexual regeneration of new plants typically from meristemmatic parts of a ‘mother plant’ or stock plant, and resulting plants are genetic copies of that plant and form a clone (Tchoundjeu et al., 2006). When a clone is derived from a genetically superior plant, it can be multiplied as a cultivated variety (cultivar). A third propagation method involves a combination of sexual and asexual methods (Garner and Chaudhri, 1976). In grafting and budding, a seedling and a vegetative plant part are combined to form a complete plant. In fruit trees, rootstocks are often derived from juvenile plant materials (seedlings), while scions are often derived from the crown of mature tree. Therefore, grafting and budding are not completely vegetative propagation methods as illustrated in Figure 1. Vegetative propagation methods have been used to multiply, test and select superior germplasm from the wild (Akinnifesi et al., 2008a). They are preferred to the use of seeds because they can capture and fix superior fruit and tree traits (Tchoundjeu et al., 2006). However, some IFTs may not be amenable to all vegetative propagation methods.

In the past, domestication of certain crops by farmers or crop breeders was based on the ease of propagation (Mudge and Brennan, 1999). This suggests that propagation methods can influence domestication of potential plants. In this case, wild tree crops which are difficult to propagate can take many years before they are domesticated. Selection of a propagation method should depend on the objective and other factors. This is because a propagation method can determine field performance and management of fruit trees. For instance, orchards established from grafted trees and marcots have resulted in early fruiting and dwarfing of trees at ICRAF-Makoka station in Malawi compared to seedling stand (Akinnifesi, unpublished data). Early fruiting (precocity), fruit size and load, and reduction in plant height (dwarfing) have been important improvements needed for the priority IFTs. The use of seeds often results in large or tall trees and making them undesirable for mixed stands with field crops. Large and tall fruit trees have been favoured, for example in cocoa and coffee plantations, where they provide shade (Tchoundjeu et al., 2006). Dwarf trees have small canopy spread and cannot provide adequate shade unless closely spaced. The different methods of propagation of indigenous fruits trees are described below.

Seeds

The use of seed has been the easiest and cheapest to

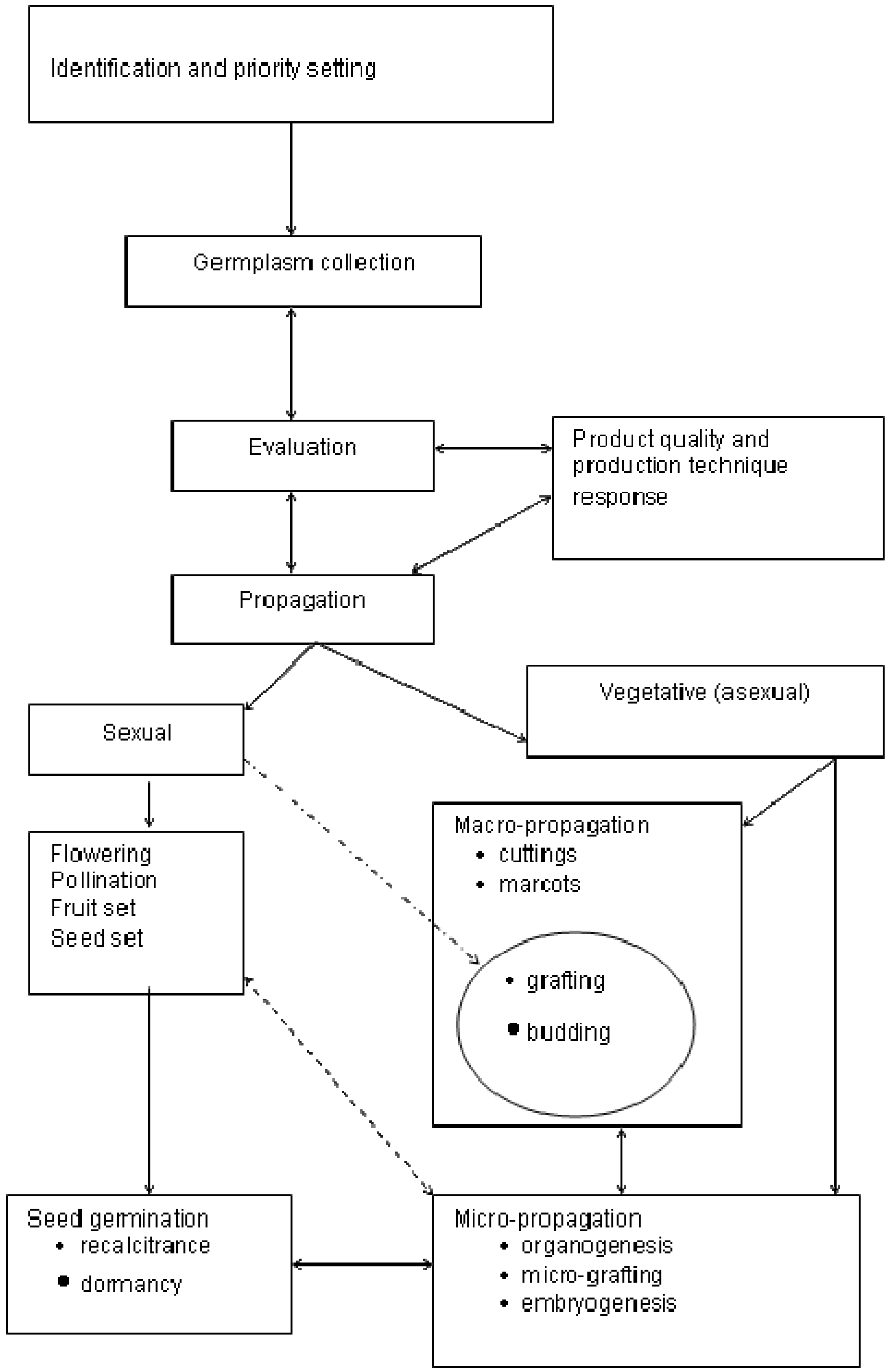

Figure 1. A general schematic pathway for conservation, improvement, domestication and propagation of tree germplasm.

produce and handle (Black, 1989) and most agroforestry and timber trees are propagated from seeds (Mng'omba et al., 2007a). The use of seeds is needed where genetic variation is the main objective (Mudge and Brennan, 1999), for example, to maximise the genetic variability where natural selection brings about adaptive evolutionary changes. The use of seeds allows segregation and recombination of genes, and hence maximises genetic diversity. Seeds have been used for genetic improvement through natural variation where superior trees are selected within a larger population (Dawson and Were, 1997). The desirable genes could be gained through sexual hybridization, but this is often low. Seed germination and seedling growth have been challenges for some IFTs such as *Parinari curatellifolia*. Seed dormancy and recalcitrance are also some common problems affecting seed germination (Figure 1). In addition, for fruit trees having no problem fruiting of precocity and which natural variation is not so high it might be reasonable to use seed.

Cuttings

The use of cuttings (stem or root) is a simple and cheap propagation method for *Tamarindus indica* (Kalinganire et al., 2008). Up to 60% rooting success has been achieved in root cuttings for *P. curatellifolia* (Akinnifesi et al., 2004), but rooting stem cuttings has not been feasible for *P. curatellifolia*, *Sclerocarya birrea*, *Uapaca kirkiana* (Akinnifesi et al., 2006) and *Pappea capensis* (Mng'omba et al., 2007c). Establishment of *S. birrea* had 25% survival in South Africa (Shackleton, 2004). Seasonal rooting of cuttings and low rooting capacity have been major problems for woody trees, but there has been limited research to improve rooting of cuttings. Luckman and Menary (2002) reported that rooting of cuttings of *Eucalyptus grandis* was improved when application of rooting hormone was delayed to two weeks after planting. This corroborates the fact that there is a specific period when the cuttings become responsive to the rooting hormones after planting the cuttings. In West Africa, non-mist propagator has been designed and refined for successful rooting of cuttings of *Irvingia gabonensis, Dacryodes edules* and several other species (Tchoundjeu et al., 2006). Such system was tested with limited success on the miombo indigenous fruit trees in southern Africa (Chilanga, personal communication). Most trees in humid environment are known to respond to stem cutting.

The use of cuttings can offer a number of benefits which include reduction in juvenility phase exhibited by some grafted trees. For instance, grafted *S. birrea* trees are known to revert to juvenility for sometime and this has been attributed to rootstock effects. This can be avoided if cuttings or layers are used as propagation methods. The use of cuttings would result in medium growth of trees suitable for providing shade, especially for the homestead. Fruit orchards can protect the landscape by reducing the impact of soil erosion. In southern Africa, homestead and field fruit orchards are the two common fruit tree planting systems. The former is preferred to the field orchard because of illegal fruit harvesting, especially during the famine or seasonal food shortage periods. Fruit trees can be planted along the field boundary or mixed with field crops or even in pure stands.

Budding and grafting

Budding and grafting involve a formation of a functional union between the two plant parts (a stock and a scion or a bud). Budding is a form of grafting where a single bud is used. The union could be between two stems, a stem and a root, and the commonest union is between two stems (Mudge and Brennan, 1999). A few agroforestry trees and timber trees have been grafted because of low biomass production achieved through grafting or budding. In a few cases, for instance in *Prosopsis*, some rootstocks have invigorating effects on the scion, and hence increase in scion biomass production (Mudge and Brennan, 1999). In some cases, rootstocks have shown a strong influence on the performance of grafted trees. Growth differences have been observed when scions are grafted on seedling or clonal rootstocks. The former group has resulted in wide growth differences, while the latter could result in a comparable growth performance.

Grafting and budding have been used to achieve a number of horticultural benefits such as early fruiting, tree dwarfing and capturing and fixing desirable tree and fruit traits (Akinnifesi et al., 2008a). Also, these methods have been used to rejuvenate old fruit trees when productivity has declined. Rejuvenation can be done through top working (a form of grafting on old fruit trees in the field). Early fruiting, dwarfing and other desirable attributes (Table 1) have been obtained using grafting and layering. It must be recognised that success in grafting, for example in *U. kirkiana*, has depended on the skill of the grafters, time of the year when the scion is collected and the interval between scion collection and grafting (Akinnifesi et al., 2006). Success in grafting has been achieved in *Vangueria infausta* (100%), *P. curatellifolia* (71%), *S. cocculoides* (40-79%) and *S. birrea* (52-80%) indigenous fruit trees (Akinnifesi et al., 2008a).

Survival in the clonal orchards was high for grafted *Adansonia digitata* (100%) in Zambia and *S. birrea* (90%) in Tanzania, but low (40%) for *S. cocculoides* in Zambia (Akinnifesi et al., 2006). Survival of grafted *U. kirkiana* declined from 98% after six months to 67% after 33 months of establishment (Akinnifesi et al., 2008b). Such decline in field survival has been attributed to early graft incompatibility (Mng'omba et al., 2007b). Graft incompatibility has been a threat to fruit tree establishment (Errea et al., 1994) hence the need to select compatible scion/stock combinations. Generally, this has been overlooked in fruit tree industry.

Top working

Another form of grafting is known as the 'top-working.' This is usually done in the field where a scion from desired tree is connected by tissues to a growing tree as a rootstock. It is used to rejuvenate an undesirable cultivar, such as old and unproductive plant or cultivar. Top working can also be used to extend the production cycle, improve the resilience or cultivar value in a wild stand or an orchard. For species that are dioecious, such as *U. kirkiana* and *S. birrea,* top-working is used to introduce male tree (staminate flowers) or branches into an

Table 1. Relative tree growth and early fruit productivity of *Uapaca kirkiana* trees four years after establishment when propagated using grafts, marcots and seedlings.

Parameter	Source of planting material		
	Marcots	**Grafts**	**Seedlings**
Tree height (m)	2.4 ± 0.11	2.0 ± 0.13	2.7 ± 0.14
Bole height (m)	0.39 ± 0.04	0.35 ± 0.04	0.46 ± 0.64
Root collar diameter (cm)	8.5 ± 0.32	9.14 ± 0.35	10.3 ± 0.36
Crown depth (m)	2.0 ± 0.13	0.35 ± 0.04	2.4 ± 0.76
Crown spread (m)	2.7 ± 0.14	2.3 ± 0.13	2.4 ± 0.16
No. of primary branches	17.2 ± 1.33	15.8 ± 0.95	15.3 ± 2.00
No. of secondary branches	25.0 ± 2.60	19.9 ± 2.60	15.3 ± 2.00
No. of tertiary branches	15.0 ± 2.97	10.3 ± 2.91	5.6 ± 1.32
Minimum number of fruits	2	3	0
Maximum number of fruits	414	127	0

Source: Akinnifesi FK, unpublished data.

existing male-deficient orchard or wild stand with predominantly female (pistillate) stand and vice versa (Akinnifesi et al., 2008c). Furthermore, top working has been successful for *U. kirkiana* at ICRAF-Makoka in Malawi and the top worked trees started fruiting four years after establishment (Akinnifesi F.K., unpublished). Scions from superior trees were grafted onto the growing *U. kirkiana* planted a few years earlier. Similarly, Mkonda et al. (2001) reported 65% graft-take for *in situ* grafting of *U. kirkiana* in the wild. This technique would be particularly useful for improving the production quality of seedling established trees on-farm. One unique advantage of top-working is that it can minimize problems associated with poor tree establishment and survival.

Layering

Layering involves induction of adventitious roots on shoot, while the shoot is still attached to the mother plant (Hartmann et al., 1997). A shoot is ring barked for root initiation. Air layering has been the most successful and commonest method compared to ground layering (Figure 2). The latter is done when the shoots are touching the ground, while air layering is when the shoots are off the ground. Root suckering is the opposite of shoot layering (Mudge and Brennan, 1999). The use of air-layers (marcots) would be desirable to make the first clonal plants from sexually matured (i.e. fruiting) wild tree that has been selected for its superior traits. Such clonal stand is used as stockplant from which cuttings, scions are collected for further multiplication by grafting or rooting.

The use of layering could avoid graft incompatibility exhibited in some grafted trees. Air-layers were successful for *U. kirkiana* (63%), but unsuccessful for *P. curatellifolia* and *S. cocculoides* (Mhango and Akinnifesi, 2001). Initially, the survival rate of established marcots was not promising in Malawi and declined with time. This has been attributed to poor root development (Akinnifesi et al., 2008b). When root development and establishment is not a problem *U. kirkiana* marcots have outperformed grafted trees in fruit production and vigour (Table 1).

Tissue culture (micro-propagation)

Micro-propagation involves *in vitro* plant regeneration and enables rapid multiplication of planting materials. Different plant parts (flower, seed, shoot, leaf and fruit) could be a starting material for plant regeneration. The reasons for use of tissue culture (Hartmann et al., 1997; Akinnifesi et al., 2008c) include 1) micro-propagation involving very small plant tissues to produce numerous plantlets, 2) somatic embryo-genesis, 3) embryo rescue, 4) anther (microspore) culture to produce haploid plants for breeding, 5) micro-grafting and 6) tree crop improvement.

In addition, it makes a mass-multiplication of specific clones possible; production of pathogen-free plants and clonal propagation of parent stock for hybrid seed production.

Generally, micro-propagation of woody trees is difficult due to low regeneration capacity, especially mature plant tissues. A major limitation is root regeneration rather than shoot multiplication (Hartmann et al., 1997). *In vitro* micro-grafting is often used where rooting capacity of micro-cuttings has been poor. Micro-grafting also ensures mass multiplication of woody trees that are difficult to root.

A few woody trees have been propagated using micro-propagation. *Maytenus senegalensis* (Matu et al., 2006), *Artocarpus heterophyllus* (Amin and Jaiswal, 1993) and *P. capensis* (Mng'omba et al., 2007c) are examples of woody trees that have been propagated by tissue culture. From various micro-propagation reports, it is clear that there is no universal recipe for all plant species and hence each species has its own requirements.

Rapid growth of micro-propagated plants in the field has been reported. Micro-propagated olive trees fruited earlier than grafted trees (Bati et al., 2006). Micro-propagated fruit trees have yielded better than those derived from seedlings (Margherita et al., 1996). The implication of rapid growth exhibited by micro-propagated fruit trees would translate into high yields per year, especially for single stemmed fruit trees since their growth is continuous. In addition, micro-propagation of endangered plants would enable mass multiplication or regeneration of planting materials from small sections of a cell, tissue or organ. Tissue culture could be used to produce plants that are free from pathogens. The use of as many seedlings as possible would enable maximum amount of genetic diversity in each new population.

Micro-propagation has become an important tool for genetic engineering (recombinant DNA technology) in tree improvement programmes where useful genes are deliberately transferred from one plant to another (Mudge and Brennan, 1999). With organogenesis or embryogenesis (Figure 1) new or modified plants can be regenerated through genetic engineering. Synthetic seeds and short breeding cycles have been achieved through embryogenesis (Singh and Chand, 2003). Embryo maturity, germination and conversion to plantlets have been the major constraints to embryogenesis (Robichaud et al., 2004). Somaclonal variation could be a threat to fruit trees, especially those with wide genetic variations. It could also be a source of genetic diversity and desirable traits when superior traits are gained.

A number of reports show that micro-propagation could be used to rescue seed embryo in some plants. This is important where flower abortions are high and this technique is useful in producing plants from hybridization that produces non-viable seeds. Embryo rescue also promotes the development of an immature or weak embryo into a viable plant (Reed, 2005). The Ovules, ovaries or the entire embryos are removed before seed abortion occurs and then grown on culture medium to produce a new plant and this enables crosses to be made between compatible plant species. This is important for distantly related plants which are crossed together and this ‘wide cross' may be desirable in transferring genetic traits from wild relatives to cultivated crop plants.

EFFECT OF PROPAGATION METHODS ON TREE PERFORMANCE AND MANAGEMENT

Grafting and layering often result in the reduction of tree height (dwarfing). This offers an advantage in fruit tree management such as pruning, fruit thinning, spraying and fruit harvesting. These activities become easy and low-cost. Furthermore, fruit damage as the fruits drop down from dwarf trees is reduced. The use of dwarf trees could be important to households with small land holdings. Among many factors, slow growth of mature trees from which air layers and cuttings are collected could be a major factor contributing to dwarfing. However, there is a need for further investigation on dwarfing mechanism. Grafting and bark ringing have been used as dwarfing mechanisms in peach trees (Hossain et al., 2006), but the main cause of dwarfness has been speculated. This has been linked to low cytokinin production and possibly scion and rootstock union disturbing cytokinin translocation from the roots to the shoots (Andrews and Marquez, 1993).

For branched or polyaxial tree crops, it must be recognised that growers must strike a balance between vegetative growth and fruiting. This is because fruit yields can not simply be improved by the application of irrigation, fertilizer or manure since these stimulate vegetative growth at the expense of fruiting. It is expected that multiple stemmed fruit tree crops propagated by seeds could prolong vegetative growth more than asexually propagated fruit trees, especially those derived from mature plant tissues. Unlike single stemmed fruit crops, tree manipulation should precede manipulation of the growing conditions in order to improve fruit yield. Tree manipulation involves pruning and training in order to achieve strong and well-balanced trees. This will also improve light and air penetration into the canopy to maximise the bearing surface area. Moreover, fruit trees will be less susceptible to wind damage. Therefore, pruning and training activities are reduced with grafts, layers and cuttings that are derived from mature plant tissues.

There is a strong positive relationship between leaf area, growing condition and tree transpiration (van Dijk and Keenan, 2007). Fast growing trees with dense canopy cover have greater water use efficiency than slow growing trees or those with sparse canopy cover. In productive stages, dwarf fruit trees could absorb less water as a result of reduced leaf area. Also, water use efficiency could be modified through tree training and pruning. With respect to propagation method, *E. grandis* cuttings have been reported to exhibit more drought stress tolerance than seedlings (Mudge and Brennan, 1999).

ECONOMIC ASPECTS OF PROPAGATION METHODS

Propagation of fruit trees through vegetative methods are profitable since the break-even point occurs only at least after two to three years (Ajayi et al., 2008). For instance, grafted *U. kirkiana* began to produce fruits only after two to three years, while those derived from seedlings took 12-15 years before fruiting (Akinnifesi et al., 2008a). This indicates that tree growers and domesticators must absorb net losses for at least two or more years before getting the fruit yields. This is a challenge for fruit trees propagated through seeds in that there is a long juvenile phase (long waiting period). Investments in establishing a fruit tree orchard from seedlings are likely to be high due to a long waiting period and also the cost of tree manage-

Table 2. Comparison of five propagating methods for tree crops in terms of technical requirements, tree performance and management and relative cost.

Parameter	Type of propagation method				
	Seeds	**Cuttings**	**Budding/ Grafting**	**Layering**	**Tissue culture**
Requirements					
Equipment	very low	low	high	medium	very high
Labour	very low	low	high	medium	medium
Technical feature					
Expertise	very low	medium	high	high	very high
Tree attributes					
Height	very tall	medium	short	short	medium
Pruning	very high	high	very low	low	medium
Spraying	very hard	easy	easy	medium	medium
Harvesting	hard	easy	easy	easy	medium
Relative cost					
Instruments/inputs	low	moderate	high	high	very high
Labour	very low	low	high	high	medium

ment during fruit bearing periods. The relatively long waiting period (compared with agricultural and annual crops) implies that farmers must commit to initial investment in terms of land, capital or labor and absorb net losses for a couple of years before receiving profits from their investment (Ajayi et al., 2008). This affects the financial attractiveness and potential adoptability of such indigenous fruit trees. This is unlike the dwarf fruit trees achieved through vegetative propagation where pruning and other tree management practices are minimal. Facheux et al. (2008) compared marcots, seedlings and grafted trees of *Dacryloides edulis* using the cost-benefit analysis. They found out that the air layering technique had a net present value greater than zero and the internal rate of return was greater than 20% in a monoculture situation.

There could be high risks when seedlings are used since the bank rates might be high and the long juvenile phase means some costs are likely to be incurred. For *U. kirkiana,* seedlings take 10-12 years before first fruiting, while the grafted trees and layers take two to three years. Layers and grafted trees would be more profitable as a result of reduced payback periods than the use of seedlings despite the fact that grafting and layers are more expensive than the use of seedlings. Data in Table 1 show an increase in secondary and tertiary branches, reduction in bole height and crown depth for grafts and marcots. This increase in number of branches could improve fruit productivity and the reduction in crown depth could improve light penetration into the canopy, and hence good fruit quality with respect to colour could be achieved.

CHOICE OF PROPAGATION METHODS

Identifying appropriate propagation methods based on the intended domestication outcome, level of technology, inputs required, timing and time lag and the level of expertise of the propagator are important for selection of the most suitable method. A generalized method that takes into consideration the low to high technology input, and simple to sophisticated technology is presented in Table 2 and Figure 2. After selecting IFTs to evaluate or multiply, it is important to check the propagation database that might be available in order to choose an appropriate method. The decision should take into consideration factors such as the value of the tree and other attributes as shown in Table 2. The use of seeds could be the starting point unless seed germination has been reported problematic (Figure 2). For example, *V. infausta* seed germination is easy and little or no genetic variability is expected. The use of seeds is an appropriate and cost effective propagation method considering that there are no regional or international markets for this indigenous fruit tree. Generally, the use of seed would depend on the seed type. For instance, orthodox seeds are considered low cost compared to recalcitrant seeds since the latter are difficult to handle and store.

The use of vegetative propagation method (Figure 2) could be selected if there is a need to fix certain desirable fruit or tree traits which would easily be lost when using seeds as propagules. *V. infausta* fruits are for local consumption and hence no need to use high input or sophisticated techniques such as tissue culture unless justified. For *P. curatellifolia*, a feasible propagation method is through the use of root cuttings (Akinnifesi et al., 2004). However, this can be difficult to achieve several hectares of *P. curatellifolia* orchard if comercialised. In this case, micro-propagation technique could be applied for mass multiplication of planting materials. Furthermore, getting the recipe that has already been developed for this fruit tree can be cost effective. How-

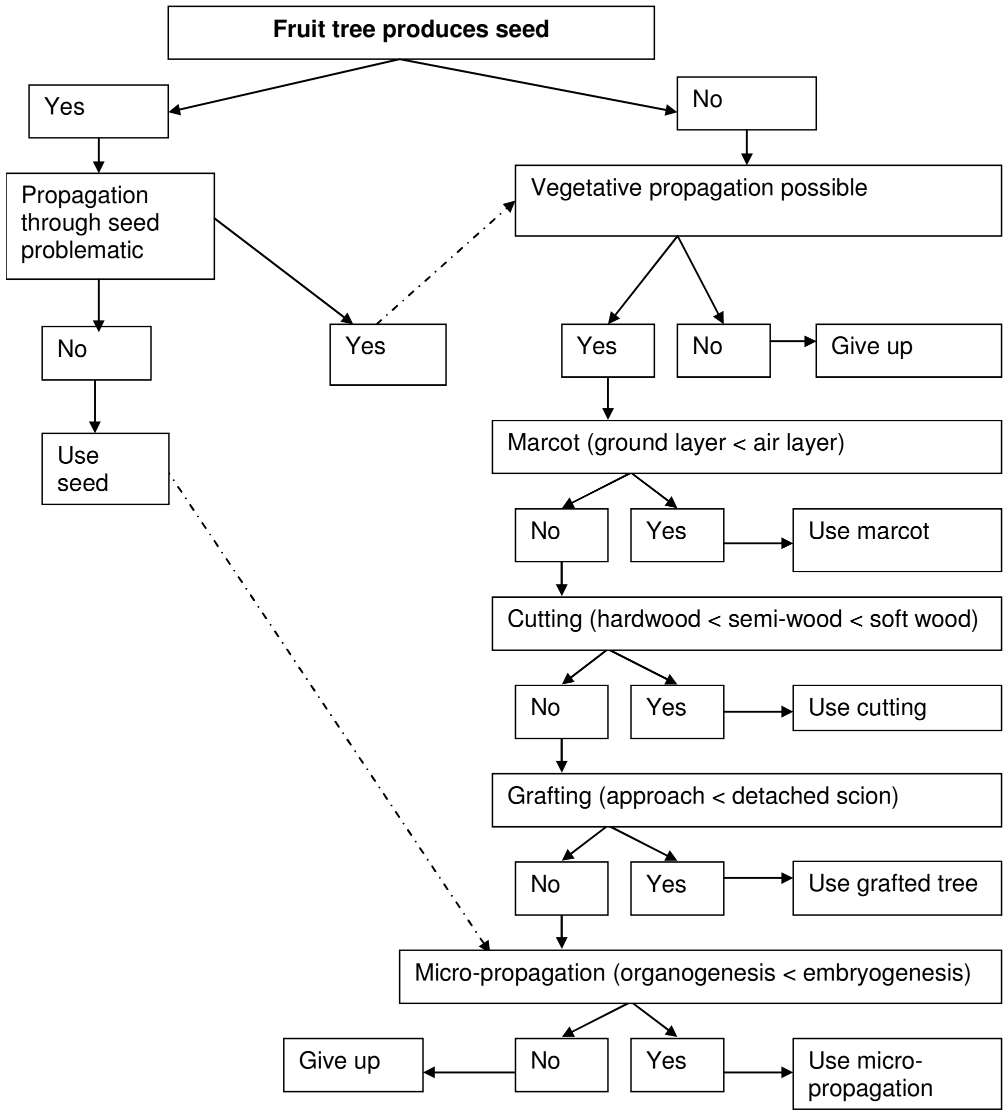

Figure 2. A decision tree based on logic processes that guide the selection of a propagation method.

ever, there is no universal recipe for micro-propagation of plants.

The first step in domestication of a potential wild fruit tree without any propagation database could be the use of seeds (Figure 2). Other vegetative methods could be considered depending upon the desired attributes to be achieved. For instance, the use of marcots would be cost effective and easy for *U. kirkiana* and at the same time fruiting precocity, orchard uniformity and dwarfing would be achieved. Data in Table 1 indicate that high fruit yields were achieved at four years after planting and hence marcots would be a cost effective propagation method considering the reduction in pay back period. *U. kirkiana* has gained a wider local market in southern Africa than other IFTs. The use of marcots would be appropriate if a few *U. kirkiana* trees are needed, while grafting could be suitable for a higher number of *U. kirkiana* trees in an orchard. The use of tissue culture would be selected only if international market or industrial demand becomes so high that it triggers a need to plant several hectares of *U. kirkiana*. At the moment, the use of layering and grafting would be suitable methods with the former being more cost effective than the latter propagation method.

The choice of a suitable propagation method is not only limited to IFTs, but also to exotic fruit trees. Mango, avocado, citrus and many other exotic fruit trees have economic value and gained global or international markets. The use of grafting would be appropriate propagation if a few avocado or mango trees are to be planted for family consumption and/or for the local markets. The use of micro-propagation technique would be appropriate for tree genetic improvements, to free tree crops from the known viral diseases or when there is a need for a wider cultivation of a new cultivar with a high market price.

The citrus industry has a global market, but growing citrus faces challenges in the tropics. Grafting has been a common practice for citrus production. In this case, the use of lemon rootstocks for orange production has been advantageous where termites and other soil-borne diseases for oranges are common. Oranges grown on their own rootstocks would not survive the termite attack or other soil borne diseases that attack orange roots. Generally, many exotic fruit trees of economic value are asexually propagated. Therefore, the choice of asexual propagation method would depend on a number of factors and these have been described in the next section.

RANKING ASEXUAL PROPAGATION METHODS

Asexual propagation options are shown in Figure 2 with ranking at each stage. This ranking takes into account simplicity and the response of the tree when a particular asexual propagation method is applied. At marcot level, for instance, ground layers are easier to root than air layers. This could be attributed to the fact that shoots that are close to the ground or close proximity to the roots are more juvenile than those away from the ground or roots.

For cuttings, it is difficult and expensive to root hardwood cuttings compared to semi-hardwood (Figure 2). Hardness of cuttings determines the quantity of rooting hormones to apply. Generally, softwood cuttings require 0.05-0.3%, while semi-hardwood cuttings require 0.1-0.5% of rooting hormone. Hardwood cuttings require 0.25-1.0% or higher concentration of rooting hormone (Hartmann et al., 1997). In terms of complexity, softwood cuttings are easy to root but more difficult to handle than semi-hardwood. Also, hardwood cuttings are more difficult to root than semi-hardwood cuttings. The specific environmental and physiological constraints must be considered when applying each propagation method (Mudge and Brennan, 1999).

The use of approach grafting technique is easier than detached scion method. Success in graft take has often been higher with approach method than the detached scions and this could be attributed to the fact that the detached scions are prone to wilting apart from disturbances in metabolic processes. The detached scion grafting method is commonly used because it is convenient considering the proximity between the desired mother trees (source of the scions) and where the rootstocks are raised. The distance is often far away, and hence it is not cost effective and convenient to bring rootstocks from the nursery to the mother orchards for approach grafting. This would also demand a lot of labour unlike detached scion method.

Tissue culture techniques require high investments in both equipment and personnel training (Table 2). Skilled labour is needed for tissue culture techniques hence it is considered as a sophisticated technology. Ecological restoration of the degraded ecosystems and multiplication of endangered plant species would warrant the use of this method. For micro-propagation (Figure 2), regeneration of plants from organs (organogenesis) is often easier than from somatic cells (embryogenesis). Micro-propagation has become an important tool in breeding and tree improvement programmes. Application of tissue culture could be important for rapid multiplication of planting materials when bringing priority species into wider cultivation. Other low-cost propagation methods could be used later.

CONCLUSIONS

Propagation of indigenous trees is drawing increased attention in cultivation for commercial use as well as ecosystem restoration. Each tree species is unique in its propagation and regeneration capacity and a better method must be established based on the intended outcome, level of technology and expertise of propagators. It is recommended that field performance and management of trees must be considered when selecting any propagation method, especially for fruit trees. Ranking propagation methods is a key to selecting a suitable method for each indigenous fruit tree. However, there is need for more research to elucidate the effects of different propagation methods on tree performance and management in the field. This will help tree domesticcators, conservationists and fruit tree growers to achieve the intended outcome. There is an urgent need to develop a database on how the individual indigenous fruit and medicinal trees should be propagated.

ACKNOWLEDGEMENTS

The authors are grateful for the financial support from the Federal Ministry of Economic Cooperation (BMZ/GTZ) Germany, Canadian International Development Agency (CIDA), and the government of Ireland through Irish Aid in Malawi. We would like to thank other people who contributed in one way or the other to this paper.

REFERENCES

Ajayi OC, Akinnifesi F, Mitti J, de Wolf J, Matakala P, Kwesiga F (2008). Adoption, economics and impact of agroforestry technologies in southern Africa. In: Batish DR, Kohli RK, Jose S, Singh HP (eds) Ecological Basis of Agroforestry. CRC Press/Taylor & Francis Group, pp. 343-360.

Akinnifesi FK, Ajayi OC, Sileshi G, Matakala P, Kwesiga FR, Ham C, Kadzere I, Mhango J, Mng'omba SA, Chilanga T, Mkonda A (2008a). Creating opportunities for domestication and commercializing miombo indigenous fruit trees in southern Africa. pp. 137-170. 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. World Agroforestry Centre: Nairobi. CABI Publishing, Wallingford, UK.

Akinnifesi FK, Kwesiga F, Mhango J, Chilanga T, Mkonda A, Kadu

CAC, Kadzere I, Mithöfer D, Saka JDK, Sileshi G, Ramadhani T, Dhliwayo P (2006). Towards the development of miombo fruit trees as commercial tree crops in southern Africa. For, Trees Livelihoods 16: 103-121.

Akinnifesi FK, Kwesiga FR, Mhango J, Mkonda A, Chilanga T, Swai R (2004). Domesticating priority for miombo indigenous fruit trees as a promising livelihood option for small-holder farmers in southern Africa. Acta Horticult. 632: 15-30.

Akinnifesi FK, Mhango J, Sileshi G, Chilanga T (2008b). Early growth and survival of three miombo woodland indigenous fruit tree species under fertilizer, manure and dry-season irrigation in southern Malawi. For. Ecol. Manage. 255: 546-557.

Akinnifesi FK, Sileshi G, Mkonda A, Ajayi OC, Mhango J, Chilanga T (2008c). Germplasm supply, propagation and nursery management of miombo fruit trees. pp. 341-368. 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. World Agroforestry Centre: Nairobi. CABI Publishing, Wallingford, UK.

Amin MN, Jaiswal VS (1993). *In vitro* response of apical explants from mature trees of jackfruit (*Artocarpus heterophyllus*). Plant Cell, Tissue Organ. Cult. 33: 59-65.

Andrews PK, Marquez CS (1993). Graft incompatibility. pp 183-232. In: Janick J (ed) Horticultural Reviews, vol. 15, Wiley, New York, USA.

Bati CB, Godino G, Monardo D, Nuzzo V (2006). Influence of propagation techniques on growth and yield of olive tree cultivars 'Carolea' and 'Nocellara Etnea'. Sci. Horticult. 109:173-182.

Black M (1989). Seed research – past, present and future. In: Taylorson RB (ed) Recent Advances in the Development of Germination of Seeds. Series A, Life Sciences. Vol. 187. Plenum Press, NY, p. 295.

Dawson I, Were J (1997). Collecting germplasm from trees - some guidelines. Agrofor. Today. 9: 6-9.

Errea O, Felipe A, Herrero M (1994). Graft establishment between compatible and incompatible *Prunus spp*. J. Exp. Bot. 272: 393-401.

Facheux C, Tchoundjeu Z, Gony H, Alain T, Asaah E (2008). Economic comparison of vegetative multiplication techniques. A paper presented at the Science Week meeting. Nairobi, Kenya.

Garner RJ, Chaudhri SA (1976). The Propagation of Tropical Fruit Trees. Horticultural Reviews No. 4. Commonwealth Bureaux of Horticulture and Plantation Crops, Commonwealth Agricultural Bureaux, Slough, England, p. 566.

Ham C, Akinnifesi FK, Franzel S, Joordan D du PS, Hansmann C, Ajayi OC, de Kock C (2008). Opportunities for commercialization and enterprise development of indigenous fruits in southern Africa. 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. World Agroforestry Centre: Nairobi. CAB International Publishing, Wallingford, UK. pp. 254-272.

Hartmann HT, Kester DE, Davies FT (1997). Plant Propagation, Principles and Practices. 6th ed. Prentice-Hall, Inc., Eaglewood Cliffs, New Jersey, p. 647.

Hossain ABMS, Mituzani F, Onguso JM, El-Shereif AR (2006). Dwarfing peach trees and development of fruit quality by maintaining partially ringed bark strips as an innovative process in dwarfing technology. Bot. Stud. 47: 251-257.

Kalinganire A, Weber JC, Uwamariya A, Kone B (2008). Improving rural livelihoods through domestication of indigenous fruit trees in the parklands of the Sahel. 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. World Agroforestry Centre: Nairobi. CABI Publishing, Wallingford, UK. p. 186-203.

Luckman GA, Menary RC (2002). Increased root initiation in cuttings of *Eucalyptus nitens* by delayed auxin application. Plant Growth Reg. 38: 31-35.

Maghembe JA, Seyani JH (1991). Multipurpose trees used by small-scale farmers in Malawi: results of an ethnobotanical survey. AFRENA Report No. 42. Nairobi: ICRAF.

Margherita B, Giampiero C, Pierre D (1996). Field performance of tissue-cultured plants of *Ranunculus asiaticus* L. Sci. Horticult. 66: 229-239.

Matu EN, Lindsey KL, van Staden J (2006). Micropropagation of *Maytenus senegalensis* (Lam) Excell. S. Afr. J. Bot. 72: 409-415.

Mhango J, Akinnifesi FK (2001). On-farm assessment, farmer management and perception of priority indigenous fruit trees in southern Malawi. In: Kwesiga F, Ayuk E, Agumya A (eds) Proceedings of a 14th Southern Africa Regional Review andPlanning Workshop, 3-7th September, Harare, Zimbabwe: ICRAF, pp. 157-164.

Mkonda A, Akinnifesi FK, Mafongoya P (2001). Response of indigenous and exotic fruit trees in Zambia to grafting and air-layering. Proceeding of the 14th Southern Africa Regional Review and Planning Workshop, 3-7th September, Harare, Zimbabwe: ICRAF, pp. 136-139.

Mng'omba SA, du Toit ES, Akinnifesi FK (2007a). Germination characteristics of tree seeds: Spotlight on southern African tree species. Tree For. Sci. Biotechnol. J. 1: 81-88.

Mng'omba SA, du Toit ES, Akinnifesi FK, Venter HM (2007b). Histological evaluation of early graft compatibility in *Uapaca kirkiana* Müell Arg. scion/stock combinations. HortSci. 42: 1-5.

Mng'omba SA, du Toit ES, Akinnifesi FK, Venter HM (2007c). Repeated exposure of jacket plum (*Pappea capensis*) micro-cuttings to indole-3-butyric acid (IBA) improved in vitro rooting capacity. S. Afr. J. Bot. 73: 230-235.

Mudge KW, Brennan EB (1999). Clonal propagation of multipurpose and fruit trees used in Agroforestry. In: Buck LE, Lassoie JP, Fernandes ECM (eds) Agroforestry in Sustainable Agriculture Systems. CRC Press, New York, USA.

Ngulube MR, Hall JB, Maghembe JA (1997). Fruit, seed and seedling variation in *Uapaca kirkiana* from natural populations of Malawi. For. Ecol. Manage. 98: 209-219.

Ray GJ, Brown BJ (1995). Restoring Caribbean dry forests: Evaluation of tree propagation techniques. Restoration Ecol. 3: 86-94.

Reed S (2005). Embryo Rescue. In: Trigiano RN, Gray DJ (eds) Plant Development and Biotechnology. CRC Press, pp. 235-239.

Robichaud RL, Lessard VC, Merkle SA (2004). Treatments affecting maturation and germination of American chestnut somatic embryos. Plant Physiol. 161: 957-969.

Shackleton CM (2004). Use and selection of *Sclerocarya birrea* (Marula) in the Bushbuckridge lowveld, South Africa. In: Rao MR, Kwesiga FR (eds) Proceedings of a Regional Agroforestry Conference on Agroforestry Impacts on Livelihoods in southern Africa: Putting Research into Practice: World Agroforestry Centre, Nairobi, Kenya, pp. 77- 92.

Sileshi G, Akinnifesi FK, Ajayi OC, Chakeredza S, Kaonga M, Matakala P (2007). Contribution of agroforestry to ecosystem services in the miombo eco-region of eastern and southern African. Afr. J. Environ. Sci. Technol. 1(4): 068-080.

Singh AK, Chand S (2003). Somatic embryogenesis and plantlet regeneration from cotyledon explants of a timber-yielding leguminous tree *Dalbergia sissoo* Roxb. Plant Physiol. 160: 415-421.

Tchoundjeu Z, Asaah EK, Anegbeh P, Degrande A, Mbile P, Facheux C, Tsoberg A, Atangana AR, Ngo-Mpeck ML, Simons AJ (2006). Putting participatory domestication into practice in West and Central Africa. For, Trees Livelihoods. 16: 53-70.

The World Bank (2004). African Development Indicators. International Bank for Reconstruction and Development, Washington D.C., p. 397.

van Dijk AIJM, Keenan RJ (2007). Planted forests and water in perspective. Fore. Ecol. Manage. 251: 1-9.

Wala BB, Jasrai YT (2003). Micropropagation of an endangered medicinal plant *Curculigo orchioides* Gaertn. Plant Tissue Cult. 13(1): 13-19.

White J, Robinson E (2000). HIV/AIDS and rural livelihoods in the Sub-Saharan Africa. Policy series 6, Chatham, NRI, UK.