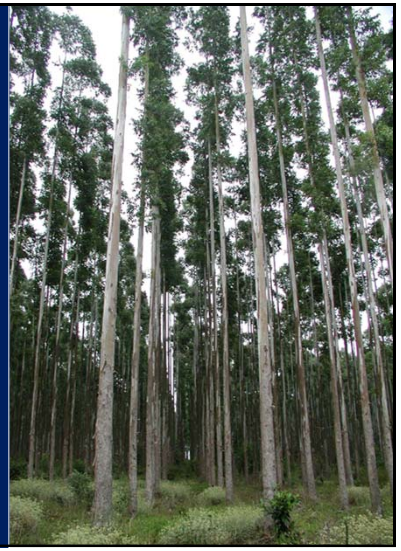
Genetic Improvement for Fast Growing Species

Objectives of Tree Improvment

- Increase productivity
- Improve quality
- Site/species/clone matching
- Sustainable yield

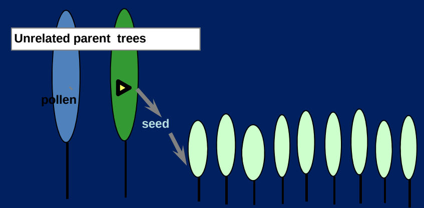


Forest tree breeding differs from breeding of agricultural crops in several ways

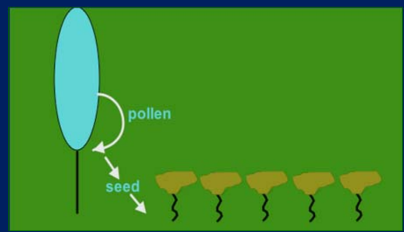
Forest tree breeding
- Subject to inbreeding depressing - inbreeding reduce vigor offspring
- Only reached second and third generation
- Many different breeding objectives

Agricultural crops breeding
- Narrow genetic material and inbred line
- Domestication in thousands of generations
- One or more breeding objectives

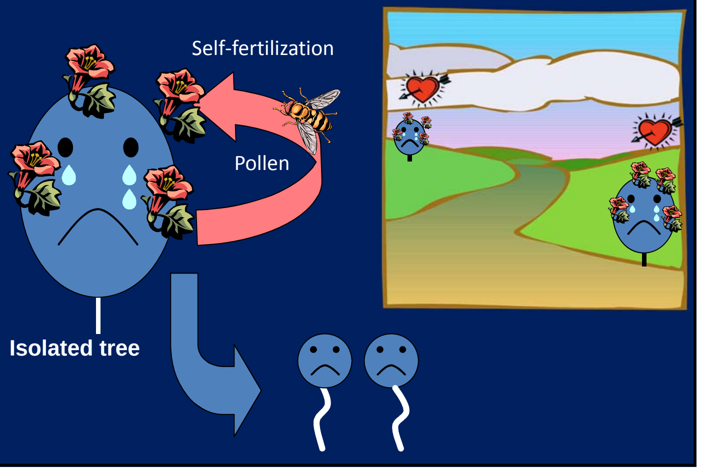
Outcrossed family (control-pollinated single-pair cross)-good performance



Self-fertilised family, inbreeding depression of yield, poor performance



Conditions for Production of Inbred Seed



Inbreeding depression of growth in control-crossed progenies of *E. camaldulensis* (Petford) at 30 months - trial near Gympie, Queensland

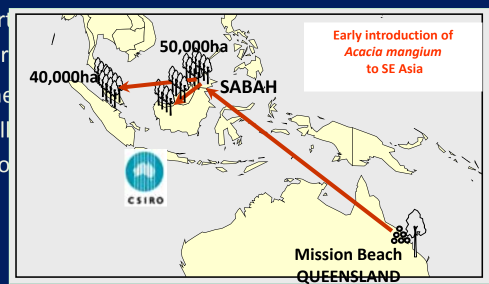
Land race

Land races develop when exotic trees are introduced in a new environment. Genetic changes take place in the population of tree over one or more generations of selection by natural or human agencies.

The natural provenance origin is of prime importance in determining the genetic makeup of a land race, although genetic change take place in later generation

Early , "pre-scientific" introduction of eucalypts and acacias to South and SE Asia

- initial introduction with narrow genetic base, from inferior provenance (e.g. seed from only one tree)
- furt ... ingle, ear
- one ... ed col ... s and dro



To develop new plantations superior to their predecessors in one or several key economic traits.

unimproved

genetically improved

E. camaldulensis: natural seed source vs local land race

Australian seedlot (collected from natural stand, one year younger)

Vietnam land race

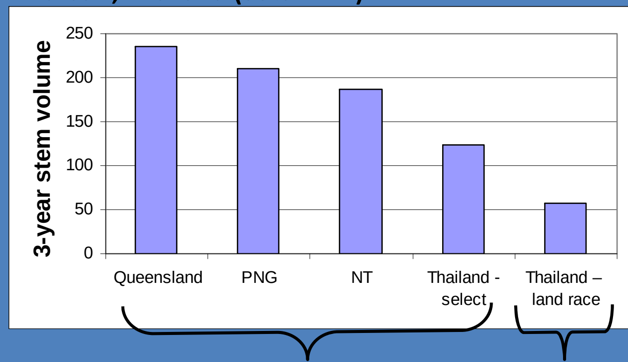
Eucalyptus camaldulensis plantations in Cambodia

Mix of best natural provenances from northern Queensland, Australia

Seed from a commercial dealer in Vietnam – same age, nearby

Genetic deterioration of unmanaged land races

Acacia auriculiformis **seed source trial: Kuiburi, Thailand (data: RFD)**



Selected progenies from first generation seed orchard

Unselected Thai landrace

Acacia auriculiformis breeding in Thailand

E. camaldulensis
Seedling Seed Orchard,
Pudukkottai

Mean Heights, age 24 months

Trial mean: 5.68 m

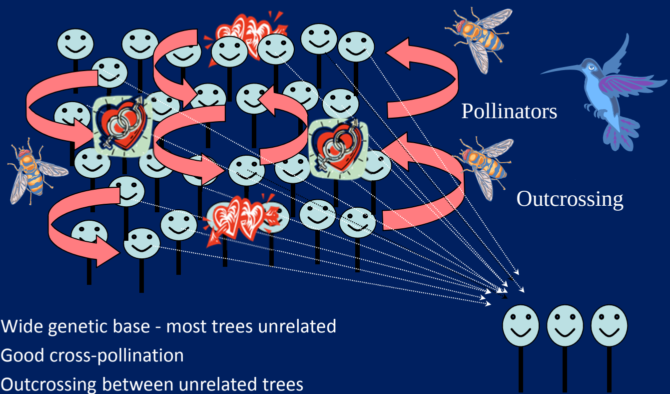
Petford Qld.	6.28 m
Kennedy R. Qld.	5.98 m

Indian selections :

E. camaldulensis	5.34 m
E. tereticornis	4.87 m

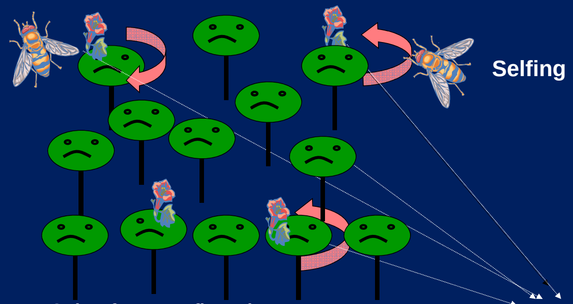
c.d. ($P = 0.05$) 0.28 m

Conditions for production of high-quality seed



- Wide genetic base - most trees unrelated
- Good cross-pollination
- Outcrossing between unrelated trees

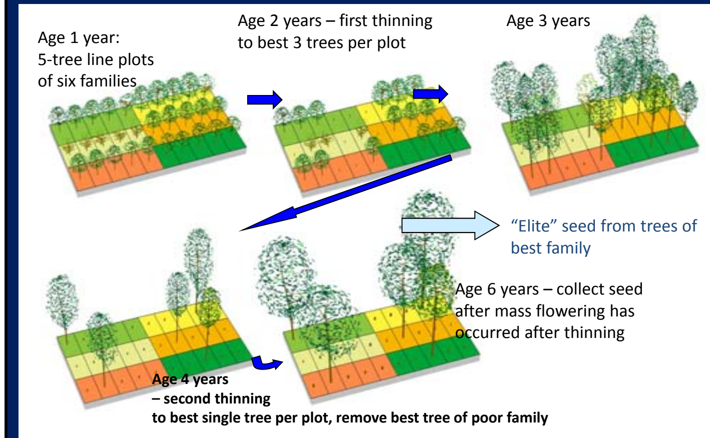
Poor-quality (selfed) seed from low-frequency, non-synchronous flowering in seed orchards



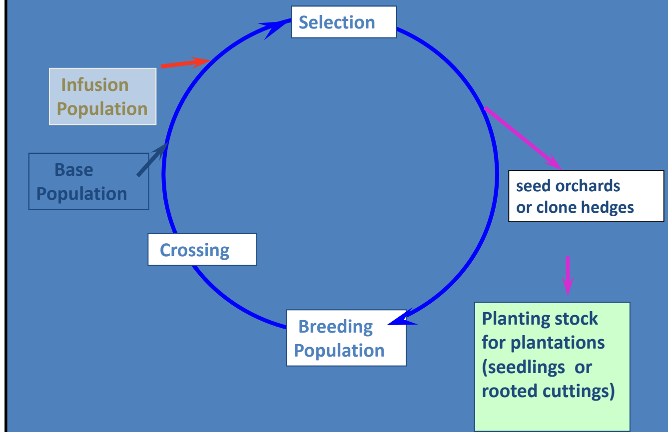
- **Only a few trees flowering**
- **Trees flowering at different times – not synchronous**
- **Most seeds result from self-fertilization**

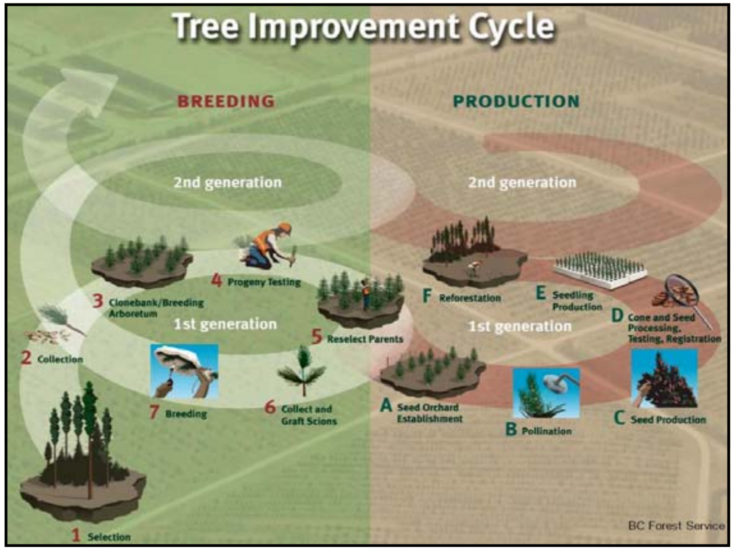
Effect of outcrossing rate on growth of orchard progeny: *Acacia mangium* seed orchards in northern Vietnam
(both orchards PNG provenance origin)

Developing part of a seedling seed orchard from a progeny trial

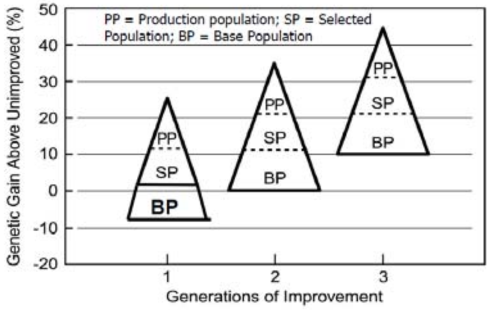


Activity cycle for tree breeding

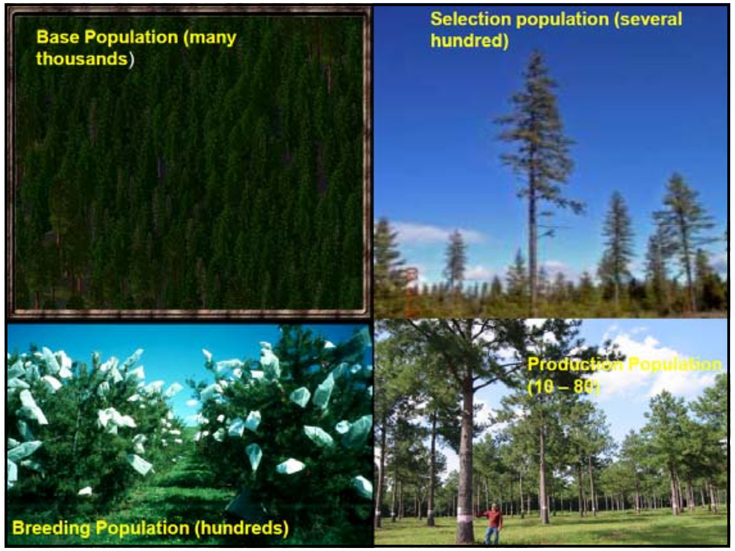




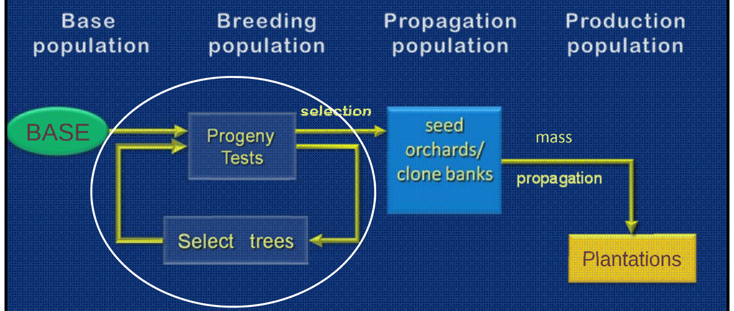
Stages of selection



www.pinegenome.org/ctgn CTGN CAP 36

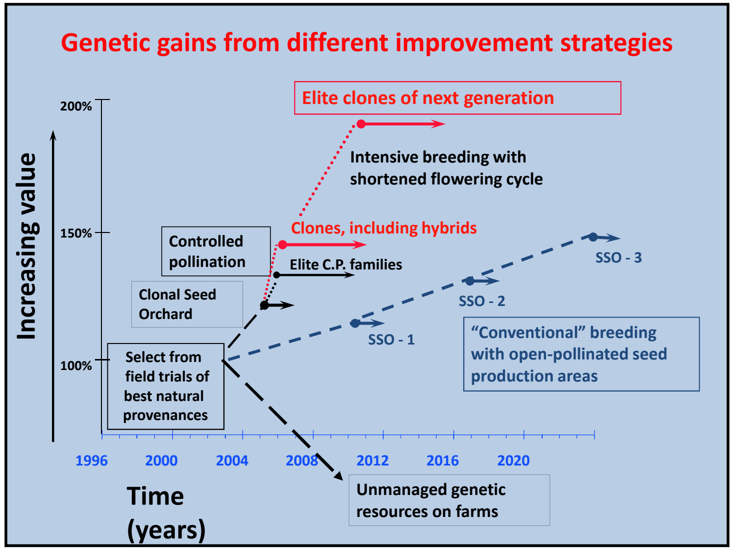


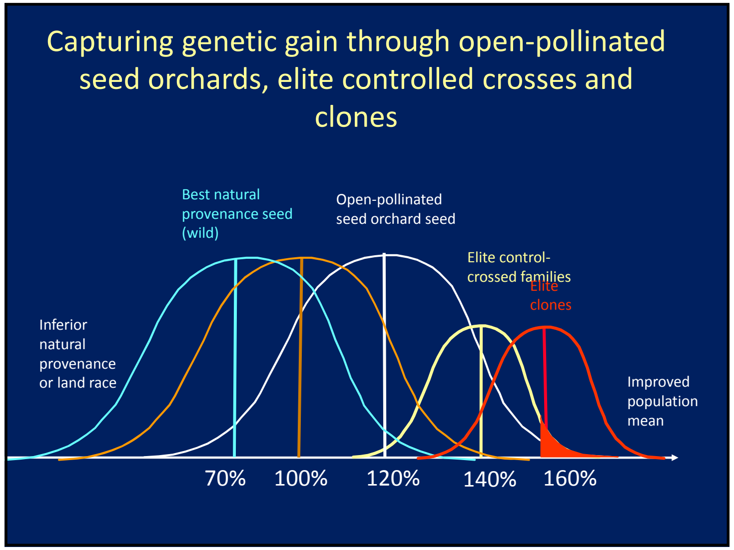
Tree Improvement Activities

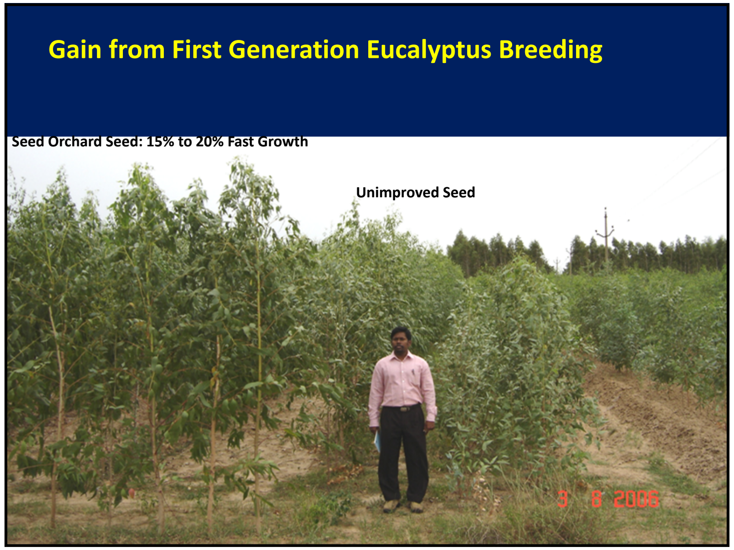


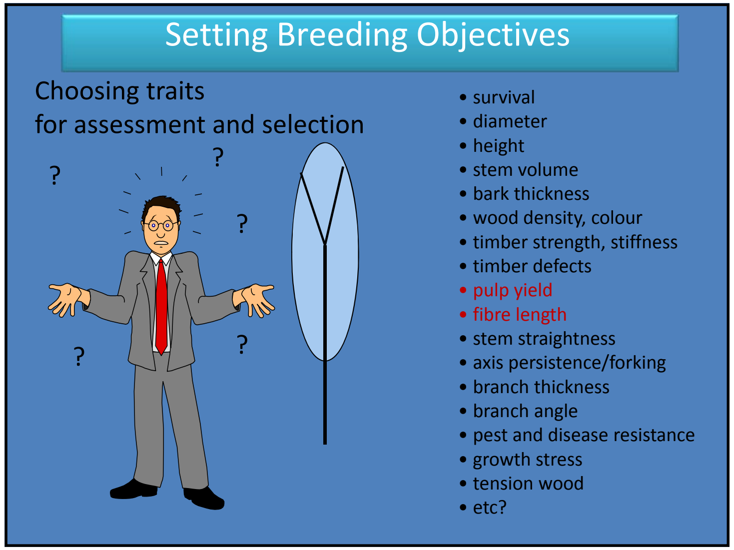
Basic Elements Tree Improvement

- Strategy and plan
- Clear breeding objectives
- Hierarchy of populations
- Selection and breeding
- Personal and fund


Genetic gains from different improvement strategies
Elite clones of next generation
200%
Intensive breeding with shortened flowering cycle
150%
Controlled pollination
Clones, including hybrids
Elite C.P. families
SSO - 3
Clonal Seed Orchard
SSO - 2
SSO - 1
"Conventional" breeding with open-pollinated seed production areas
100%
Select from field trials of best natural provenances
Increasing value
1996
2000
2004
2008
2012
2016
2020
Time (years)
Unmanaged genetic resources on farms


Capturing genetic gain through open-pollinated seed orchards, elite controlled crosses and clones
Best natural provenance seed (wild)
Open-pollinated seed orchard seed
Elite control-crossed families
Elite clones
Inferior natural provenance or land race
Improved population mean
70%
100%
120%
140%
160%


Gain from First Generation Eucalyptus Breeding
Seed Orchard Seed: 15% to 20% Fast Growth
Unimproved Seed
3 8 2006


Setting Breeding Objectives
Choosing traits for assessment and selection
?
• survival
• diameter
• height
• stem volume
• bark thickness
• wood density, colour
• timber strength, stiffness
• timber defects
• pulp yield
• fibre length
• stem straightness
• axis persistence/forking
• branch thickness
• branch angle
• pest and disease resistance
• growth stress
• tension wood
• etc?

Selection Traits

- Economic importance
- Easy to measure
- ***Genetically variable ?***

Four populations in tree improvement

- **base population** - a large, genetically unimproved sample of the natural gene pool of the species
- **breeding population** - many selected individuals from the base population are improved through successive cycles of selection, breeding and testing
- **propagation population** - a subset of the breeding population used for producing large quantities of genetically improved seed or vegetative propagules
- **wood-producing plantations** - use genetically-improved material for production forestry

Improvement strategy for *Eucalyptus camaldulensis* in Thailand - medium intensity

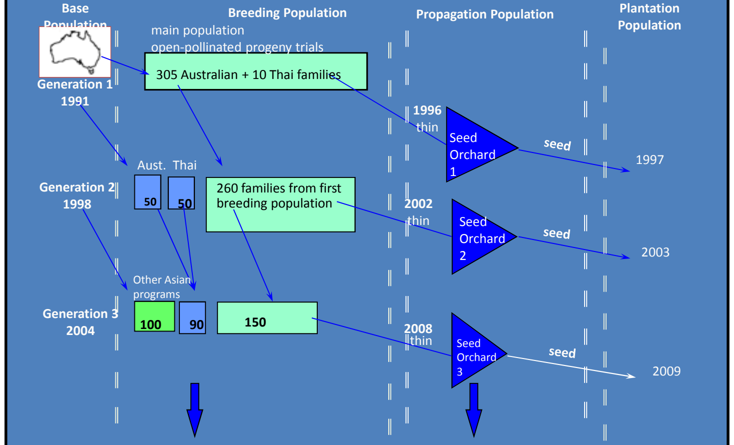
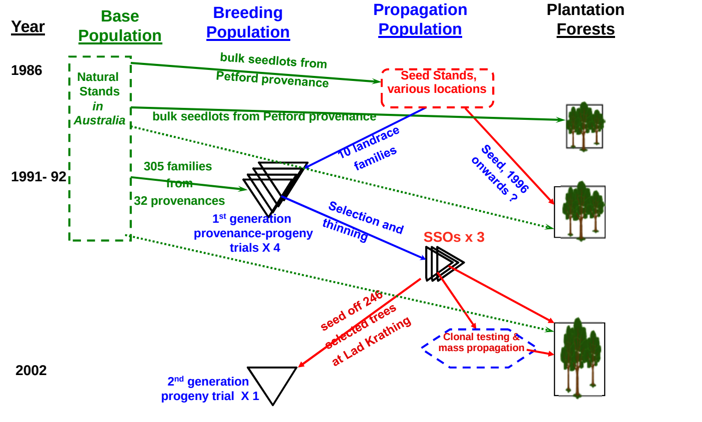


Figure 1. Breeding program for *Eucalyptus camaldulensis* in Thailand - progress to date

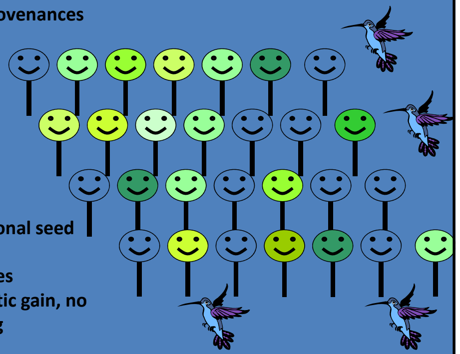


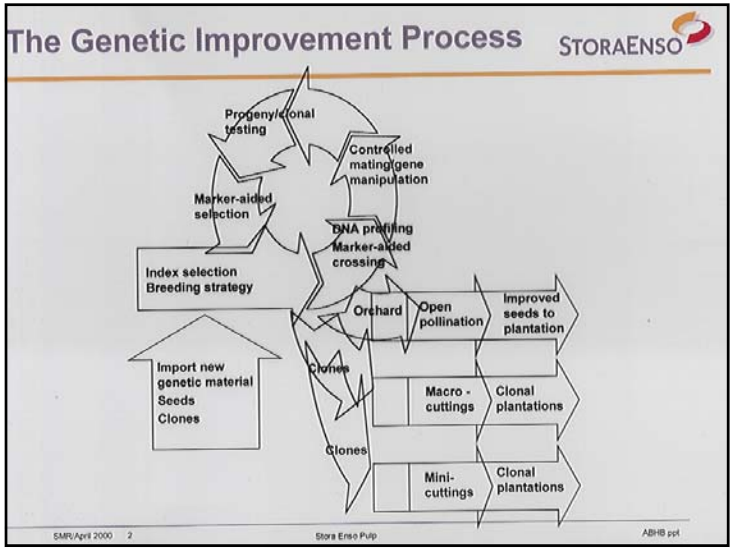
Genetic improvement strategy for *Grevillea robusta* in Africa

Genetic resource stand at Malava, Kenya
91 families from Australian natural provenances

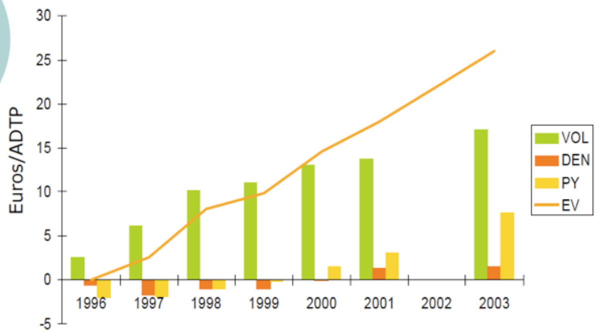
Select the best tree from each of 20 best families

Grafted clonal seed orchard of 20 clones
High genetic gain, no inbreeding





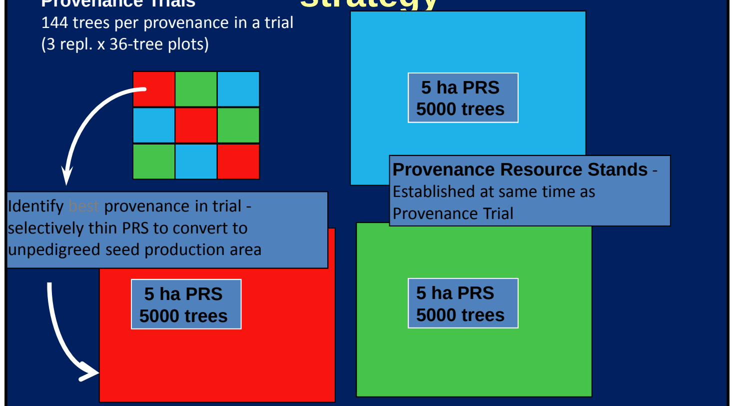
Economic gain of clonal plantations



Low, medium and high intensity improvement programs

- **Low intensity**
  - identify best provenances, establish seed production areas of best provenances
- **Medium intensity**
  - maintain family pedigrees in breeding populations, controlled pollination? vegetative propagation?
- **High intensity**
  - controlled pollination
  - advanced selection methods (index selection, BLUP)
  - multiple breeding populations?
  - aim for clonal forestry
  - use biotechnology (pedigree control, marker-assisted selection?)
  - only justified for very large planting programs

Low intensity, low cost improvement strategy



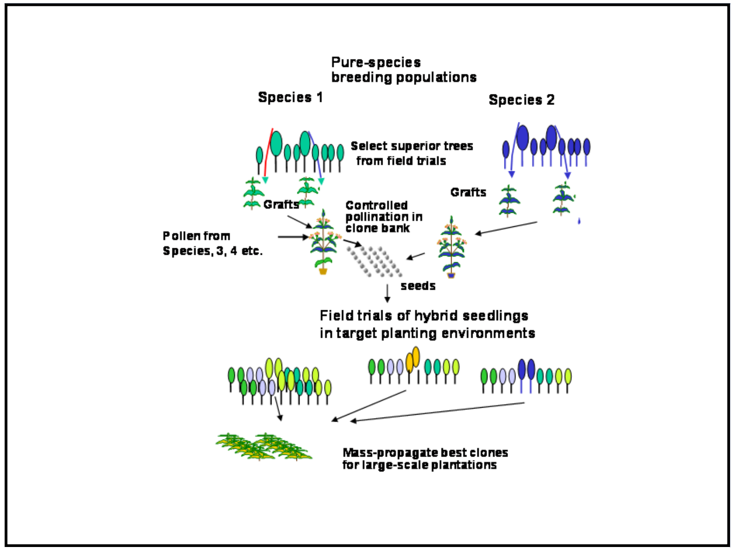
Low Intensity Improvement Program

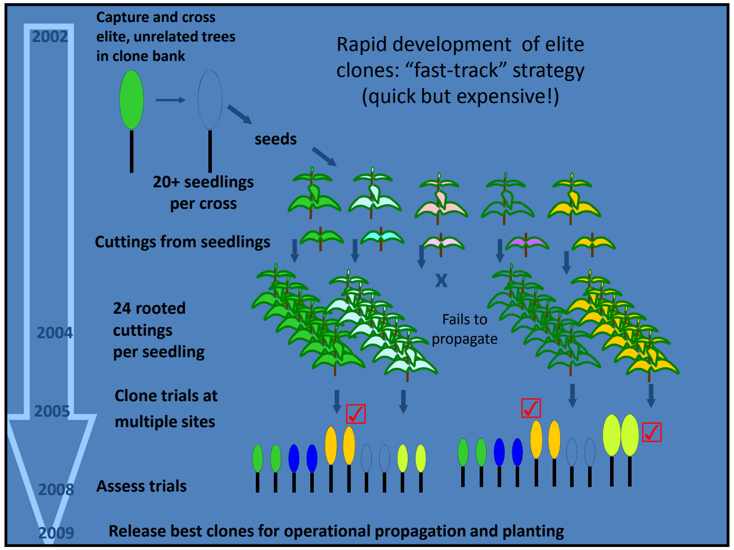
- Establish stands with a mix of 50-100 unrelated seed parents from many sources
- Start at close spacing to allow heavy and early selective thinning
- Produce seed of somewhat improved quality
- Outstanding individuals may be used for clonal forestry after field testing

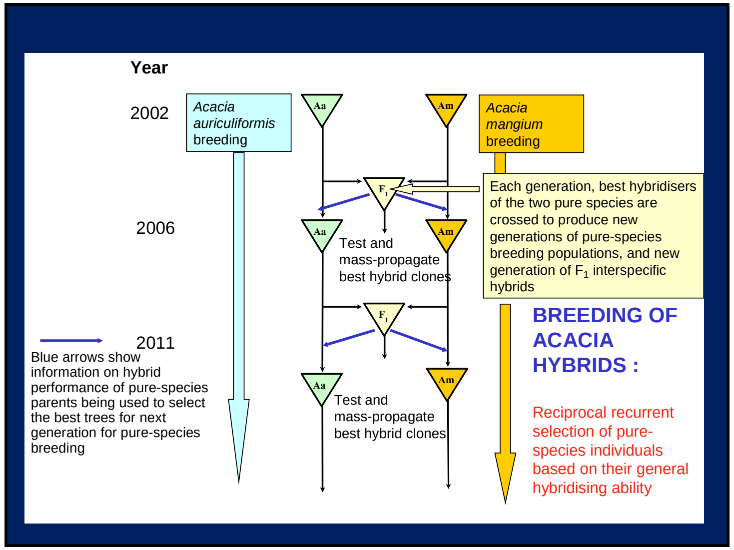
Intensive management of clone banks for controlled pollination

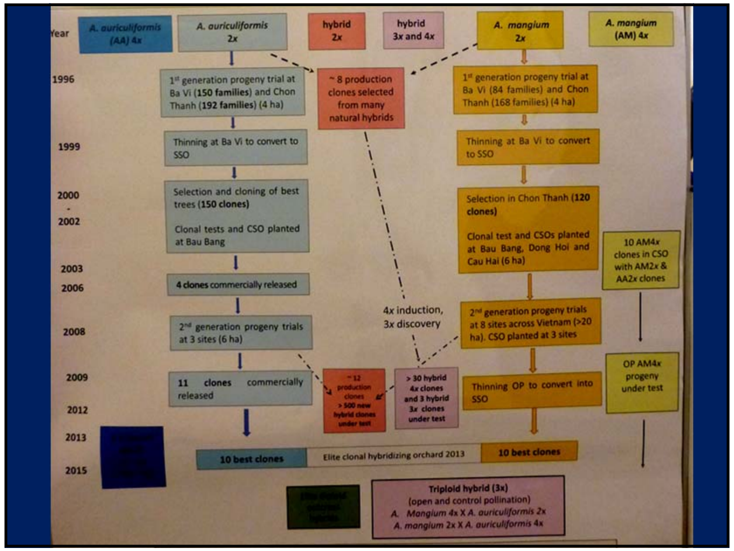
Use of paclobutrazol to induce early, prolific flowering


Intensive breeding program


Pure-species
breeding populations
Species 1
Species 2
Select superior trees
from field trials
Grafts
Grafts
Controlled
pollination in
clone bank
Pollen from
Species, 3, 4 etc.
seeds
Field trials of hybrid seedlings
in target planting environments
Mass-propagate best clones
for large-scale plantations


2002
Capture and cross
elite, unrelated trees
in clone bank
Rapid development of elite
clones: "fast-track" strategy
(quick but expensive!)
seeds
20+ seedlings
per cross
Cuttings from seedlings
X
24 rooted
cuttings
per seedling
Fails to
propagate
2004
2005
Clone trials at
multiple sites
2008
Assess trials
2009
Release best clones for operational propagation and planting


Year
2002
Acacia
auriculiformis
breeding
Aa
Am
Acacia
mangium
breeding
F1
Each generation, best hybridisers
of the two pure species are
crossed to produce new
generations of pure-species
breeding populations, and new
generation of F1 interspecific
hybrids
2006
Aa
Am
Test and
mass-propagate
best hybrid clones
BREEDING OF
ACACIA
HYBRIDS :
2011
F1
Blue arrows show
information on hybrid
performance of pure-species
parents being used to select
the best trees for next
generation for pure-species
breeding
Aa
Am
Test and
mass-propagate
best hybrid clones
Reciprocal recurrent
selection of pure-
species individuals
based on their general
hybridising ability



Biotechnology

STORAENSO

- **Molecular Markers**
  - DNA fingerprints which are unique to an individual

Application

- *Marker-Aided Crossing:* Reduces time and increases genetic gain
- *Genetic Diversity Index:* Maintaining genetic diversity (plantation survival and environment)
- *Clone ID/Variety Registration:* Stora Enso's ownership
- *Genome Mapping:* Marker-aided selection

Value of Biotechnology

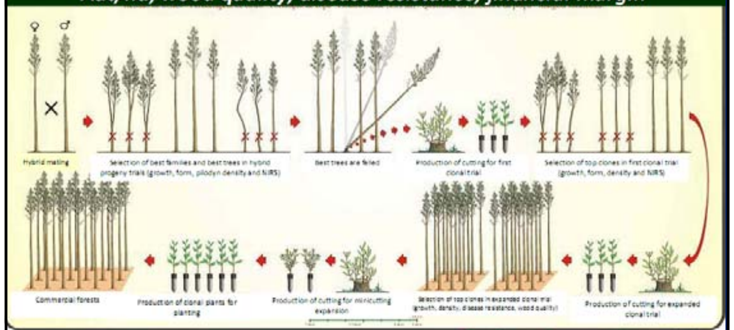
STORAENSO

Molecular genetics	Enhancement of conventional breeding: Genetic gain per generation	Lead time (genetic gain/year)	Other (e.g. diversity & registration)
Molecular markers[1]			
DNA fingerprinting			Yes
Marker-aided crossing	Yes		
Diversity Index			Yes
Marker-aided selection		Yes[A]	
Genetic modification[2]	Yes	Yes	

[1] Non-controversial, [2] Controversial

Steps taken for the selection of new elite clones

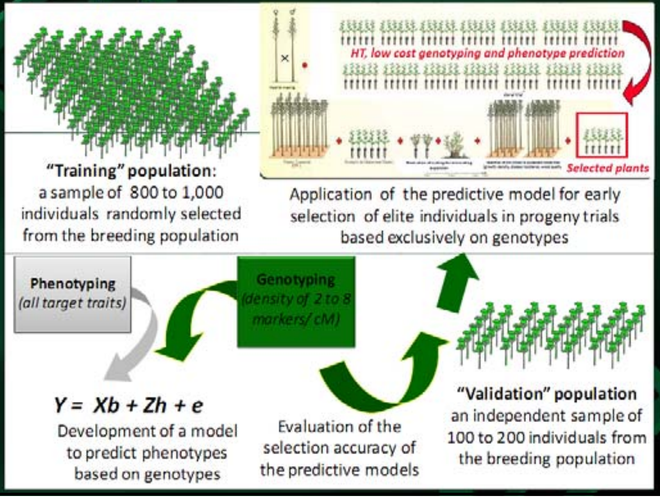
Selection parameters: trunk and crown form, % bark, productivity Adt/ha; wood quality; disease resistance, financial margin



Even in fast growing *Eucalyptus* this process takes between 12 and 18 years

Early selection methods for late expressing traits and hard to measure traits would be very useful especially wood quality and disease resistance

General principle of Genomic Selection or Genome-Wide Selection



Major challenges to *Acacia* plantation forestry. Can genomics help?

Issue	Solution(s)?		Comment
	Genetics	Silviculture	
Volume Yield	Hi	Hi	
Stem form	Hi	Mod	form pruning increases disease risk
Site Adaption	Hi	Lo	
Disease resistance - root rot	Lo	Hi	
Disease resistance - wilts	Lo?	Mod?	focus on reduced infection
Disease resistance - heart rot	Lo?	Mod?	
Disease resistance - foliar pathogens	Hi	Lo	
Wind Stability	Mod	Mod	Crown size issue?
Wood properties	Hi	Mod	rotation length important
Cloning potential	Hi	Lo	

* In eucalypts we use many inter[illegible]fic hybrids. For acacia only 1 so far. Huge potential

Trait Gene Discovery via QTL Mapping

- **QTL mapping**
  - Development of mapping populations
  - Development of genome wide markers
  - Construction of linkage maps
  - Regression of trait values on marker intervals

BREEDING WITHOUT BREEDING:

molecular markers, spatial statistics, pre-selection and quantitative genetics melting pot

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Faculty of Forestry
University of British Columbia
Vancouver, B.C. Canada

UBC

NovelTree

Treebreedex

NOVELTREE & TREEBREEDEX
"Long-term Breeding Strategies Applied to Forest Trees"
Orléans, France
October 12-14, 2009

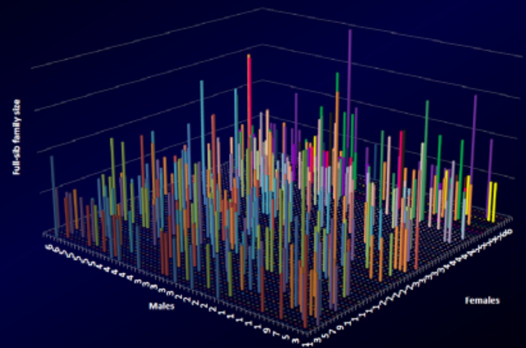
Breeding Without Breeding (BWB)

Spatial Statistics

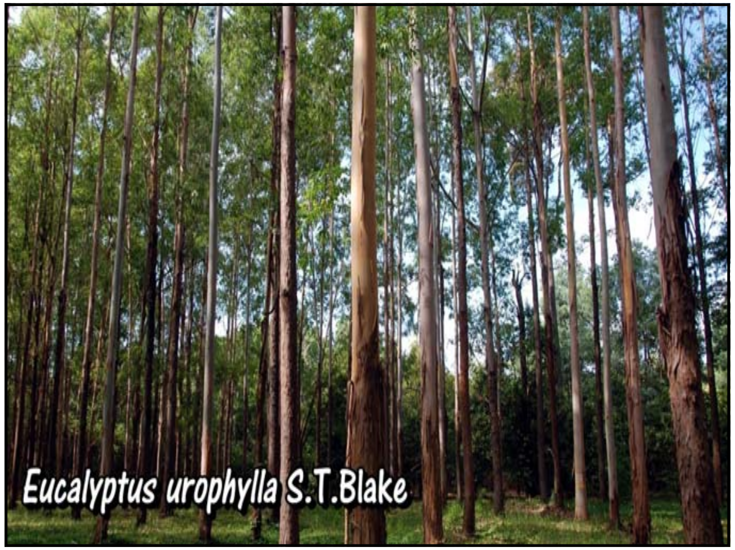
Site Variability Removal

DNA Fingerprinting & Pedigree Reconstruction

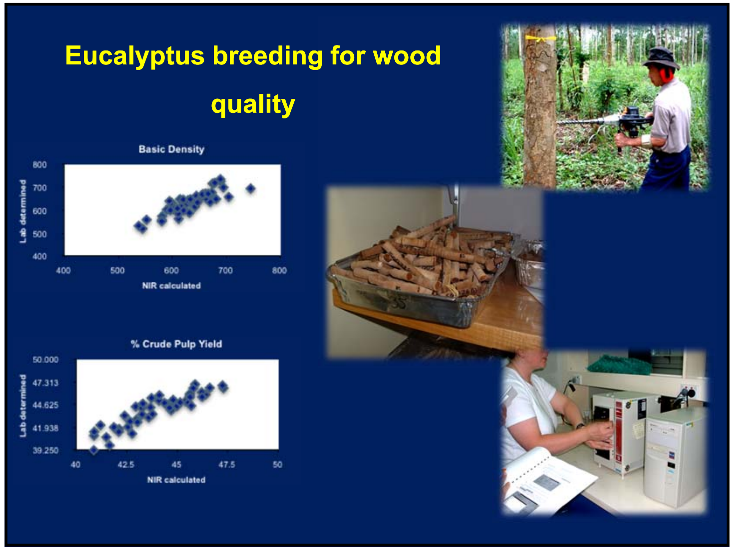
Known parents: Full (lodgepole pine)

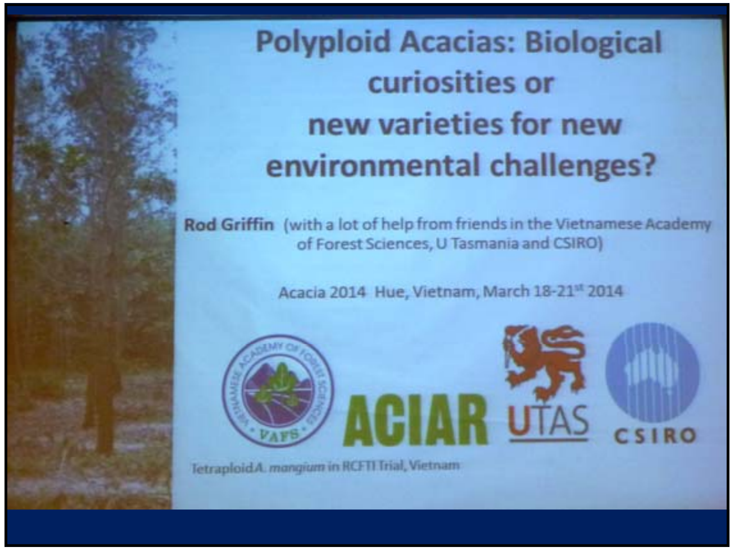


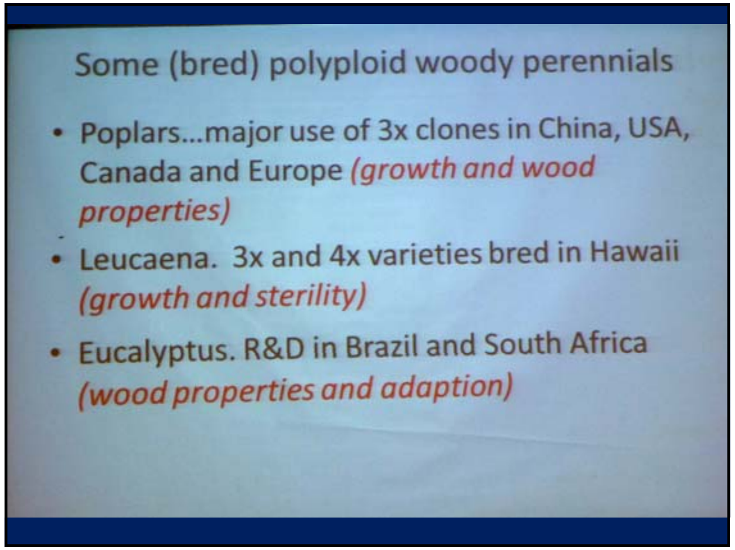
Liewlaksaneeyanawin et al 2009

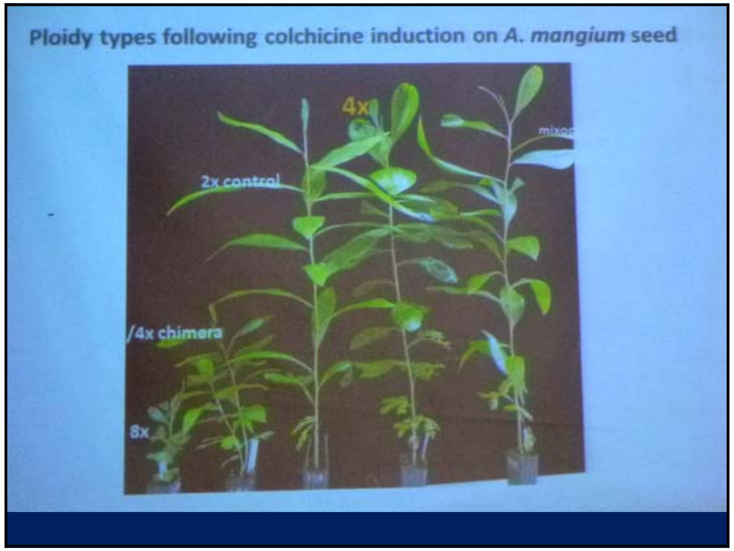



Tissue & wood sampling collection

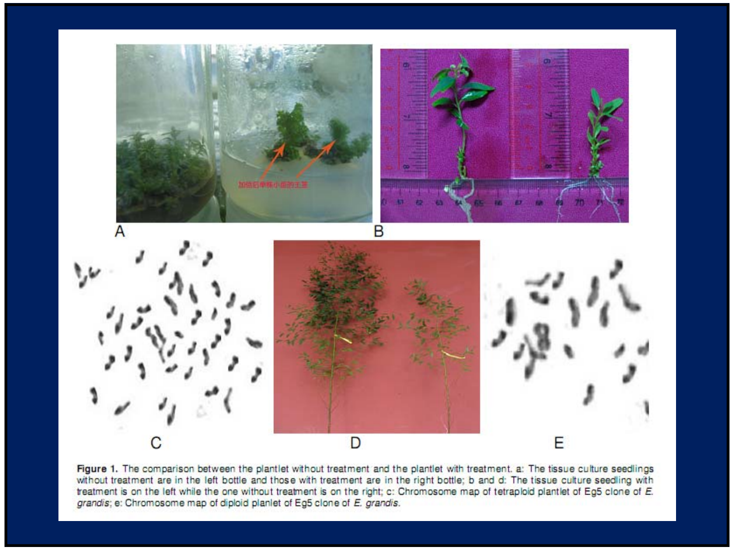

Eucalyptus breeding for wood quality
Basic Density
Lab determined
NIR calculated
% Crude Pulp Yield
Lab determined
NIR calculated

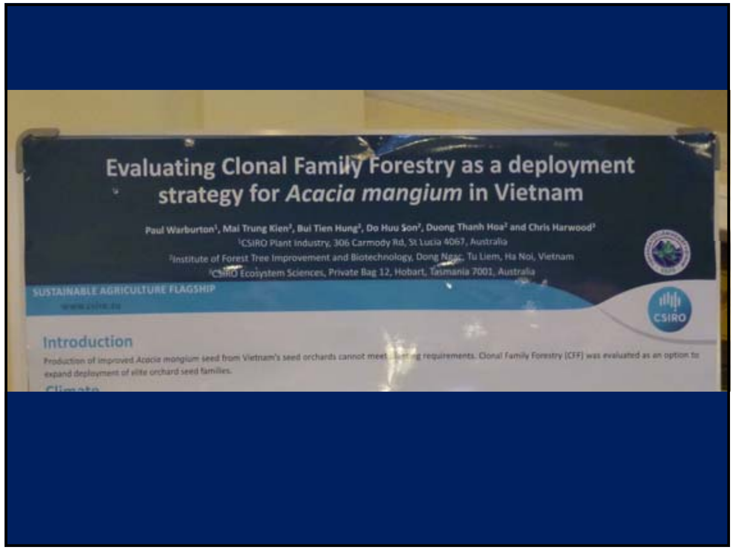

Polyploid Acacias: Biological curiosities or new varieties for new environmental challenges?
Rod Griffin (with a lot of help from friends in the Vietnamese Academy of Forest Sciences, U Tasmania and CSIRO)
Acacia 2014 Hue, Vietnam, March 18-21st 2014
VAFS
ACIAR
UTAS
CSIRO
Tetraploid A. mangium in RCFTI Trial, Vietnam


Some (bred) polyploid woody perennials
• Poplars...major use of 3x clones in China, USA, Canada and Europe (growth and wood properties)
• Leucaena. 3x and 4x varieties bred in Hawaii (growth and sterility)
• Eucalyptus. R&D in Brazil and South Africa (wood properties and adaption)


Ploidy types following colchicine induction on *A. mangium* seed
4x
2x control
/4x chimera
8x


2012/04/25


A
B
C
D
E
Figure 1. The comparison between the plantlet without treatment and the plantlet with treatment. a: The tissue culture seedlings without treatment are in the left bottle and those with treatment are in the right bottle; b and d: The tissue culture seedling with treatment is on the left while the one without treatment is on the right; c: Chromosome map of tetraploid plantlet of Eg5 clone of *E. grandis*; e: Chromosome map of diploid planlet of Eg5 clone of *E. grandis*.

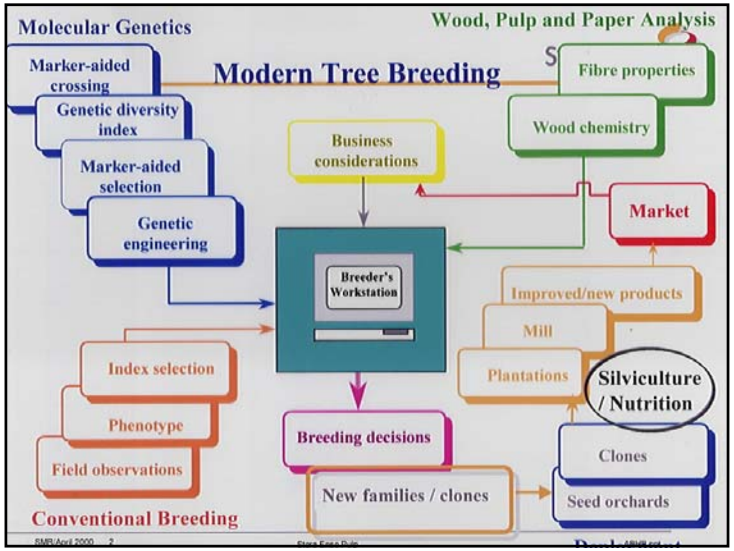

Evaluating Clonal Family Forestry as a deployment strategy for *Acacia mangium* in Vietnam
Paul Warburton[1], Mai Trung Kien[2], Bui Tien Hung[2], Do Huu Son[2], Duong Thanh Hoa[2] and Chris Harwood[3]
[1]CSIRO Plant Industry, 306 Carmody Rd, St Lucia 4067, Australia
[2]Institute of Forest Tree Improvement and Biotechnology, Dong Ngac, Tu Liem, Ha Noi, Vietnam
[3]CSIRO Ecosystem Sciences, Private Bag 12, Hobart, Tasmania 7001, Australia
SUSTAINABLE AGRICULTURE FLAGSHIP
CSIRO
Introduction

So, if we are NOT growing easy-to-root hybrids ?? USE HIGH QUALITY SEEDS

- Seedling or Clonal Orchard Bulk.
- Tested OP or CP Families (Family forestry FF).
- Increase planting stock by vegetatively propagating seedlings with identity at family not individual genotype level (Clonal Family Forestry (CFF or Monoprogenies).

Uniform growth of a CP family of *E.globulus* age 8 Years (courtesy CMPC)

Suzano -Mother plants of *E.grandis* for CFF plantation


Molecular Genetics
Wood, Pulp and Paper Analysis
Modern Tree Breeding
Marker-aided crossing
Genetic diversity index
Marker-aided selection
Genetic engineering
Business considerations
Fibre properties
Wood chemistry
Market
Breeder's Workstation
Improved/new products
Mill
Plantations
Silviculture / Nutrition
Index selection
Phenotype
Field observations
Breeding decisions
New families / clones
Clones
Seed orchards
Conventional Breeding