TREE IMPROVEMENT STRATEGY FOR SOUTHERN HIGHLANDS

APRIL, 2016

TREE IMPROVEMENT RESEARCH WORKING GROUP

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PREFACE

Establishment of forest plantations in Tanzania started as early as the 1890s with the sole objective of supplementing dwindling wood supplies from natural forests. This was then subsequently followed by large scale industrial forest plantation establishment in the 1950s. Tree improvement research is one of the key areas that supports productive forest plantations and indeed, this research played a key role in the success of these early industrial plantations.

However, the levels of investment in research and development related to plantation forest productivity became inadequate due to lack of both financial resources and technical expertise in various departments. Over time therefore, tree improvement research was unable to address key constraints of the forestry sector including access to improved seed and narrow genetic base of industrial tree species in both public and privately owned plantations.

The southern highlands remains the most important part of the country in terms of plantation establishment by public and private sector, and therefore contributes heavily towards revenue generation, local livelihoods and meeting urban wood demand. This Tree Improvement Strategy has been developed for the Southern Highlands and outlines a step-by-step process of how the constraints facing the industry can be mitigated in the short, medium and long term.

The process to develop the strategy has been inclusive and involved the inputs of many major sector players. Representatives of various institutions who belong to Tree Improvement Research Working Group will now come up with work plans for effective implementation of the collaborative Tree Improvement Programme for Southern Highlands. If implemented in accordance with the strategy, the development and application of high quality and diverse genetic material will certainly help maintain competitiveness and resilience of the commercial forestry sector.

Simon Milledge
Forestry Development Trust Director

EXECUTIVE SUMMARY

This Tree Improvement Strategy for the Southern Highlands was produced by public and private sector stakeholders to help ensure the application of high quality and diverse genetic material will maintain competitiveness and resilience of the commercial forestry sector.

The strategy builds on a 2013 scoping study covering forestry plantations and institutions which derive their raw materials for industrial application from wood, conducted by the Forestry Development Trust (FDT), Tanzania Forest Research Institute (TAFORI) and Tanzania Tree Seed Agency (TTSA).

Two species, *Pinus patula* and *Eucalyptus grandis*, were selected as priority species for the initiation of tree improvement in the Southern Highlands based on their dominance in the forestry landscape. Other species should, however, be tested in a series of site-species trials, as species choice plays a highly significant role in the sector particularly on the marginal sites which fall outside high productivity sites in terms of average rainfall and soil depths. Indeed, site species trials now exist for the most common genera Eucalyptus, Pine and Corymbia spp. (see Appendices I and II).

Strategies for the introduction, breeding, commercial production, and conservation of the species are outlined. The strategy outlines the need for securing improved germplasm for further breeding, the development of facilities and infrastructure, and the recruitment and training of staff for such a program.

Above all, the Tree Improvement programme should now focus on having institutional arrangements in place through the already established Tree Improvement Research Working Group that will drive a collaborative approach for the benefit of all sector players.

ACKNOWLEDGEMENTS

The development of this strategy was made possible through substantial technical support from a range of institutions including the Forestry Development Trust (FDT), Tanzania Forest Research Institute (TAFORI), Tanzania Tea Seed Agency (TTSA), Tanzania Forest Services Agency (TFS) and Sokoine University of Agriculture (SUA).

FDT also facilitated meetings of the Tree Improvement Research Working Group (TIRWG), while FDT's Genetic Resources team has continued to implementing the strategy in collaboration with many TIRWG members. TAFORI and TTSA are acknowledged for funding and providing their respective senior researchers in conducting a joint initial scoping study for genetic resources in the Southern Highlands which formed the basis of this strategy document. SUA and TFS also provided valuable inputs to this collaborative initiative all the way from inception to adoption stage.

Other members of the TIRWG to have contributed towards development of this strategy include Green Resources Limited, New Forests Company, Kilombero Valley Teak Company, TANWAT, Mufindi Paper Mill, Sustainable Forestry Investment, Jambe Agro and the Private Forestry Programme.

A range of private players and church organisations have availed land, technical inputs and other forms of cost-sharing in the establishment of some of the early site species matching trials, including Green Resources Limited, New Forests Company, Kilombero Valley Teak Company, TANWAT, Mufindi Paper Mill, Kisolanza Farm, Njombe Catholic diocese and Morovian church organisation in Rungwe-Tukuyu district. These players have also been integrally involved in the development of this strategy.

In addition, several tea companies and associations (Igominyi Tea Outgrowers Association, Wakulima Tea Company, Unilever Tea Tanzania Limited, Kibena Tea Company) are thanked for voicing their needs for energy requirements which helped informed species selections, while Tanzania Forest Industries Federation (SHIVIMITA) is acknowledged for full participation in the programme from inception.

Lastly, the financial contributions from the Gatsby Charitable Foundation and UK Department for International Development is gratefully acknowledged.

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ABBREVIATIONS AND ACRONYMS

CAMCORE	Central America Mexico Conifer Resources
CSIR	Council for Scientific and Industrial Research
DFID	Department For International Development
EAAFRO	East African Agricultural and Forestry Research Organisation
ERD	Effective Rooting Depth (cm)
FDT	Forestry Development Trust
FITI	Forestry Industries Training Institute
GCF	Gatsby Charitable Foundation (UK)
GRL	Green Resources Limited
ISAAA	International Service for the Acquisition of Agri-Biotech Applications
KEFRI	Kenya Forestry Research Institute
KVTC	Kilombero Valley Teak Company
M.A.S.L (m)	Meters Above Sea Level (m)
MAP (mm)	Mean Annual Precipitation (mm)
MAT (^{O}C)	Mean Annual Temperature (^{0}C)
MNRT	Ministry of Natural Resources and Tourism
MoU	Memorandum of Understanding
MPM	Mufindi Paper Mill
NAFORI	National Forestry Research Institute
NFC	New Forests Company
PFP	Private Forest Programme
SHIVIMITA	Shirikisho la Viwanda vya Misitu Tanzania
SUA	Sokoine University of Agriculture
TAFORI	Tanzanian Forestry Research Institute
TANWAT	Tanganyika Wattle Company
TBP	Tree Biotechnology Project
TFS	Tanzania Forestry Service
TIRWG	Tree Improvement Research Working Group
TTBP	Tanzania Tree Biotechnology Project
TTSA	Tanzanian Tree Seed Agency
ZFC	Zimbabwe Forestry Commission

DEFINITIONS OF TREE BREEDING TERMS

Advance generation selection	Selection of a tree by genetic test of crosses among parents from previous generation. Some form of family and within family selection is usually used to construct the advanced generation.
Base population	The population of trees from which the tree breeder chooses to make selections for the next generation of breeding. The base population can be natural stand (first generation) or a genetic test.
Breeding strategy	An overview of the management plan of the genetic improvement of a tree species used in man-made forests.
Breeding Seed Orchard	A breeding trial which is converted to a seed orchard.
Breeding Population	A subset of individuals from a base population that is selected for their desirable qualities to serve as parents for the next generation of breeding.
Certified tree seed	Seed collected from trees of proven genetic superiority, as defined by certifying agency, and produced under conditions that assure genetic identity. This could come from trees in seed orchards, or from superior (plus) trees in natural stands with controlled pollination.
Clonal Trial	Comparison and evaluation of a number of clones in replicated tests. Such tests provide performance estimates of respective genotypes, but do not necessarily provide information on breeding behaviour.
Clonal Seed Orchard	Seed orchard raised from selected clones propagated by grafting, budding, air-layering or rooting of cuttings.
Seedling Seed Orchard	Seed orchards raised from seedlings produced from selected parents through natural or controlled pollination.
Forward selection	Selection of an individual tree, based on the performance of the tree plus that of it's siblings (and parents), in predicting the breeding performance of the individual.
Backward selection	Selection of an individual tree, based on the performance of the tree's progeny, in predicting the breeding performance of the individual.
Family	The sexually produced individuals derived from a common male and /or female parent tree.
Family Selection	The selection of families based on their mean performance. In addition, the best individuals are usually selected in the best families.
Gene conservation	Protecting and maintaining the genetic variation of a species in order to keep a genetic resource for future research and improvement.
In-situ gene conservation	Protection of genetic variation of a species at its native sites, e.g. by establishing forest reserves.
Ex-situ gene conservation	Protection of genetic variation of a species outside its native site e.g. established plantations.
Plot	A group of trees of single family, provenance or species. The plots vary in size from one (single-tree plot) to several hundred (multiple-tree plot) trees that are treated as a unit in a field trial.

Plus Tree	A tree appearing distinctly superior to the average. The term is used for describing phenotypes of both stands (plus stands) and single trees (plus trees). The superior character(s) should be specified i.e. plus for volume, quality, pest-resistance, or a combination of characters.
Pollen	The microspores of seed plants, produced in vast numbers in the male part of the flower (anther).
Population	Genetically, a group of similar individuals related by descent and so delimited in a range by environmental or endogenous factors as to be considered a unit. In cross-bred organisms the population is often defined as interbreeding group.
Progeny Trial	Evaluation of parents by comparing the performance of their offspring (see backward selection).
Provenance Trial	A well-designed comparison of population sampled from a range (preferably the whole range) of species. Each 'provenance' is a potential 'ecotype' of that species. Should be established in two or more environments to enable assessment of provenance x environment interaction.
Resistance	Relative ability to endure pests or other damaging influences.
Replicated Trial	Part of a test trial duplicated in two or more sites
Replication	Duplicated part of a test (site) (in terms of entries) with the same experimental design.
Rootstock	The root-bearing plant or plant part, usually stem or root, onto which another plant is grafted.
Scion	An aerial plant part, often a branchlet that is grafted onto the root-bearing part (stock, rootstock) of another plant.
Seed	Morphologically the structure developed from fertilized ovule in seed plants.
Seedlot	A quantity of seeds of the same species, provenance, date of collection and handling history, and which is identified by a single number.
Seedling Seed Orchard	An orchard derived from seed composed of several individual families (typically >50 families)
Trait (Character)	A distinctive but not necessarily invariable feature exhibited by all individuals of a group and capable of being described or measured; e.g. Size, straightness, form and wood properties.
Forest Tree Breeding	Practices applying knowledge of genetics to develop improved trees. Conventional tree breeding is based on selection of individuals for certain desired characters and mating these individuals for certain desired characters and mating these individuals to produce an improved population. Forest tree breeding may connote breeding systems varying from harvesting seed from only the best sources (mass selection) to sophisticated multi-phase, multi-generation programmes with controlled pollination.

1. TREE IMPROVEMENT IN TANZANIA

1.1. BACKGROUND

Commercial forestry is a growing industry in many developing countries such as Tanzania. Increased domestic and international demand for wood-based products requires an ever increasing supply. Demand can be met by either increasing the size of the forest area, by increasing the productivity of the existing forest area, or both. Population pressure and environmental constraints usually inhibit large-scale afforestation programmes required to meet future demand, whilst investing in methods to increase the yield potential of existing forests is often more feasible. Yields per unit area of forests land can be increased in a number of ways:

- **Tree improvement (breeding) programmes:** breeding for improved volume yield, specific density, form, wood quality, disease resistance and other characteristics;
- **Optimised silvicultural operations:** soil preparation, site-species matching, spacing, planting, fertilising, weeding, thinning, pruning and fire/pest/disease management;
- **Optimised harvesting operations:** increased fibre utilisation and reduced site disturbance (e.g. soil compaction) that can affect productivity; and
- **Optimised manufacturing processes:** increased product output per unit of raw material input.

In Tanzania, the establishment of exotic tree species on a trial basis was started by the Germans during the early 1900s, and continued by the British from 1921. Large-scale planting started seriously in the 1950s and culminated in the 1970s with the exception of some plantations such as Sao Hill.

Industrial forestry particularly of fast growing species was necessary to reduce pressure on indigenous forest for timber. There are several advantages associated with intensively managed plantations. These may include and not limited to the following:

- Possibilities of getting high yield of volume of known size and uniform quality per unit area. Production figures of the order 15 to 25m^3 per hectare per annum can be achieved on fairly good sites while on better sites the production can go up to and beyond 35 m^3 per hectare per annum.
- Potential to meet projected demand from fairly smaller areas and hence reduce pressure on land;
- Flexibility in locating plantations in relation to markets and transport facilities;
- Cost effectiveness to organise harvesting from these plantations;
- Possibilities for genetic and silvicultural improvements; and
- Increasing the predictability or reliability of long-term yield projections.

To date, several thousand hectares of industrial plantation species have been planted mostly in three main areas of Tanzania: the North East; South and Lake Victoria.

Although a relatively wide range of exotics as well as indigenous tree species have proved suitable in various ecological conditions, past forest management placed emphasis on four major genera: *Pinus patula, Cupressus lusitanica*, *Eucalyptus globulus* ssp *maidenii* and *E. grandis*/*saligna* and *Tectona grandis*.

1.2. IMPORTANCE OF TREE IMPROVEMENT

Tree improvement plays a major role in forestry development; application of high quality and diverse genetic material is essential to maintain competitiveness and resilience of commercial forestry sector. Having access to good quality genetic stock and implementation of good silvicultural management makes it possible to optimise productivity and quality in relation to end-market use. While many forestry programmes recognise this and invest in tree improvement activities, those that don't suffer the consequences of poor form and growth in their growing stock. Tree improvement enables diversification in planting material to offer some protection against risks such as disease, pests and fire.

The range of activities associated with tree improvement can seem numerous, expensive and necessitate specialist experience, but in reality this is no different from any other area of forestry. All sectors have their own specialists and have their own unique activities. The difference between tree improvement and many other forestry sectors is that the consequences of failure to invest are not always immediately apparent. Poor quality growing stock can be attributed to many causes, and is often a result of interacting forces, but the fact that we can't see the genetic make-up of a tree means that attribution of blame frequently falls at the feet of areas of forestry management other than tree improvement.

In any country and in any situation, if the plantation growing stock is to be improved significant attention needs to be paid to its genetic constitution. This entails careful management through a clearly defined tree improvement strategy.

1.3. GATSBY/MONDI INVOLVEMENT IN FORESTRY DEVELOPMENT

A regional tree improvement programme (EAAFRO) which was mandated to carry out research contributed a lot to the growth of the sector in the early years partly through involvement of technical experts from Europe but with the breakup of the East African community in 1977, individual countries started focusing on their own country needs and immediately they started facing problems often related with funding challenges and technical expertise and that slowed down meaningful progress in research and development in the forestry sector regionally until Gatsby intervention in 1997 through the initiation of tree biotechnology project (TBP) in collaboration International Service for the Acquisition of Agri-Biotech Application (ISAAA) and started implementation in the East African region firstly in Kenya (1997) followed by Uganda (2000) and finally in Tanzania (2003). In Tanzania the programme then became known as Tanzanian Tree Biotechnology Project (TTBP) which focused (among others) on testing land races of both Eucalyptus species and one species from the Corymbia genus (*E. camaldulensis*, *E. tereticornis*, *E. grandis*, *E. saligna* and *C. citriodora*). 17 Eucalyptus clonal hybrids were tested in 15 representative sites countrywide.

Gatsby/ Mondi partnership introduced improved eucalyptus hybrid clonal material in East Africa and that rejuvenated improved technology in propagation of hybrid clones. With the pressure being exerted on tree genetic resources worldwide due to, inter alia, the advent of new diseases emerging at a much faster rate, it is logical to start broadening genetic bases of eucalypt and pine germplasm in East Africa by testing additional resources. The experience of running programmes of regional trials in the region through the national forestry research institutes (KEFRI, NaFORI and TAFORI) has yielded fragmented and inadequate results on which to grow a sector. Some trials' results could not be obtained at a regional level and that makes it difficult to consolidate results for sector benefit and, besides, the wood properties of most the clones were not of benefit to regional forestry sector predominantly based on sawn timber and transmission poles markets. It therefore became necessary to look at other more inclusive models that incorporate more market actors including the private sector, and that link research to outputs and targets. Gatsby wish to develop a strategy for reinvesting and accelerating tree improvement research (focusing on eucalypt and pine germplasm development, but not excluding other species with potential) in Southern Highlands Tanzania as a pilot with potential to similar models being adopted to include the entire country and later to the entire region particularly with market players beginning to have a shared vision of Tree Improvement playing a significant role in improving the competitiveness of planted forestry sector in the region to the benefit of all market players through having healthy financial returns . Furthermore, Gatsby wish to invest in strategies for the rapid deployment of genetic gains in the sector on an ongoing sustainable basis. This can be assisted by exploring the opportunity to make new crosses in interspecific hybrid clones, widening areas previously not covered by the clones that have been tested, and broadening the genetic bases of the breeding populations of the parental species contributing the hybrid clones (*E. grandis*, *E. urophylla*, *E. tereticornis* and *E. camaldulensis*). In addition, there is the opportunity to procure additional hybrid clones to test in the region with special attention being paid to the target market requirement. Lessons were learnt after critical evaluation of Gatsby 15 year participation in clonal forestry in the region. East African membership of Camcore, a genetic material network, as well as models of tree improvement from comparable countries such as Zimbabwe and South Africa were also looked at and the following areas needed urgent attention;

a) Testing introduced improved seed sources of pine and eucalypts (CAMCORE, ZFC, Private sector RSA and others)

b) exploring the opportunity to make new crosses in interspecific eucalypt hybrid clones, widening areas previously not covered by the clones that have been tested, and

c) Broadening the genetic bases of the breeding populations of the parental species contributing to hybrid clones (*E. grandis*, *E. urophylla, E. tereticornis*, *E. nitens* and *E. camaldulensis*) and

d) Procuring additional hybrid clones to test in the region for specific market requirements

Realising that introduced clones were not bred for multiple use in different markets, Forestry Development Trust together with TAFORI and TTSA funded a genetic resources inventory in Southern Highlands and potential market for wood products in 2013. A comprehensive report was compiled and the recommendations were put forward was presented to stakeholders in Morogoro. The Tree Improvement Strategy was then formulated which is now being implemented in phases to try and address the inadequacy in place to make resources available for deployment in the Southern Highlands through the involvement of all key sector players.

2. TREE IMPROVEMENT SCOPING STUDY

The Tree Improvement scoping study for the southern highlands (Komakech and Blakeway 2014) forms a background to this document and proposes a three phase implementation strategy (Short, Medium and Long Term).

1. Short term:
    a. Secure commercial seed (and clones) from abroad for distribution to nurseries and establishment of clonal hybrid trials
    b. Start sourcing material for Seedling Seed Orchards (locally and abroad)
    c. Start marking plus trees and collect breeding material
    d. Prepare rootstocks for grafting operations (in the case of Clonal Seed Orchards)
    e. Start planning establishment of Site-Species matching trials (Species listed in **Appendix I**)
2. Medium term:
    a. Establish *P. patula* and *E. grandis* breeding populations
    b. Conserve Tree Biotechnology Project clones (from the entire regional project)
    c. Acquire land and start planting Clonal and/or Seedling Seed Orchards
3. Long term:
    a. Develop breeding populations of more species based on potential markets (both current and future), broader climatic adaptability, pest and diseases, growth conditions in Tanzania and suitability for both small scale and industrial application (*E. saligna, E. urophylla, E. tereticornis, E. camaldulensis, E. cloeziana and E. globulus ssp maidenii, P. elliottii, P. caribaea vr caribaea, P. caribaea* vr. *hondurensis*, *P. caribaea* vr. *bahamensis P. tecunumanii* (H&L elevation), *P. taeda, P. oorcapa P. maximinoi P. greggii* (N), *P. greggii* (S) and *P. kesiya*) and develop seed orchards and clonal material.
    b. Develop and test new hybrids for the region based on material coming out of the breeding programme established in Tanzania.
4. Other research and development:
    a. Focussed clonal technology where it can add most value only

The above phases are a logical approach and are assumed to form a background to the following discussion. It is suggested, however, that clonal seed orchards would be preferred if at all possible, however the resources may not be immediately available for clonal seed orchards- in which case, seedling seed orchards are a practical alternative (however most likely lower genetic gains). The expansion to other species should be decided upon in due course, with input from proposed site-species trials and from monitoring of both member and market needs.

3. BROAD FRAMEWORK

A broad framework is represented in Figure 1. The current phase entails initiation of the breeding programs, the acquisition of the appropriate materials, infrastructure and staff, and discussions around the formulation of a co-operative or similar body.

An important research process parallel to the breeding process is to develop a set of site-species matching trials. These trials will serve various valuable roles:

1. Inform the members as to the relative performances of species in various sites, with respect to growth, wood properties, health and other attributes. This is crucial as the largest impact is usually derived from genus/species/hybrid choices. The tree improvement value is usually 'added' to the base value attributed to this initial choice of species. It is therefore important to gather this information as soon as possible.
2. These trials often serve as demonstration trials for field days and extension work.
3. Data derived from these trials can be used for quantification of relative growth rates and modelling of appropriate sites for various species.

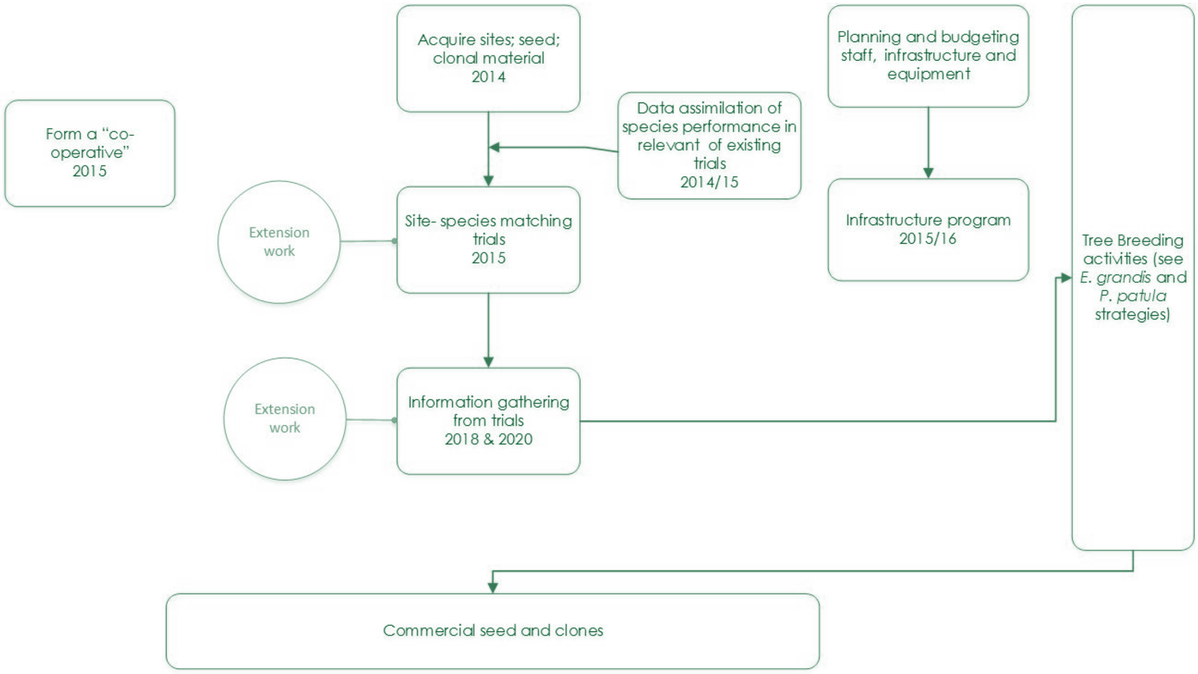

Figure 1 A broad framework of development of a tree improvement program, noting the supportive processes and structures required.

Regarding the infrastructure noted in Figure 1, there are a number of requirements including:

1. Planting and measuring equipment;
2. A research nursery with good hygienic facilities and practices to prevent the introduction of pests and diseases;
3. Holding nursery, materials and equipment’
4. Seed store and handling facilities;
5. Pollen storage and handling facilities;
6. Grafting and cloning, labelling materials and equipment;
7. Office equipment, and tree breeding database and analysis software;
8. Seed orchard sites, fencing and maintenance;
9. Trial sites; and
10. Vehicle and seedling transport trailer.

4. GENUS AND SPECIES CHOICE

Successful tree breeding programs are often dependant on a fine balance of two opposing imperatives. The first is to be focussed, as the programs can become unmanageable should the tree breeding program have too many species and hybrids to breed (each with their own technical challenges). The second imperative for a tree breeding program is to have sufficient genetic diversity and alternative species choice to be able to adapt to a changing environment, for example new pests/diseases and market forces can force species changes.

As commercial tree breeding in Tanzania is in initial stages of development, the best information at hand is to a large extent that of current practice and experience. It is suggested that currently available trials and data be synthesised and shared in order to ensure that those involved have the best current information as rapidly as possible.

Concurrently with the initiation of the breeding programs, a new series of site-species matching trials should be designed and deployed so as to update knowledge and gain insights in the relevant new and existing planting areas. This would typically be done on a co-operative basis.

There are a wide range of species being planted in Tanzania, and this poses a problem, especially for a young, start-up breeding program. There are needs for construction timber and fuel wood, with the greatest demand in terms of volume being construction timber (by a significant margin). Most of the area planted in the S. Highlands is *P. patula* and *E. grandis*, and it is therefore recommended that the initial tree improvement program focus on these two species, with the understanding that this species choice may be modified and added to as information is assimilated, and as the markets develop. There has been a global migration towards the rapidly growing eucalypt hardwoods, and this may happen in Tanzania too. However, pines are often easier and cheaper to plant and tender and it may be a while before there is greater market uptake of eucalypts. Eucalypts are also not as easy to process in sawmills as pines are, and there is a need to acquire material which has been bred for solid wood products (CSIR/Hans Merensky).

The large financial benefit in the growing of eucalypts lies in their rapid growth rate. They are widely planted by small forest growers in South Africa and India, the latter where they are harvested for poles and for pulp at ages 3-5 years, before large mechanical harvesting equipment is needed. Eucalypts, however, do present problems when it comes to water consumption, and care should be taken not to plant them in water-scarce regions. Eucalypts tend to be fire- tolerant.

Pines, on the other hand, are slower growing than eucalypts, but they are more robust at seedling stages (assuming *Fusarium circinatum* does not spread to the region). *P. patula* is highly fire sensitive, and this can be problematic in certain regions.

In conclusion, it is suggested that *P. patula* and its hybrids will remain an important species for construction and especially for the higher, cooler regions, whilst *E. grandis* and its hybrids will play an important and growing role in the warmer regions. These two species are a good starting point for the breeding program, whilst further species and hybrid information is gathered as rapidly as possible.

5. BREEDING STRATEGIES

The following strategies are suggested frameworks for the introduction, breeding, deployment and conservation of the two primary species, *P. patula* and *E. grandis* (schematically represented in Figure 2 and Figure 3). In both cases, the acquisition of the founder germplasm may be problematic and take resources and time (to negotiate acquisition and collect material – the latter depending on analysis and identification of selections, field crew collection, flowering seasons, seed set, etc.)

A beneficial aspect of breeding is that gains which are bred into a population will remain there (unless they are hybrids). This also implies that it is rather important to start with the best possible genetic material (although the breeder still needs genetic diversity as well), especially to remain up to date and competitive compared with other advanced breeding programs. The recommendation is therefore to acquire the best material of sufficient diversity, on which further improvements can be made.

Another important aspect is speed. Genetic gains are often measured in genetic gains per year. Rapid breeding is therefore important, so long as one does not make 'wrong' selections at too early an age.

5.1. PINE (PINUS PATULA)

The primary germplasm sources for *Pinus patula* are the Central America Mexico Conifer Resources (CAMCORE), the Zimbabwe forestry department and the Council for Scientific and Industrial Research, South Africa (CSIR). The outline of the strategy is captured in Figure 2 and entails conservation of the genetic resource, breeding and production.

As suggested in Komakech and Blakeway (2014), an initial step can be to collect both seed and grafts from the best local landrace trees. At this stage, the performance of such seed and parent trees is unknown, and the selections are most likely to only be phenotypic. The tested seed, which will be included in the breeding population, will provide genetic rankings. The grafted material collected from such trees can be included in a clonal seed orchard, however care should be taken to prevent too much relatedness in such a seed orchard. Should the resources not be available for the development of a clonal seed orchard, a seedling seed orchard is a simpler alternative.

Imported seed and seed from the local landrace selections would be included in at least three breeding population trials. *P. patula* breeding should be based on 300 families on a minimum of three sites. The pine breeding and seed production time intervals will be several years longer than that of *E. grandis.*

This species is known to change ranks at different altitudes (genotype-by-environment interaction, GEI). Careful consideration should be given to this possibility, taking the target planting regions and sizes of these regions (Field 1995; Snedden and Verryn 1999; Snedden 2001). There is a possibility that the strategy needs to be adapted to cater for targeting cold and warmer sites separately.

The primary form of production is likely to be seed for the pure species, although if compelled to use hybrids (due to diseases) then cuttings (clones) would be the likely form of production. Development of hybrid clones in Tanzania will take a good number of years, and the initial step would be to establish flowering seed orchards or breeding archives in which to make such crosses.

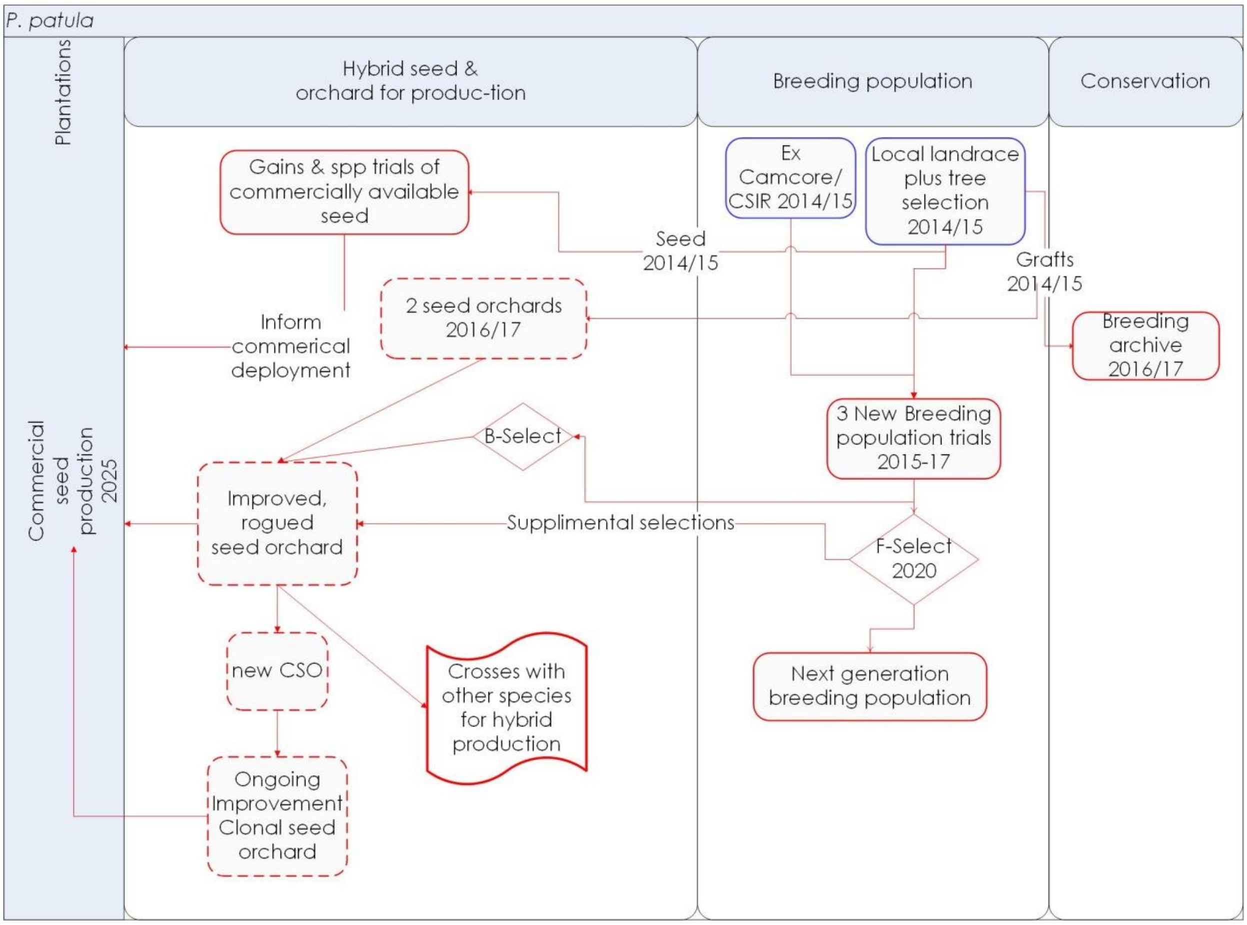

Figure 2 Tree Improvement and production strategy for P. patula

5.2. EUCALYPTUS (EUCALYPTUS GRANDIS)

The genetic sources for *Eucalyptus grandis* are most likely to be CSIR (which has most likely the most advanced solid wood breeding program of this species (Donnelly, Flynn et al. 2003). An alternative or supplementary source may be the Zimbabwe forestry department and Pomera, Uruguay.

The outline of the strategy is captured in Figure 3 and entails conservation of the genetic resource, breeding and production. The form of production of *E. grandis* is proposed to be seed. Hybrids are best reproduced on a clonal basis, and any current, newly imported and future hybrid material is likely to be deployed on a clonal basis.

Clonal seed orchards (CSO) are recommended, as the genetic gains from such orchards are usually significantly more than that of seedling seed orchards (SSO), and the cost-benefit is definitely in favour of CSOs.

Seed for plantation establishment has distinct advantages in areas where there is not a lot of information on clonal performance and where costs and technology are a consideration. Clones typically cost twice as much as seed to raise in the nursery, and require more research costs and time to validate in the field.

The breeding populations should be placed in a minimum of three trials and target approximately 300 families (and not less than 100 families).

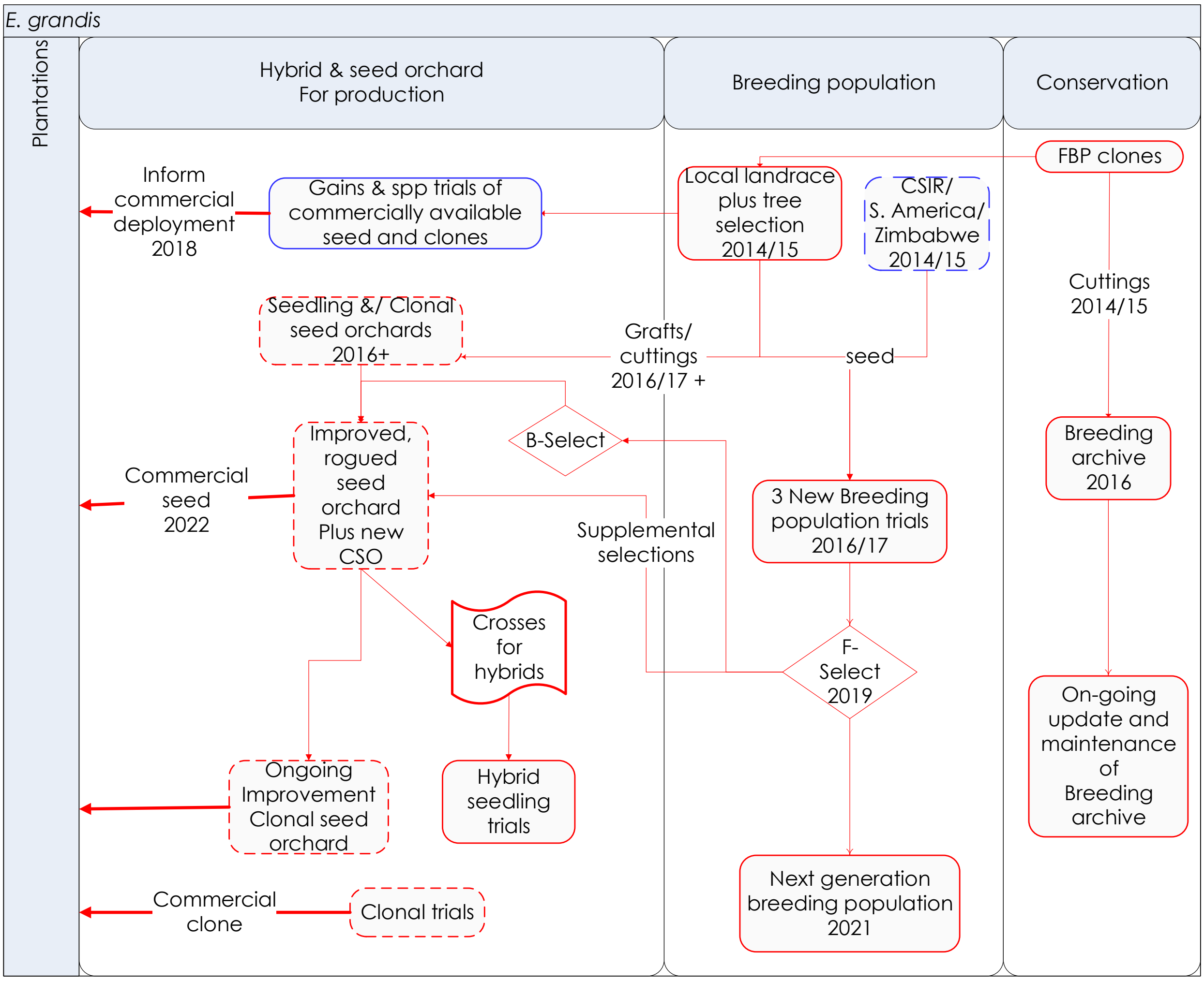

Figure 3 E. grandis introduction, breeding, conservation and production strategy

6. STRATEGIC CONSIDERATIONS

The following are important strategic considerations with respect to the breeding and production strategies and should be among the issues addressed by the Tree Improvement Research Working Group:

1. Target markets: There is a need to define target market(s). The current assumption is that the primary market is smaller-scale growers and construction market, although larger growers and the energy market undoubtedly hold potential.
2. Genus and species choice: How many species/ genera, and which species to breed for? It is suggested that the program initially focus on only two species, *E. grandis* and *P. patula*, with revision and inclusion of other species as information and capacity is increased.
3. Infrastructure: The extent to which tree breeding infrastructure (and associated services) are going to be out-sourced is an important institutional consideration.
4. Resource mobilisation: Research trials, seed orchards, breeding populations and gene conservation blocks (Breeding archives) will be planted on member's land, by agreement, taking specific site requirements into account. The members will provide in-kind assistance with the following; Land, labour, fire protection management and fencing where appropriate, maintenance (weeding) as well as felling operation at the end of the rotation for wood properties characterisation. Technical assistance on choice of species, trial designs, data collection, analysis and reporting will have to be carefully planned with responsibilities distributed between members.
5. Intellectual property (IP): Tree Breeding programs often develop valuable IP and tensions may arise if the 'rules' are not clearly defined and agreed up front. IP can become an underlying driving force for sustainable income generation, requiring good control of the resources (seed orchards, breeding populations, trials) from the onset. This aspect has to be managed very sensitively.
6. Management of invasive nature and water considerations: Most human activity tends to impact the environment, however there needs to be an awareness of the appropriate management to deal with potential weediness of some species (wattle) and the potential impact on water of some eucalypt species in water-stressed catchments.
7. Training and knowledge dissemination: Skills capacity development is an important aspect of tree breeding, as well as the need to transfer knowledge to all scales of tree grower. Mechanisms for such deployment are important.
8. Market development: The formation/strengthening of grower aggregation/coordination arrangements and marketing may be an important dimension. Members will have priority in acquiring the improved seed/ clones over non-members.
9. Sustainability of the tree improvement program: An exit strategy of the primary funder should be developed in such a way as to ensure that the breeding program continues for many years to come. This probably means that the collaborative breeding program should entrench certain principals which result in a willingness for member companies to remain members, whilst having acceptable autonomy. The competitive dynamic is also an important ingredient for success. It is suggested that a balance be achieved along the following lines, as outlined in Figure 4.

a. Two breeders, one responsible for each species program. This is important for the group dynamics and succession. They should be given a certain level of responsibility and accountability so as to encourage innovation, productivity and ownership.

b. The breeding material is tested over a range of members' sites with no one member managing all the breeding material and trials. There would be cost savings through the sharing of trial information, germplasm specialist services and facilities between members.

c. All members can have their own (competitive) trials, clones and orchards, but not complete copies of the collaborative breeding populations.

d. Such a model works best with many members as it achieves economies of scale.

e. Leadership is key, with the leader of such an initiative able to manage the dynamics between members.

f. The cooperative may sell seed and license clones as part of the sustainable business model.

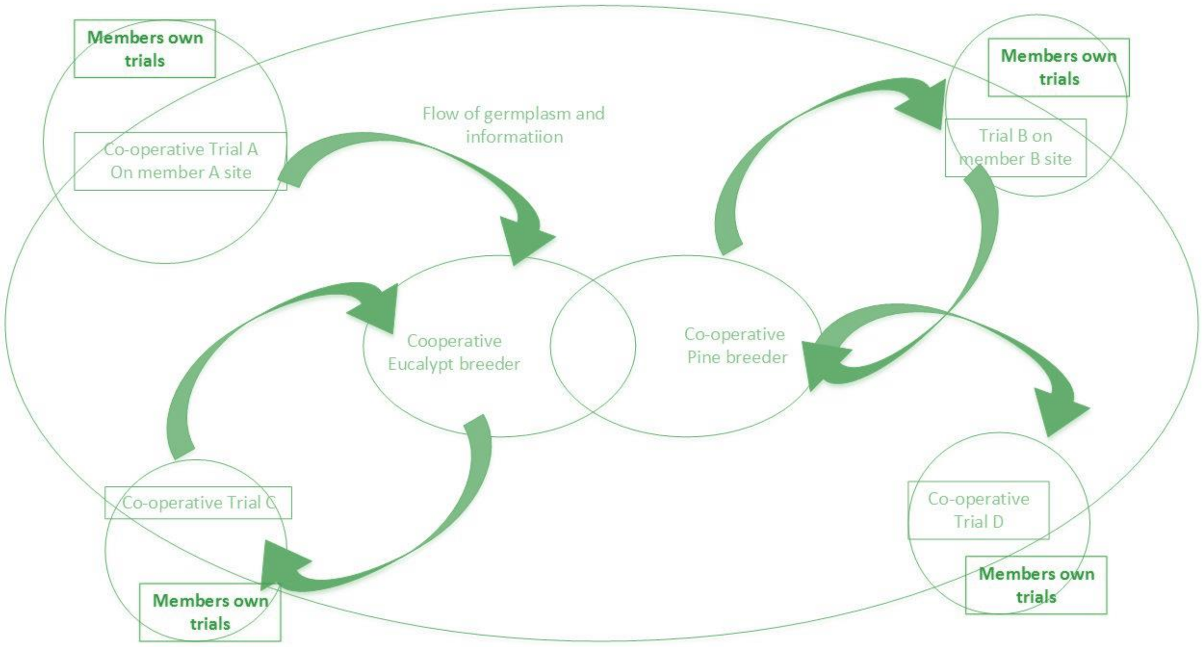

Figure 4 A co-operative model illustrating the shared benefit of resources for members, whilst members also maintain their own breeding material.

7. CONCLUSIONS

An initial tree breeding program with a focus on the southern highlands can target the two primary species, *P. patula* and *E. grandis*. These species can also serve as important hybrid parents for advanced breeding and for responses to potential changes, such as pest and disease introduction.

The breeding program will require the appointment of staff and acquiring facilities and genetic material. Two outlines of breeding strategies are presented. The initial target production channel will be seed from clonal (/seedling) seed orchards.

Various strategic considerations are listed, the primary consideration being the formation of a sustainable, collaborative tree breeding arrangement in the context of other initiatives supporting the development of the sector. Formation of a Tree Improvement Research Working Group involving all key interested public and private sector partners can help to realise a collaborative approach.

APPENDICES

Appendix I

List of species and clones established in site species matching trials by FDT with collaborating partners during 2014/2015 and 2015/2016 planting seasons

	Warm temperate							Sub-tropical			
	MAT 17-21 ^{O}C							MAT 21-24 ^{O}C			
	ALT 1500-2400 m							ALT 300-1500 m			
	2400	1820	1800	1800	1725	1700	1800	1300	1200	380	
Genus	Makete *Catholic church*	Lwangu *Catholic Church*	Njombe (#1) *Tanwat*	Njombe (#2) *Tanwat*	Kisolanza *Kisolanza Farms*	Kilolo *Smallholders*	Tukuyu *Morovian church*	Uchindile (#1) *Green Resources*	Uchindile (#2) *Green Resources*	Kilombero Valley *KVTC*	**Industrial applications**
Eucalyptus											
E.alba									1	1	pulp, sawtimber, bioenergy
E. badgensis	1	1	1	1	1			1			pulp,bioenergy
E. benthamii	1	1	1	1	1			1			pulp, bioenergy
E. botroydes	1			1		1	1		1		veneer logs, transmission poles
E. cloeziana	1	2	2	2	2	1	1	2	1	1	poles, sawtimber
E. dorrigoensis		1			1						pulp, bioenergy
E. dunnii	1	1	1	1	1	1	1	1	1		poles, bioenergy
E. globulus ssp globulus	1	1	1	1	1	1	1	1			poles, sawtimber, pulp, bioenergy
E. globulus ssp maidenii	2	1	1	2	1	2	2	1			poles, sawtimber, pulp, bioenergy
E. grandis	5	3	3	5	5	5	5	3	5	5	poles, sawtimber, pulp & paper, veneer & plywood
E. longirostrata		1	1		1			1			poles, bioenergy, pulp
E. macurthurii	1	1	1	1	1	1	1	1	1		bioenergy, pulp
E. nitens	1	1	1	1	1	1	1	1	1		poles, sawtimber, pulp
E. paniculata	1	1	1	1	1	1	1	1	1		poles, timber
E. pelita				2		2	2	2	2	2	construction timber, pulp & paper
E. saligna	2	1	1	2	1	2	2	1	2	2	poles, sawtimber, pulp, bioenergy, veneer & plywood
E. smithii	1	1	1	1	1	1	1	1	1		pulp, bioenergy, essential oil
E. urophylla		2	2	1	2	1	1	2	1	1	sawtimber, bioenergy
E. viminalis		1			1						bioenergy, pulp
Eucalyptus clonal hybrids											
E. grandis x camaldulensis (GxC)	2	3	2	2	3	2	2	2	2	2	poles, bioenergy, pulp
E. grandis x nitens (GxN)	6	4	4	6	4	6	5	4	4		sawtimber, poles, pulp
E. saligna x urophylla (SxU)	1	1	1	1	1	1	1	1	1	1	sawtimber, poles, pulp
E. grandis x urophylla (GxU)	5	3	3	5	3	5	5	3	4	4	sawtimber, poles, pulp
Corymbia											
C.citriodora ssp. citriodora	3			3		3	3		3	3	sawtimber, essential oils
C citriodora ssp. Variegata	1			1		1	1		1	1	sawtimber, poles
C. henryi	2	1	1	2	1	2	2	1	2	2	sawtimber, poles, pulp
C.maculata	2			2		2	2		2	2	veneer logs, transmission poles
C. torelliana				1				1			sawtimber, poles, bioenergy
Pinus											
P. caribaea var. hondurensis	2	2	2	2	2	2	2	2	2	2	sawtimber, pulp
P. elliottii	1			1		1	1		1	1	sawtimber, pulp
P. elliottii x caribaea (seedlings)	1			1		1	1		1	1	sawtimber, pulp
P. elliottii x caribaea (clonal hybrid)	2	2	2	2	2	2	2	2	2	2	sawtimber, pulp
P.greggii (N)	1			1		1	1	1	1		sawtimber, pulp
P. greggii (S)	2			2		2	2	2	2		sawtimber, pulp
P. kesiya	2			2		2	2		2		sawtimber
P. maximinoi	2	3	3	2	3	2	2	3	2		sawtimber
P. oocarpa	3	2	2	3	2	3	3	2	3	3	sawtimber
P. patula	3	2	2	3	2	3	3	2	3		sawtimber
P. patula x tecunumanii	2	1	1	2	1	2	2	1	2		sawtimber, pulp
P. taeda	3			3		3	3		3	3	sawtimber, pulp
P. tecunumanii (Low)	3	2	2	3	2	3	3	2	3	3	sawtimber

Appendix II

List of trial plots established by Green Resources Limited since 2013

A: CAMCORE TRIALS						
SN	**Species**	**Trial type**	**Plantantion**	**Compartment**	**Planted year**	**Area(ha)**
1	*E. urophylla*	F2	U1FP	D 237	2013	3.05
2	*E. urophylla*	F2	U1FP	A 031	2013	3.21
3	*E. grandis*	F2	U1FP	D 236	2013	3.58
4	*E. grandis*	F2	U1FP	A 030	2013	2.35
5	*P. tecunumanii(HE)*	Progeny	MFP	F 232	2014	2.16
6	*P. tecunumanii(HE)*	Progeny	U1FP	E 226	2014	2.16
7	*P. maximinoi*	F2	MFP	F 232	2014	2.00
8	*P. maximinoi*	F2	IFP	H 185b	2014	2.00
9	*P. tecunumanii(LE)*	F2	U1FP	E 226	2014	2.30
10	*P. tecunumanii(LE)*	F2	IFP	H 185b	2014	2.30
10	*E. pellita*	Progeny	MFP	C 071	2014	1.49
11	*E. pellita*	Progeny	U1FP	E 226	2014	1.33
12	*E. camaldulensis*	Progeny	U1FP	E 226	2015	1.15
13	*E. camaldulensis*	Progeny	U2FP	B 056	2015	1.15
14	*E. longirostrata*	Progeny	U1FP	E 226	2015	1.15
15	*E. longirostrata*	Progeny	U2FP	B 056	2015	1.15
16	*Pine hybrid*	Hybrid trial	MFP	F 232	2015	2.40
	Sub total					**34.95**
B: GRL TRIALS						
1	*Pines spp*	Species trial	MFP	B 025a	2013	2.00
2	*Pines spp*	Species trial	U1FP	C 118	2013	1.77
3	*Eucalyptus spp*	Species trial	IFP	F 103b	2013	2.00
4	*Eucalyptus spp*	Species trial	U1FP	B 142, 143	2013	3.61
3	*Eucalyptus urophylla*	Fertilizer application trial	MFP	B 025B	2013	0.28
4	*GC 15 Clones*	Fertilizer application trial	Incomet	C 10a	2013	1.00
7	*Pinus tecunumanii*	Provenance trial	U1FP	C 206	2014	0.55
8	*Pines spp*	Species trial	IFP	H 168	2015	0.50
9	*Eucalyptus spp*	Species trial	UKAMI	UK 36	2015	0.50
10	*Eucalyptus spp*	Species trial	IFP	H 168	2015	0.50
	Sub total					**17.61**
						52.56