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Domestication of trees in semi-arid East Africa: the current situation

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ABSTRACT

In East Africa, pastoralists in the dry savannahs rely heavily on trees and shrubs for browse, fodder, shade, fencing and firewood, etc. This review focuses on the use of non-industrial trees and shrubs, and discusses the role of domesticated indigenous trees in agroforestry systems.

To date, much attention has been paid to matching species to different ecoclimatic zones, especially with regard to drought tolerance. More recently, specific studies have been initiated on provenance variation, for example in *Acacia* species, and low-technology vegetative propagation techniques have been developed for a number of species. Multipurpose tree species offer numerous opportunities for genetic selection and domestication, such as improvements in survival, growth rate and yield, as well as various quality attributes associated with different forest products.

Mycorrhizal inoculation has been found to enhance greatly the survival of trees planted in degraded areas, which have low mycorrhizal inoculum potential. Inoculated trees have been used to restore the soil inoculum and have been shown to enhance the growth of interplanted agricultural crops. Studies in progress in Kenya are screening for the effectiveness of indigenous rhizobial strains associated with N-fixing tree species. There are opportunities to exploit tree/crop symbiotic associations further in agroforestry systems, using trees selected both for their own attributes and for soil-improving qualities.

INTRODUCTION

Africa is faced with the serious problem of not being able to feed its population or supply it with wood fuel. Production of more than one crop plant by each farmer is a common feature of traditional farming systems in Africa (Sanginga, Mulongoy & Swift 1992), and plant species that provide more than one product are favoured for planting (Konuche & Milimo 1989). Multiple cropping systems usually involve the use of multipurpose trees and shrubs, including legumes, in intimate association with seasonal and perennial food crops and livestock. The success of these systems lies in a high overall biomass yield, good nutritional value of the edible products, and a wide diversity of products. This diversity also reduces the chances of complete crop failure (Torquebiau 1992).

In East Africa, pastoralists in the dry savannahs rely heavily on trees and shrubs for browse, fodder, shade, living fences and windbreaks. These species are also important as sources of wood (firewood, poles, posts) and non-wood products (gums, resins, fruits, food, medicines) and for maintaining soil fertility (Table 1). Certain decorative woods, especially the black ones (*Diospyros* spp., *Dalbergia melanoxylon*, etc), are also commercially very important for carvings for the tourist trade.

This review focuses on the non-industrial trees and shrubs in semi-arid East Africa which could be selected for use in agroforestry systems. The multipurpose nature of trees and shrubs in agroforestry poses difficulties for tree improvers, such as whether single or multipurpose characteristics should be selected when breeding or selecting improved lines of multipurpose trees (see Owino, Oduol & Esegu, pp205–209; Simons, MacQueen & Stewart, pp91–102). This paper covers progress in three stages of the domestication process:

i. species selection;

ii. propagation and intraspecific genetic selection, and

iii. the incorporation of these selections into sustainable management systems.

In East Africa, a start has been made with these processes by screening species for adaptation to different climatic/edaphic conditions (Table 2), the evaluation of provenance variation and the creation of a small number of clones. In addition, investigations are in progress to examine the role of symbiotic soil micro-organisms, including inoculating trees with vesicular–arbuscular mycorrhizal fungi (VAM) and nitrogen-fixing bacteria (rhizobia).

Table 1. Tree and shrub species listed by their common uses in East Africa

Poles and posts	Fuelwood	Erosion control	Carving
Acacia albida	*Acacia nilotica*	*Acacia albida*	*Acacia albida*
A. nilotica	*A polycantha*	*A. elatior*	*A. polycantha*
A tortilis	*A saligna*	*A senegal*	*A tortilis*
Azadirachta indica	*A. seyal*	*A. tortilis*	*Balanites aegyptiaca*
Balanites aegyptiaca	*A tortilis*	*Albizia coriaria*	*Commiphora* spp.
Callitris glauca	*Azadirachta indica*	*A. lebbeck*	*Croton megalocarpus*
Cassia siamea	*Balanites aegyptiaca*	*Cajanus cajan*	*Delonix elata*
C. spectabilis	*B. orbiculans*	*Cordia sinensis*	*Diospyros scabra*
Casuarina equisetifolia	*Callitris glauca*	*C. ovalis*	*Dobera glabra*
Cordia sinensis	*Cassia siamea*	*Croton megalocarpus*	*Erythrina* spp.
C. ovalis	*Casuarina equisetifolia*	*Combretum micranthum*	*Hyphaene ventricosa*
Croton megalocarpus	*Combretum micranthum*	*Dalbergia melanoxylon*	*Terminalia brownii*
Delonix elata	*Cordia sinensis*	*Euphorbia tirucalli*	*Ziziphus mauritiana*
Eucalyptus camaldulensis	*Croton megalocarpus*	*Lannea alata*	
E. tereticornis	*Diospyros scabra*	*Lantana camara*	
Hyphaene ventricosa	*Eucalyptus camaldulensis*	Leucaena leucocephala	
Leucaena leucocephala	*E. tereticornis*	Prosopis chilensis	
Melia azedarach	*Leucaena leucocephala*	P juliflora	
Melia volkensii	*Melia azedarach*	Salvadora persica	
Prosopis chilensis	*Parkinsonia aculeata*	*Tamarix aphylla*	
P juliflora	*Prosopis chilensis*	*Ziziphus* spp.	
Salvadora persica	*Salvadora persica*	*Ziziphus mauritiana*	
Tamarindus indica	*Syzygium cumini*		
Terminalia brownii	*Ximenia americana*		

Windbreaks	Ornament	Hedges	Human food	Human food
Acacia albida	*Acacia albida*	*Bixa orellana*	*Adansonia digitata*	*Manilkara butugi*
A. nilotica	*A. nilotica*	*Cassia edulis*	*Annona chrysophylla*	*Mimusops fruticosa*
A. polyacantha	*A. polycantha*	*C. grandiflora*	*Azanza garckeana*	*Phoenix reclinata*
A. tortilis	*A. tortilis*	*Caesalpinia decapetala*	*Balanites glabra*	*Rhus natalensis*
Berchemia discolor	*Adansonia digitata*	*C. pulcherrima*	*Bequaertiodendron natalense*	*R. vulgaris*
Cassia siamea	*Adenium obesum*	*Chrysophyllum albidum*	*Berchemia discolor*	*Sclerocarya birrea*
C. spectabilis	*Berchemia discolor*	*Duranta repens*	*Borassus aethiopum*	*S. caffra*
Croton megalocarpus	*Cassia siamea*	*Dovyalis caffra*	*Canthium gueinzii*	*Sorindeia obtusifoliolata*
Delonix elata	*C. spectabilis*	*Opuntia dellenii*	*Carissa edulis*	*Strychnos decussata*
Diospyros scabra	*Croton megalocarpus*	*Pithecellobium dulce*	*Cordia sinensis*	*Syzygium guineense*
Euphorbia tirucalli	*Delonix elata*		*C. somaliensis*	*Vangueria apiculata*
Ficus sycomorus	*D. regia*		*Cordylogyne africana*	*V tomentosa*
Leucaena leucocephala	*Diospyros scabra*		*Diospyros mespiliformis*	*Vitex payos*
Schinus molle	*Erythrina abyssinica*		*Ficus glumosa*	*Ximenia americana*
Tamarindus indica	*Ficus sycomorus*		*F urceolaris*	*X. caffra*
	Melia azedarach		*F vallis-choudae*	*Ziziphus abyssinica*
	M. volkensii		*Flacourtia indica*	*Z. mucronata*
	Panax fruiticosa		*Grewia ectasicarpa*	
	Phyllanthus roseoptia		*Hirtella zansibarica*	
	Schinus molle		*Hyphaene coriacea*	
	Terminalia spinosa		*Lannea alata*	

SPECIES SELECTION

Until recently, when it became government policy in Kenya to promote the replanting of indigenous rather than exotic tree species, most of the work on the selection of trees of semi-arid lands in Kenya was with exotic fast-growing species. For example, a trial with Australian *Acacias* on two semi-arid Kenyan sites (Marimanti and Lanchiathurio) at 18 months indicated that *Acacia holosericea, A. cowleana, A. plectocarpa, A. leptocarpa* and *A. brassii* were promising (Chege & Stewart 1991). In other trials in the Embu/Meru/Isiolo project, species showing promise were *Acacia albida, A. cyanophylla, A. nilotica, A. polycantha, A. victoriae, Atriplex nummularia, Atriplex semi-baccata, Balanites aegyptiaca, Melia volkensii, Prosopis juliflora, Terminalia spinosa* and *Ziziphus mauritiana* (Armstrong & Lugadiru 1986). Subsequently, the performance of exotics was compared with indigenous species but seldom with a wide range of provenances. Comparative results of 58 exotic and indigenous tree and shrub species at

Table 2. Tree and shrub species listed according to site requirements

	Ecoclimate and rainfall zone[1]	Geomorphology[2]	Soils[3]	Soil/water regimes[4]
Acacia albida	1–4	1	1,2	1,2
A. gerrardii	3–4	1,2	1	3
A. mellifera	2–3	0	1,2	3
A. nilotica	1–4	0	1	3
A. polyacantha	4	1,0	1,2	3
A. senegal	1–4	1	3	2,3
A. seyal	2–4	2	3	3
A. tortilis	1–4	1,0	1,3	1,2,3
Adansonia digitata	2–4	1,2	1	3
Azadirachta indica	2–4	2	1	1,3
Balanites aegyptiaca	1–4	0	1,3	3,0
Berchemia discolor	3–4	1,0	3	3
Boscia angustifolia	2–3	0	1,3	3
B. coriacea	2–3	0	1,3	3
Boswellia hildebrandtii	2–3	2,0	1	3
Carissa edulis	3–4	1,2	1	3
Combretum molle	3–4	2,0	1,3	3,0
Commiphora africana	2–3	2	1,3	3
Conocarpus lencifolius	3–4	1	1	1,3
Cordia sinensis	1–3	1,2	1,3	1,3
Croton megalocarpus	4	2	1	3
Dalbergia melanoxylon	2–4	2	1	3
Delonix elata	1–3	2,1	3	3
D. regia	4	0	1	3
Diospyros mespiliformis	3	0	1,3	3
D. scabra	1–3	1	1,3	3
Dobera glabra	2–3	0	1,2	2,3
Dodonaea viscosa	4	3,0	2,3	3
Euphorbia tirucalli	2–4	0	2,3	0
Grewia villosa	2–3	0	2	3
Hyphaene ventricosa	1–3	1	2	1
Melia azedarach	3–4	0	2	3
M. volkensii	3–4	1	2	3
M. stenopetala	3–4	1	2	1
Parkinsonia aculeata	2–3	0	1,2,3	0
Piliostigma thonningii	4	0	2,3	3
Pithecellobium dulce	4	2	2	3
Populus ilicifolia	2–4	1	1,2	1
Salvadora persica	1–3	1,0	2	0
Syzygium cumini	2–4	1	1,2	1

[1] 1, 150–350 mm; 2, 300–350 mm; 3, 450–900 mm; 4, 600–1100 mm

[2] 1, depressions/river banks; 2, plains; 3, hills/slopes; 0, not specific

[3] 1, clays; 2, loam, sand, groundwater alluvial; 3, rocks, gravel, hardpans

[4] 1, dependent on groundwater; 2, tolerates seasonal inundation; 3, requires moist, well-drained soils; 0, not specific

two years of age at Loruk (Kenya) are reported by Kimondo (1991). From these results, the Australian *Acacias* generally were superior in height growth, but had poor survival with only three out of the 15 species achieving greater than 80% survival (Table 3), compared with nine out of 12 of the indigenous species. The indigenous *Sesbania sesban* was the tallest, but had only 25% survival. Of the other indigenous species tested, the height and survival of *Acacia seyal* and *Melia volkensii* were acceptable (Kimondo 1991).

Similarly, trials with exotic (25) and indigenous (16) species have also formed part of the objectives of the Baringo fuel and fodder project based near Lake Baringo in Kenya. Mortalities less than 50% occurred with only *Acacia tortilis* and the exotics *Prosopis pallida, P. chilensis, Acacia aneura, Cassia sturtii, Gleditsia triacanthos, Prosopis tamarugo, Acacia albida, Simmondsia chinensis, Azadirachta indica* and *Atriplex canescens.*

In order to facilitate domestication, it is necessary to determine the tree and shrub characteristics desired by a particular community, and to identify genetically outstanding natural populations and individuals for propagation by seed or vegetative techniques. In semi-arid areas, there is considerable variation in soil types, rainfall (quantity, frequency, duration of dry

Table 3. Mean height and survival of Australian *Acacia* spp. and 12 other species indigenous to Kenya at two years of age at Loruk, Kenya (500 mm mean annual rainfall) (source: Kimondo 1991)

Species	Country of origin	CSIRO seedlot number	Mean height (m)	Survival (%)
Acacia holosericea	Australia	14660	2.8	85
A. holosericea	"	14632	2.8	93
A. farnesiana	"	–	2.6	55
A. torulosa	"	14888	2.6	33
A. plectocarpa	"	17207	2.5	74
A. brassii	"	15480	2.4	15
A. difficilis	"	14623	2.4	51
A. ampliceps	"	14668	2.4	74
A. ampliceps	"	14631	2.3	55
A. shirleyi	"	14622	2.2	26
A. cowleana	"	14885	2.1	35
A. cowleana	"	14683	2.1	32
A. julifera	"	14656	2.1	44
A. raddiana	"	–	1.7	82
A. trachycarpa	"	15767	1.6	18
A. nilotica	India	–	2.8	78
Tamarindus indica	Kenya	–	2.9	97
A. nilotica	"	–	1.9	82
A. nubica	"	–	1.0	23
A. tortilis	"	–	1.6	99
Cordia sinensis	"	–	1.6	91
Dalbergia melanoxylon	"	–	1.5	97
Terminalia brownii	"	–	1.3	95
A. mellifera	"	–	1.1	98
Croton megalocarpus	"	–	1.1	94
Berchemia discolor	"	–	1.1	74
Sesbania sesban	"	–	3.2	25
Balanites aegyptiaca	"	–	0.9	68

season, reliability, etc), proximity to water table, pH, salinity, and topography. Thus, there is a likelihood that wild tree populations will have adapted to their environments on a local scale. In addition to this small-scale variation, there are superimposed regional gradients of increasing aridity. Species trials in Kenya at Hola, Ramogi, Baringo, Kibweze, Lodwar, Embu and Meru have screened more than 500 different exotic and indigenous tree and shrub species for their adaptation to different ecological zones. In East Africa, therefore, it is clear that there has been considerable genetic testing at the species level. This testing now needs to be extended to a study of the genetic variation between provenances, as well as the likely variation within different populations.

INTRASPECIFIC GENETIC SELECTION

International provenance trials with dry-zone *Acacia* spp. are currently in progress, co-ordinated by the Oxford Forestry Institute (Fagg & Barnes 1990). Four African *Acacia* species (*A. tortilis, A. nilotica, A. senegal* and *A. albida* [now called *Faidherbia albida*]) with wide geographical distributions, which include East Africa, were identified as having particular potential as producers of a range of products and as being suitable for planting on arid, degraded sites. As a prerequisite to the successful establishment of provenance trials, a study was made in 1987–90 of:

- morphological and phenological variation of the tree species and of their rhizobial symbionts throughout their natural range;
- the breeding systems of the species.

In addition, a sampling strategy was developed and utilised to provide the basis for genetic exploration, evaluation and conservation as a basis for subsequent domestication (Fagg & Barnes 1990).

In the second phase of this project (1990–93), *A. eriloba* was added to the project and the above research was extended and seed collections were made. These collections were for distribution to collaborators in the establishment of international provenance trials. In addition to superior performance in terms of growth, these trials are intended to test other characteristics, such as nutritional value, fodder production, and gum quality and productivity (Fagg *et al.* 1990).

By 1991, over 30 provenances had been deposited in the UK Forestry Commission's seedbank at Alice Holt, Surrey, England. For a number of these provenances, seed collections were made from individually sampled trees for more detailed studies of genetic variation and breeding systems. Leaf collections were also made for studies on peroxidase activity and nitrogen fixation assessments. Wood samples were collected for dendrochronology studies, and gum samples were taken for chemical analysis. In a parallel study funded by the European Commission, further seed collections of *Faidherbia albida* have been made from East Africa for a collaborative study between institutions in the UK, France and Senegal on its reproductive biology, and its genetic variability in agroforestry characteristics and in its isoenzyme patterns (Lockhart, Fagg & Barnes 1990).

In another study, 30 families within three provenances of *Melia volkensii*, in which seeds were collected along a sharp climatic gradient, were established on three sites in Kenya (Embu, Bura and Malindi) in 1990. Preliminary results have indicated pronounced variation at the family level, but not at the provenance level, in growth, drought tolerance, root architecture, branch density and size, leaf phenology and resistance to spider mite attacks. These results have important implications for the selection of genotypes for dry and wet season fodder production, the provision of shade for livestock, and for intercropping with agricultural crops (P Milimo, unpublished data).

In other areas of semi-arid Africa, studies are in progress on species also indigenous to East Africa. In two different experiments involving *F. albida*, provenances raised from West African seed had generally smaller shoots compared with those from South Africa, under moist soil conditions (Wanyanja, Mills & Gwaze 1991; Vandenbeldt 1991). In the drier West African plots, all provenances of *F. albida* from South Africa had 100% mortality at the end of the second year, while survival of both provenances in South Africa was the same. In South African plots, local provenances outperformed the West African ones in height growth. The South African provenances had greater shoot dry biomass compared with those from the West African provenances, which allocated 20% more dry matter to the roots. These results indicate that, in this instance, local provenances were better adapted to the prevailing conditions than introduced ones.

A detailed study of variation between 75 provenances of *Sesbania sesban* has been made by the International Centre for Research in Agroforestry (see Owino *et al.*, pp205–209). A further component of the study with this species is to select individual and contrasting phenotypes for their apparent suitability for producing poles, fodder and biomass. These will be propagated vegetatively to assess their potential for maximising productivity of a particular product by selecting single-purpose clones of this multipurpose species (P. Oduol, personal communication; see also Owino *et al.*, pp205–209).

Variations between and within species in their capacity to resist drought are likely to be a major characteristic influencing the survival and growth of trees in the semi-arid lands of East Africa. Although stable performance of a provenance over a wide range of environments is generally regarded as desirable, past attempts to identify and select trees for semi-arid areas have resulted in a wide range of responses among species and provenances to different environments, as would be expected. This has been demonstrated in progeny/provenance tests of *Melia volkensii* and *M. azedarach* established on three sites with 400 mm, 950 mm and 2000 mm annual rainfall, in northern Queensland, Australia. Results from these studies show marked variation within and between species in leaf phenology, survival and above-ground dry mass production (P Milimo, unpublished data). Thus, given the range of soil types and water availability in these conditions, genotype/environment interactions are almost certain to prevent the selection of a widely acceptable provenance.

The detection of early indicators of good field performance is a valuable step in tree improvement. In hot dry sites, high water use efficiency, and the absence of photo-inhibition, may be determined by examining morphological and physiological characteristics. This examination, however, is likely to be more successful at the clonal rather than the provenance level. Success would depend on the capacity to use juvenile tissues to predict the responses of mature trees to drought conditions. However, because mature trees are more likely to be able to utilise water deep underground, drought tolerance is probably much more important in seedlings and young plants.

Most of the indigenous trees of semi-arid East Africa could be selected for a range of genetic traits. Thus, selection in multipurpose tree species could include not only the typical, forestry-related characteristics such as growth rate and stem form, but also selection for resistance to drought, salinity, alkalinity; fodder and pod yields and quality (nutritive value, digestibility, freedom from alkaloids, thornlessness, etc); yields and quality of gums, resins and pharmaceuticals (see Waterman, pp42–48); firewood and charcoal quality (high wood density, presence of oxalates (Prior & Cutler 1992), etc); as well as for nitrogen-fixing ability in the leguminous species. The problems associated with selection of multipurpose species are considered by Simons *et al.* (pp91–102): see also Felker (pp183–188) for studies on *Prosopis* spp.

PROPAGATION BY SEED

Although propagation by seed is the main method of plant multiplication in E Africa, availability of quality seed is a major constraint affecting planting (Shakacite 1987; Shehaghilo 1987; Wate 1987; Milimo 1987). Problems that prevent the use of seed can be broadly classified as irregular or infrequent flowering and seed inviability and/or dormancy.

Fruit-bearing species like *Ziziphus mauritiana*, *Diospyros scabra, Balanites aegyptiaca* and *Dobera glabra* have well-defined seed collection periods, although their viability declines rapidly with time (Zumer-Linder 1983). However, seedlings of many of the popular wood-producing indigenous tree species cannot be propagated easily by seed because they exhibit dormancy. Amongst these are *Melia volkensii* (Milimo & Hellum 1989a, b), *Terminalia* spp. (Specht & Schaefer 1990) and *Hyphaena coriacea* (Zumer-Linder 1983). The techniques that have been used to break dormancy are not practical for large-scale seed production, and therefore more research on this aspect is needed. Insect damage is a major constraint on seed availability in some genera, eg *Balanites* and *Acacia.*

VEGETATIVE PROPAGATION

Vegetative propagation is becoming increasingly important in forestry and agroforestry for the multiplication of limited seed material and for the production of genetically uniform stock for planting. The value of vegetative propagation to multiply selected planting material and to capture genetic potential has long been known (Libby 1973; Zobel & Talbert 1984; Leakey 1987). Vegetative propagation gives the tree improver the ability to multiply, test, select from and utilise the large genetic diversity present in most tree species. In this way, selected, highly productive but unrelated clones can be used commercially for reforestation and agroforestry (Leakey 1991).

Studies to determine the best propagation environment for semi-arid species have indicated that a non-mist propagation system is generally more effective than conventional mist propagation (Dick, East & Leakey 1991). In particular, the better rooting of cuttings in non-mist propagators seems to be related to a lower susceptibility to rotting and consequent mortality (Figures 1 & 2). The low-technology non-mist propagator currently used in Kenya has been described by Leakey *et al.* (1990) (see also Ladipo *et al.*, pp239–248). This design does not require electricity or piped water, and is therefore particularly suitable for rural areas in the tropics. Several groups working in Kenya have successfully utilised this technology to root a variety of species (Table 4).

Trials have started in Kenya to determine protocols for the larger-scale propagation of semi-arid zone species. Initial work has shown that *Acacia tortilis* and *Prosopis juliflora* both root well from pollarded material. Three months after pollarding *P. juliflora* trees 1 m above ground

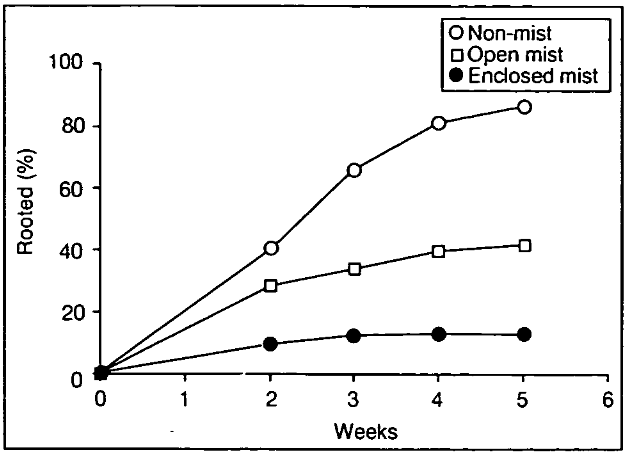

Figure 1. Effect of three propagation environments: (i) a low-technology non-mist propagator, (ii) an open mist system, and (iii) a mist system enclosed in polythene, on the percentage of *Prosopis juliflora* cuttings forming adventitious roots

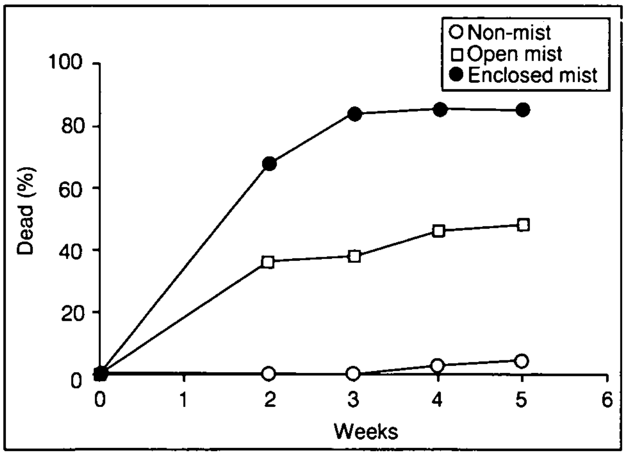

Figure 2. Percentage mortality of *Prosopis juliflora* cuttings in three propagation environments

level (to avoid grazing by goats), between 50 and 250 cuttings were harvested and transported the same day to the propagators in Nairobi, four hours' drive away. Two-node cuttings (approximately 5 cm length) were taken from each shoot after discarding the very soft 10 cm at the tip. The cuttings were dipped in a commercial rooting powder 'Seradix 2' (May & Baker Ltd, active ingredient 0.8% indole-3-butyric acid, IBA), and placed in the non-mist propagators. The number of cuttings rooted was assessed five weeks later when 43% and 96% rooting had occurred in *A. tortilis* and *P. juliflora*, respectively. Three harvests were collected from one tree of *P. juliflora* pollarded in December 1988; cuttings were collected in February, August and November 1989, with rooting success of 43%, 56% and 83%, respectively. The differences in rooting success are probably attributable to the stage of growth of the resprouted material when collected, rather than to season. Older, more lignified tissue was collected in the first two harvests and is less likely to root than younger material.

It is clear that the system developed in Kenya has great potential for practical implementation in semi-arid areas with species which coppice. The ability to root tropical trees from leafy stem cuttings depends upon many factors, such as the physiological state of the stockplant, the propagation environment and the treatment applied to the cutting prior to propagation, eg the leaf area and the concentration of applied auxins (Leakey 1985). A good understanding of these factors is necessary to sustain output from vegetative propagation systems (Leakey, Newton & Dick, pp72–83).

The state of the leaf on the cutting is an important factor in determining the rooting potential of a cutting. For example, leaves on cuttings of *Terminalia spinosa* trimmed to 30 cm^2 produced roots in a shorter period than those trimmed to only 7.5 cm^2 (Newton, Muthoka & Dick 1992), whereas leafless cuttings did not root. The mean length of the longest root increased with increasing leaf area (0, 7.5, 15 and 30 cm^2), which is almost certainly important for subsequent cutting survival and establishment in the nursery. Large-leaved cuttings were droughted, displaying the lowest foliar relative water content. In response to this drought, these cuttings closed their stomata and thus had the lowest stomatal conductance, and displayed the highest rate of leaf shedding (Newton *et al.* 1992). These self-regulated changes in leaf area resulted in cuttings with optimal leaf area for rooting in the environment tested.

Stockplant management is also critical for sustained, successful rooting. The light

Table 4. Dry zone species propagated by vegetative stem cuttings at ITE, Edinburgh, National Museums of Kenya and Baringo fuel and fodder project

Acacia albida
A. karoo
A. polyacantha
A. senegal
A. tortilis
Balanites aegyptiaca
Carissa edulis
Cassia siamea
Combretum heroense
Cordia sinensis
Dalbergia melanoxylon
Diospyros mespiliformis
Dobera glabra
Faidherbia albida
Ficus sycomorus
Leucaena leucocephala
Melia volkensii
Prosopis juliflora
Sclerocarya birrea
Sesbania sesban
Tamarindus indica
Terminalia brownii
T. prunioides
T. spinosa
Vangueria infausta
V. madagascariensis
Ximenia americana
Ziziphus mauritiana
Z. mucronata

environment to which stockplants are subjected also influences rooting potential of cuttings. In *Acacia tortilis* grown under different light qualities at constant irradiance (150 μmol m^{-2} s^{-1}) in controlled environment conditions, stockplants grew tallest in light with a red/far-red ratio (R:FR) of 0.61, rather than at 1.09, 3.14 or 4.48 R:FR (Dick & East 1992). Cuttings from shoots harvested from plants grown at low R:FR (0.61 and 1.09) rooted better (77–79%) than those from R:FR 3.14 (63%) or R:FR 4.48 (22%). This response is similar to that of other tropical trees (see Leakey *et al.*, pp72–83).

TREE ESTABLISHMENT AND SUSTAINABLE MANAGEMENT

The value of domestication in capturing a range of genetic potential is lost if, when the selected material of multipurpose trees is planted out in the field, they either do not establish or grow poorly. Such problems have often occurred when reforesting drylands where soil moisture and nutrients are limiting (Wood 1989; Armstrong & Lugadiru 1986; Chege & Stewart 1991; Chirchir & Stewart 1989), or when the seedlings have been inadequately protected from grazing animals. The change in environmental conditions experienced by the plants during transplanting may be severe, and may result in severe droughting of the plants, which can be at least partly alleviated by irrigation (Newton, Munro & Wambugu 1993). Although the application of water-retaining polymers has also been recommended to improve tree establishment by alleviating the effects of drought (see Callaghan et al. 1989), initial field results have not been encouraging (Newton *et al.* 1993; Wilson *et al.* 1991).

Many tropical soils are degraded, contain low concentrations of plant nutrients, and have high phosphorus-fixing capacity (Sanchez & Salinas 1981). Attempts to solve this problem usually involve application of chemical fertilizers or the addition of organic matter. Since chemical fertilizers are unaffordable by most subsistence farmers, except through credit schemes which can plunge the farmer into debt, this review examines the role of soil microflora in tree establishment.

The role of VA mycorrhizas

Symbiotic soil micro-organisms possess the potential to assist trees and crops to access greater quantities of nutrients (Torquebiau 1992) and therefore survive better in difficult habitats (Wilson *et al.* 1991; Sprent, pp176–182; Mason & Wilson, pp165–175). Vesicular–arbuscular (VA) mycorrhizal fungi perform a range of functions, including enhancement of mineral nutrient uptake (particularly phosphorus) by the plant root system (Harley & Smith 1983). Under tropical conditions, little is known about the occurrence and distribution of VA mycorrhizal fungi, but they are considered essential for the growth of many grain crops, forage legumes, pasture plants, forest trees and horticultural plants (Janos 1987). In degraded arid areas, there may be a need to enhance the mycorrhizal and rhizobial symbioses if, as is likely, the processes of degradation have had detrimental effects on the soil inoculum.

In Kenya, observations of spore numbers and types were made around naturally occurring *Acacia tortilis* trees at Olorgasailie, in the Rift Valley. Samples were taken in April 1989, at the end of the wet season, from the top 15 cm layer of soil along transects from the boles of *A. tortilis* trees outwards to bare ground. The trees were of variable size and unknown age, and transect lengths were varied according to tree size so as to accommodate variation in the areas of canopy and rooting zone influence.

Following extraction from the collected soil samples, the numbers of live and dead spores were counted and types were distinguished. Twelve types were found, including *Acaulospora scrobiculata*, *Entrophospora* sp., *Scutellospora* sp., *Glomus geosporum*, six other *Glomus* species, and two unknown types (J Wilson, unpublished data). This is a reasonably diverse population. Total numbers of spores were 5–6 times greater close to the trees than at a distance (Table 5). Live spores, which probably represent an important component of the soil inoculum in degraded sites (see Mason & Wilson, pp165–175), outnumbered dead spores in each sample, and the ratio of live/dead spores was 1.6–2.7 close to the trees, while it was lower (1.2–1.3) away from the trees. The presence of higher spore numbers with a greater proportion of viable spores close to trees may be a direct effect of their root systems or an indirect effect of soil temperature, moisture, chemistry or other factors.

Table 5. Distribution of live and dead VA mycorrhizal spores in soil samples taken close to and on bare ground at a distance from naturally occurring *Acacia tortilis* trees at Olorgasailie, Kenya (results are numbers per 50 g fresh mass of soil)

	Tree A			Tree B		
	Live	Dead	Total	Live	Dead	Total
Close	369	231	600	664	242	906
Distant	61	46	107	100	82	182

In Kenya two trials have recently shown the benefits of nursery inoculation on tree survival in semi-arid lands (Wilson *et al.* 1991). Inoculation of four tree species was examined: *Acacia tortilis, Prosopis juliflora, Terminalia brownii* and *Terminalia prunioides* (Wilson *et al.* 1991). Pre-germinated tree seedlings were inoculated with root and adhering soil inoculum of endomycorrhizal fungi cultured on maize and cowpea. The leguminous trees were also inoculated with rhizobia. After growth in a nursery, they were planted in two successive wet seasons at two sites, Marimanti and Olorgasailie, both semi-arid but with annual rainfalls of 847 mm and 476 mm, and soil pH of 6.5 and 8.1, respectively. The percentage of seedlings surviving at each site 30 weeks after planting is shown in Table 6.

Table 6. Percentage survival of inoculated (+S) and uninoculated (-S) plants 30 weeks after outplanting, and improvement in survival (% gain) as a result of inoculation with VA mycorrhizal and with rhizobia for leguminous tree species. Experiment at two semi-arid sites in Kenya (data based on 90 plants per treatment of *Acacia* and *Prosopis* and 45 plants for the *Terminalia* spp. in each experiment)

	Planting date					
	Experiment 1 November 1988			Experiment 2 March 1989		
	+S	–S	% gain	+S	–S	% gain
Marimanti						
*A. tortilis**	94	78	21	98	76	29
*P. juliflora**	92	84	9	76	73	4
T. brownii	89	87	2	61	44	39
T. prunioides	93	68	37	64	31	106
Olorgasailie						
*A. tortilis**	100	81	23	94	87	8
*P. juliflora**	97	91	6	65	80	–18
T. brownii	89	76	18	94	90	4
T. prunioides	84	47	79	87	70	24

* Leguminous tree

Inoculation generally improved plant survival, although effects varied with both season and species. Substantial effects of inoculation on tree growth were also observed in the nursery prior to outplanting. Observations on these experiments and others indicate that benefit from mycorrhizal inoculation is most marked when roots are more than 70% mycorrhizal at planting (Wilson *et al.* 1991) and when environmental conditions are most stressful.

Irrespective of the cause, the presence of a greater quantity of inoculum in the soil close to trees may lead to higher rates of mycorrhizal infection in crops grown among trees than in those grown on their own, provided that the types of inoculum are compatible. The dynamics of VA mycorrhizal populations in agroforestry systems are unknown, although the cycle of soil and vegetation disturbance is likely to have adverse effects. Agricultural crops can benefit substantially from inoculation with VA mycorrhizal fungi (Howeler, Sieverding & Saif 1987). While inoculation of agricultural crops is restricted by the large quantities of inoculum required, inoculation of nursery-grown trees intended for agroforestry systems may be worthwhile, particularly in stressful environments. Because of the wide host ranges of these fungi, and the diversity of fungal species occurring with trees, the tree roots may sustain inocula which are also of value to the intercrop (Wilson *et al.* 1991). Inoculation of trees, therefore, may have two benefits:

i. improvement of tree survival and growth, and
ii. maintenance of populations of mycorrhizal species suitable for intercrops in the period between harvesting one intercrop and sowing the next.

Past experience would indicate that, if an adequate heterogeneous VA mycorrhizal population is present, crops should have no problem in finding sufficient compatible fungi for growth (Sieverding 1991). However, more extensive observations are needed to confirm this effect of trees and to examine the effects on intercrops.

Rhizobia and nitrogen fixation

A large programme of research is in progress on nitrogen-fixing trees at the Kenya Forestry Research Institute (KEFRI). The work entails isolation, characterisation and screening for the effectiveness of indigenous rhizobial strains, found in association with selected N-fixing trees. This programme is also developing appropriate inoculation techniques for tree seedlings, for enhanced nodulation, nitrogen fixation and tree establishment (D Odee, personal communication). As already mentioned, microsymbiont inoculation (VA mycorrhizas and rhizobia) has improved tree establishment on degraded sites (Table 6). In collaboration with the Department of Biological Sciences, University of Dundee, KEFRI is also engaged in programmes to map and test indigenous tree rhizobial flora across the various ecoclimatic zones of Kenya; and to test inoculants for *Acacia* spp. of East and southern Africa. Further studies are planned to determine the compatibility of Kenyan rhizobial strains with Australian *Acacia* spp., when grown in Kenya (J Sutherland, personal communication).

CONCLUSIONS

The domestication of trees for the production of wood and other products in semi-arid areas of East Africa is at an early stage. A wide range of exotic and indigenous species have been tested for their suitability. In general, indigenous trees have shown better survival but slower growth than exotics, especially the Australian acacias (see Booth & Turnbull, pp189–194). To what extent this better survival of indigenous species may be related to their symbiotic relationships with soil microflora is not known, but it seems clear that inoculating trees with root symbionts can greatly enhance tree establishment. Following on from species selection, a start has been made on provenance selection in the African acacias and the development of vegetative propagation techniques so that the potential of clonal approaches can be evaluated.

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