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BIOLOGICAL CONSIDERATIONS IN THE UTILIZATION OF *RACOSPERMA AURICULIFORME* AND *RACOSPERMA MANGIUM* IN TROPICAL COUNTRIES WITH EMPHASIS ON ZAIRE

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KHASA, P.D., VALLEE, G. & BOUSQUET, J. 1994. Biological considerations in the utilization of *Racosperma auriculiforme* and *R. mangium* in tropical countries with emphasis on Zaire. *Racosperma auriculiforme* (*Acacia auriculiformis*) and *R. mangium* (*A. mangium*), two fast-growing species belonging to the Leguminosae family, have been introduced into Zaire for industrial fuelwood plantations as well as for social agroforestry purposes. We report here on our current knowledge on the biological considerations in the utilization of both species in tropical countries with emphasis on Zaire. The taxonomy and ecology, reproductive biology and breeding systems, genetic diversity, biotic interactions, silviculture and present uses of these species are examined. Because these species will play a major role in reforestation programmes for the next decades in developing countries such as Zaire, the necessity for the genetic improvement of these species as well as adaptability, site trials and silvicultural requirements are discussed in relation to the increase of plantation productivity.

Key words: *Acacia* - biotic interactions - genetic diversity - fuelwood plantations, reproductive biology - taxonomy - silviculture - social agroforestry - Zaire

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negera-negara tropika dengan penekanan kepada negara Zaire. Dua spesies dari famili *Leguminose*, iaitu *Racosperma auriculiformis* (*Acacia auriculiformis*) dan *R. mangium* (*A. mangium*), telah diperkenalkan di Zaire untuk industri ladang kayu api dan juga untuk perhutanan tani sosial. Di sini, kami melaporkan dengan pengetahuan semasa kami, tentang perimbangan biologi penggunaan kedua-dua spesies ini di negara-negara tropika dengan memberi tumpuan kepada negara Zaire. Taksonomi dan ekologi, pembiakan biologi dan sistem pembiakbaikan, kepelbagaian genetik, interaksi biotik, silvikultur dan penggunaan semasa kesemua spesies ini dikaji. Keperluan untuk memperbaiki genetik spesies ini serta kebolehsesuaian dan keperluan silvikultur yang berkaitan dengan peningkatan produktiviti ladang dibincangkan. Ini adalah kerana kedua-dua spesies ini akan memainkan peranan utama dalam program-program penghutanan semula dalam dekad-dekad yang akan datang di negeri-negeri membangun seperti Zaire.

Introduction

As in many tropical Sub-Saharan African countries, shifting and modern agriculture, fuelwood gathering, fires in dry forests and savannas, and selective logging system have been reported to be the main causes of loss of forest biodiversity in Zaire (Khasa *et al.*, in preparation). In order to overcome the problems associated with forest depletion and to maintain a sufficient supply of wood for fuelwood, timber, and chemicals, reforestation with fast-growing tree species is being intensified in many tropical countries. It is estimated that in Sub-Saharan Africa, at least 25 million *ha* of plantations and woodlots with fast-growing trees are required to satisfy the demand for fuelwood and other rural needs (Schönau 1990). Most forest tree plantations in tropical countries consist of exotic fast-growing tree species (Evans 1982, Zobel *et al.* 1987). Their growth and yields generally exceed those of natives, attaining for instance 30 $m^3\ ha^{-1}\ y^{-1}$ or more with *Eucalyptus* in Congo at 7-*y* rotation (Vigneron & Delwaulle 1990). However, the monoculture of exotics is often criticized, because of apparent lack of adaptation of the exotics used and their susceptibility to pests. A better knowledge of the performance and adaptation of exotics in their new environments is therefore crucial before proceeding to large scale introductions. At the same time, the long-term environmental impacts of the introduction of exotics are often unknown. This may be depicted by the slow decomposition of litter of introduced *Casuarina equisetifolia* along the coast of Senegal. Native species might represent a logical alternative but unfortunately, little research has been devoted to them for their use in reforestation and land reforestation in the tropics (Butterfield 1990).

Eucalyptus spp. and *Pinus* spp. are generally selected for exotic monocultures and several industrial tree planting programmes for timber and pulp production have been established with these species (Martin 1987, Campinhos & Ikemori 1989, Moutanda 1990, Schönau 1990, Vigneron & Delwaulle 1990). However, polar and non-polar allelochemicals from the leaves of *Eucalyptus* have been shown to inhibit growth of annuals, to decrease biodiversity in the area of eucalypt forest, and to cause economic loss to agricultural crops (Kohli & Singh 1990). These problems are also exacerbated by the high competitiveness of some *Eucalyptus* species for nutrients and water (Martin 1987). On the other hand, *Pinus radiata* has been used successfully in silvopastoral systems by the forest industry in the southern temperate zones of New Zealand, Chile and Australia (Knowles *et al.* 1990).

Several shrubs and trees from the genera *Acacia sensu lato, Calliandra, Cassia, Gmelina, Gliricidia* , *Leucaena,* and *Tectona* have been used in tropical countries for fuelwood plantations and agroforestry purposes (National Academy of Sciences 1980, National Research Council 1983). Fast-growing leguminous, actinorhizal, and other nitrogen-fixing trees are often preferred in rural community plantations for agroforestry systems, in part due to their ability to improve the nitrogen status of soils in symbiotic association with either *Rhizobium, Bradyrhizobium, Azorhizobium, Sinorhizobium, Photorhizobium,* or *Frankia* (Baker 1990, Brewbaker *et al.* 1990, Sprent & Sutherland 1990), and also due to the increase in the uptake of immobile nutrients, especially phosphorus, in symbiotic association with endomycorrhizal and/or ectomycorrhizal fungi (Khasa *et al.* 1990, 1992, Bolan 1991, Molina *et al.* 1992). Many of these species are early colonizers of cleared or disturbed sites, being mycorrhizal dependent and becoming less important and less competitive as soil fertility increases (Molina *et al.* 1992). They play a major role in soil nitrogen accretion and in organic matter accumulation, contributing to early soil development (see Baker 1990).

Of the exotic leguminous plants selected as multi-purpose trees for planting in the tropical countries, *Racosperma auriculiforme* (Cunn. ex Benth.) Pedley (*Acacia auriculiformis*) and *R. mangium* (Willd.) Pedley, comb. nov. (*A. mangium*) are often cited as having the highest priority (National Academy of Sciences 1980, National Research Council 1983, Turnbull 1987, 1991). The present review focuses on the biological considerations in the utilization of both species in tropical countries with emphasis on Zaire. Their taxonomy and ecology, reproductive biology and breeding systems, genetic diversity, biotic interactions, silviculture and uses are discussed.

Introduction of *Racosperma auriculiforme* and *R. mangium* into Zaire

R. auriculiforme and *R. mangium* have been introduced as plantation species into many countries of tropical Asia, America, and Africa (Catinot 1984, Turnbull 1987, 1991, Boland *et al.* 1990, Souvannavong 1990). Trial plots have been established in some western, central, southern African countries (Table 1), and in other countries of tropical Asia and America. According to Kankolongo and Kanu (1989), *R. auriculiforme* was introduced into Zaire in 1967 as part of a programme funded by the Food and Agriculture Organization of the United Nations and the United Nations Development Programme (FAO/UNDP). *R. mangium* was introduced into Zaire in 1979 at the Kinzono arboretum situated 150 *km* northeast from Kinshasa. However, the seed origins of both introduced *Racosperma* species were not recorded. Because of the outstanding amenity attributes of *R. auriculiforme* (Jim 1990), a few hectares of urban planting in and around Kinshasa City have been established, mainly for ornamentation and energy biomass production.

In Zaire, reforestation activities have been supervised by the Service National de Reboisement (SNR) since 1978. In 1979, the Centre Forestier Kinzono (CFK)

Table 1. Some African countries where *Racosperma auriculiforme* and *R. mangium* have been introduced

Country	*R. mangium*	*R. auriculiforme*
West Africa		
Benin	yes	yes
Ivory Coast	yes	
Niger		yes
Nigeria		yes
Sierra Leone		yes
East Africa		
Kenya		yes
Tanzania	yes	yes
Uganda		yes
Central Africa		
Burundi	yes	
Cameroon	yes	yes
Congo	yes	yes
Zaire	yes	yes
Southern Africa		
Malawi		yes
Zimbabwe		yes
South Africa	yes	

initiated the introduction of exotic species such as those of *Racosperma, Eucalyptus,* and *Pinus* in Kinzono arboretum on the Bateke Plateau. From 1979 to 1985,about 300 *ha* were planted, including *R. auriculiforme, Cassia siamea, Eucalyptus camaldulensis,* and *Millettia laurentii.* In 1985, a fund named "Fonds de Reconstitu-tion du Capital Forestier" (FRCF) was created in order to promote reforestation activities throughout the country. Since 1986, with the assistance of the European Economic Community, the private society HVA-Holland Agro Industries bv is carrying out an industrial tree planting programme on 8,000 *ha* in the Bateke plateau for energy biomass production. Of the fast-growing trees selected, *R. auriculiforme* was the major species being planted. Recently, the potential use of *R. mangium* has also been demonstrated (Khasa *et al.* 1993a). Both *Racosperma* species are now being used to reforest degraded and nutrient-impoverished sites generally covered by *Hyparrhenia* and *Imperata* grass across the country. Local non-governmental organizations as well as Belgian, German, Italian, and Swiss cooperation programmes, and the "Projet Pilote d'Appui au Reboisement Communautaire" (PPARC), funded since 1988 by the Canadian International Agency (CIDA), are also involved in community forestry at the village level. In 1988, about 750,000 seedlings mainly of *R. auriculiforme,* were produced by the farmers through the PPARC, of which 70% were outplanted (Kankolongo & Kanu 1989). The total allocated surface for reforestation programmes is approximately 112,000 *ha* in Zaire (Pagezy & Ntoto 1990). In all of these reforestation activities, *R. auriculiforme* and *R. mangium* should play a major and increasing role.

Taxonomy and ecology

R. auriculiforme and *R. mangium* are members of the Leguminosae family (subclass Rosidae, order Fabales, subfamily Mimosoideae, tribe Acacieae). Based on morphology, palynology, chemistry of heartwoods and seeds, cyanogenesis and susceptibity to rusts, Pedley (1986) has recently divided the genus *Acacia sensu lato* into three genera: *Acacia* Miller, *Senegalia* Rafinesque and *Racosperma* Martius. The majority of Australian acacias have been placed in the genus *Racosperma* Martius (Pedley 1987a), which contains about 850 species grouped into four sections (sc Racosperma, uninerved species, sc Plurinervia including Acacia sc Juliflorae, sc Lycopodiifolia and sc Pulchella). *R. auriculiforme* and *R. mangium* belong to the traditional section Juliflorae, a large group of 219 species having a mainly tropical distribution in the north and the northwest (but also in the southwest) of Australia (Boland *et al.* 1990). *Acacia* Miller is a pantropical genus of some 200 species best represented in Africa and South America with about eight endemic Australian species (Pedley 1987b). The genus *Senegalia* has about 150 species grouped into two sections (sc Senegalia and sc Filicinae), and has about the same geographic range than *Acacia* with two representatives in the northeast of Australia (Pedley 1987b).

Although Pedley's proposal (Pedley 1986) was not accepted by the International Group for the Study of Mimosoideae, it has resulted in further research into the genus which will be beneficial in elucidating the relationships of the *Acacia sensu lato* (Playford *et al.* 1992). In our opinion, this new classification from Pedley might be right. Apart from reasons raised above, the Australian acacias are quite different from the African acacias at the morphological and ploidy levels. Australian acacias are diploid while African acacias are polyploid (Atchison 1948, Joly 1991). Using the 5S DNA units of *Acacia sensu lato*, the Australian species of subg. Phyllodineae (equivalent to *Racosperma*) grouped together as a unit separated from the other subgenera *Aculeiferum* (equivalent to *Senegalia*) and *Acacia* (Playford *et al.* 1992). Further work might be required to confirm if these three subgenera of *Acacia* should be elevated to the generic rank as proposed by Pedley (1986). Work involving the estimation of morphological, biochemical and molecular phylogenies (Strauss *et al.* 1992) and their levels of congruence (Bousquet *et al.* 1992) in the genus *Acacia sensu lato* and related species (Mimosoideae) should be undertaken. Sampling should be done in all parts of the distributions, including Oceania, Asia, Africa, and America.

The phytogeography and ecology of both *Racosperma* species are well documented (Turnbull 1986, Atipanumpai 1989, Boland *et al.* 1990). *R. auriculiforme* and *R. mangium* are indigenous to Australia, Papua New Guinea, and Indonesia (Turnbull 1986, Atipanumpai 1989, Boland *et al.* 1990). These species are well adapted in the humid and subhumid tropics on several soil types from near the sea level to about 500 *m*, and with temperature ranging from 16° to 34°*C*. In their natural habitat, the annual rainfall ranges from 900 to 2,000 *mm*, and from 1,500 to 3,000 *mm*, for *R. auriculiforme* and *R. mangium* respectively (Turnbull 1986, Boland *et al.* 1990). *R. mangium* is commonly found at low altitude, along the mangrove forest fringes associated with *Rhizophora* spp. and *Melaleuca* spp., or more often along forest margins sympatrically with *Dillenia alata* Banks, *R. cincinnatum* (F. Muell.) Pedley, comb. nov., *R. aulacocarpum* (Cunn. ex Benth.) Pedley, comb. nov., and *Eucalyptus tessellaris* F. Muell. (Atipanumpai 1989). During the Quaternary periods there were severe stresses on alpine, coastal, and coralline environments so that the present distribution of *R. mangium* is of very recent origin, as a result of individuals that have survived in small scattered refuges during the glaciations (Moran *et al.* 1989a). *R. auriculiforme* is opportunistic and very mobile, colonizing many ecological niches. The species is fairly primitive and may have evolved on rain forest fringes sympatrically with *R. aulacocarpum* and *R. crassicarpum* (Cunn. ex Benth.) Pedley, comb. nov., but thriving better in marginally more difficult sites than its two allied species (Boland *et al.* 1990).

Newly-germinated seedlings of *R. auriculiforme* and *R. mangium* produce compound-bipinnate leaves which are transformed into veined phyllodes (flattened leaf stalks) after a few weeks. *R. auriculiforme* phyllodes are about 2 ± 0.5 *cm* wide and four to nine times as long as wide (Pinyopusarerk 1990), while those of *R. mangium* are large, up to about 25 × 10 *cm* (National Research Council 1983). The stem form of *R. auriculiforme* is variable, ranging from crooked and heavily branched to single straight and dominant for the greater part of the tree height, reaching up to 25 - 30 *m* tall and 80 *cm* in diameter on best sites (Pinyopusarerk 1990). *R. mangium* develops straight, clear boles and cone-shaped canopy with relatively short, occasionally self-pruning branches. Its height can reach up to 30 *m* and its diameter up to 90 *cm* on best sites (National Research Council 1983).

Flowers of *R. auriculiforme* are yellow and are in spikes or racemes up to 8 *cm* long, with peduncles 2 - 7 *mm* long, in pairs in the upper axils of the phyllode (Figure 1). Pods of about 1.5 *cm* wide and 6.5 *cm* long are flat, cartilaginous or rather woody, glaucous, transversally veined with undulate margins. They are straight initially but become very twisted with irregular spirals at maturity (Figure 3). Flowers of *R. mangium* are white or cream colour and are in spikes up to 10 *cm* long (Figure 2). Initially green and straight, the pods twist and intertwine irregularly in blackish-brown spiraled clusters at maturity (Figure 4).

Our preliminary results on chromosome counts from the root-tip cells indicate diploidy with a chromosome number of $2n = 26$ for both species. However, out of 14 specimens examined, the chromosome number in one individual of one population of *R. auriculiforme* investigated was $2n = 22$. This may indicate possible variation in chromosome number among and within populations of *R. auriculiforme*. These early observations are consistent with previous reports (Brewbaker 1987, Darus 1989).

Reproductive biology and breeding systems

Knowledge about the reproductive biology and the breeding systems are

Figure 1. Flowering spikes of *R. auriculiforme*

Figure 3. Fruits of *R. auriculiforme*

Figure 4. Fruits of *R.mangium*

important for a proper understanding of the distributions and life-histories of *R. auriculiforme* and *R. mangium*, their population genetics, and efficient domestication and use of their genetic resources. In Zaire, these species produce abundant flowers from the third year but collection of seeds is conducted only from the fourth year. Despite that no detailed phenological studies are available, the two species prove to show synchronous flowering in plantations during the second period. The first flowering occurs only for *R. auriculiforme* between February and April and ripe seeds are available from May to July. The second flowering occurs for both species between June and August and ripe seeds become available from September to October. Variations in timing and intensity of flowering and fruiting may also occur, depending on behavioural changes of insect pollinators and environmental conditions (Sedgley *et al.* 1992). Furthermore, even though synchronous flowering is observed, this may take place at different times from year to year (Sedgley *et al.* 1992).

We have determined the floral formulae for *R. auriculiforme* : the flowers are hermaphrodite with 5 joined sepals, 5 unjoined petals, numerous hypogynous stamens and a single ovary with 1 locule, 1 carpel and numerous ovules ((S(5) P(5) $A\infty\underline{G}\infty^{1,1}$)). Similar investigations on *R. mangium* indicated that flowers are hermaphrodite with 5 joined sepals, 5 unjoined petals, numerous hypogynous stamens and a single ovary with 1 locule, 1 carpel and 5 to 10 ovules ((S(5) P(5) $A\infty$ $\underline{G}5\text{-}10^{1,1}$)). The pollen grains in *Racosperma* are generally grouped into polyads commonly consisting of 16 grains (Sedgley 1987, Sedgley *et al.* 1992).

No root suckers are observed in plantations of both species and sprouting appears to be poor after cutting at the ground level (Khasa, unpublished results). Better results have been obtained elsewhere when stumps are cut at high level (*i.e.*, 1*m*) from the ground (Pinyopusarerk 1990). Vegetative propagation via juvenile rooted cuttings is possible for both species and the role of indole butyric acid phytohormone (IBA) in increasing the number of roots and the rooting success has been shown (Khasa *et al.* 1994a). *In vitro* culture has been achieved in other countries with *R. auriculiforme* (Mittal *et al.* 1989) and *R. mangium* (Crawford & Hartney 1987, Darus 1991, Galiana *et al.* 1991a,b), and layering and grafting have also proved to be successfully applicable (Liang 1987, Pinyopusarerk 1987). Agamospermy has never been reported in Racosperma.

R. auriculiforme and *R. mangium* are both allogamous, hermaphrodite, and monoecious. Insect pollinations appear the rule as bees are visitors of the flowers. Flowers lack nectaries but have extra-floral secretory glands located on the phyllodes (see Sedgley *et al.* 1992). *R. mangium* shows high outcrossing rates in natural stands (Moran *et al.* 1989a) and in exotic plantations in Zaire (Khasa *et al.* 1993). From allozyme data derived from 11 populations of *R. mangium* (Moran *et al.* 1989b), the extent of inbreeding as estimated from Wright's fixation index (F_{IS}) was moderate. The survey of progeny arrays at the more variable loci strongly suggested that *R. mangium* is predominantly outcrossing (see Moran *et al.* 1989b). Similar results were obtained by Khasa *et al.* (1994b) with F_{IS} being near 0. As pointed out by Sedgley (1987), and Sedgley and Griffin (1989), there are three floral mechanisms which promote outcrossing in *Racosperma* :(1) These species may show protogynous dichogamy with the stigma receptive to exogenous pollen before the pollen is released from the anther. (2) Andromonoecy with male and hermaphrodite flowers on the same plant also promotes pollen transfer from flower to flower. (3) Self-incompatibility or self-sterility, the failure of pollen to produce seed set in the same and related individuals is the third outcrossing mechanism explained by prezygotic and postzygotic barriers. Seed abortion detected as unfilled seeds occurs at a low level in both *Racosperma* species and this could be a consequence of low levels of self-pollination (Khasa *et al.* 1993c).

R. auriculiforme is closely related to *R. aulacocarpum* and sometimes confused with *R. leptocarpum* (Cunn. ex Benth.) Pedley, comb. nov. and *R. polystachyum* (Cunn. ex Benth.) Pedley, comb. nov. (Pinyopusarerk 1990). Hybrids of *R. auriculiforme* × *R. mangium* have been reported both in natural stands and in exotic plantations (Skelton 1987, Kiang *et al.* 1989, Wickneswari 1989, Sedgley *et al.* 1992). The genetic distance between the two species, estimated from allozyme data, was in the range of values representative of conspecific taxa (Khasa *et al.* 1994b). Therefore, selection of suitable provenances and artificial hybridization between *R. auriculiforme* and *R. mangium* should be pursued in the breeding programmes of these species. These hybrids may have great potential for plantation forestry by combining desirable properties of the parental species such as the straightness of stem form, the resistance to heartrot and other economical characters. These hybrids could be further introduced into intensive clonal silviculture via rooted cuttings or tissue culture.

Genetic diversity

Several types of biochemical and molecular genetic markers can be used to estimate the levels of genetic diversity of forest trees (Li *et al.* 1992). So far, only biochemical genetic markers have been successfully used in *Racosperma* (Moran *et al.* 1989a,b, Wickneswari & Norwati 1993, Khasa *et al.* 1994b). Based on allozyme markers, *R. mangium* was shown to be more genetically depauperate than *R. auriculiforme* (Moran *et al.* 1989a, b, Khasa *et al.* 1994b, Wickneswari & Norwati 1993,) (Table 2). The proportion of the total diversity residing among populations (G_{ST}) is also substantial for both species (Table 2), and somewhat higher than values recorded for largely outcrossed angiosperm tree species (Hamrick & Loveless 1989, Bawa 1992, Li *et al.* 1992). Therefore, the absolute amounts of genetic diversity and the relative distribution of this diversity are both important components to consider in designing efficient selection and breeding programmes for these species. For *R. auriculiforme*, these observations are corroborated by results from field provenance trials established in several countries (Turnbull 1991), which have shown a great deal of variation in growth traits within and among populations. For *R. mangium*, provenance trials have also shown significant amounts of variation that could be exploited in selection programmes (Atipanumpai 1989, Khasa 1993a).

Table 2. Allozyme diversity in *Racosperma auriculiforme* and *R. mangium*[a]

Species	N	n	A_p	P_p (0.99)	H_e	G_{ST}	Reference
R. auriculiforme	2	19	-	-	0.146	0.18	Moran *et al.* (1989a)
	18	22	1.5	39.8	0.081	0.27	Wickneswari & Norwati (1993)
	13	18	1.9	52.1	0.122	0.18	Khasa *et al.* (1994b)
R. mangium	11	30	1.1	12.7	0.017	0.31	Moran *et al.* (1989b)
	13	18	1.5	24.3	0.064	0.09	Khasa *et al.* (1994b)

[a] Abbreviations: N = number of populations surveyed, n = number of gene loci surveyed, Ap = the average number of alleles per locus per population, P_p (0.99) = the average proportion of polymorphic loci per population (0.99 criterion), H_e = the average expected proportion of the genetic diversity due to population differentiation.

Biotic interactions

R. auriculiforme and *R. mangium* are involved in symbiotic associations with natural populations of endomycorrhizal fungi and *Rhizobium* or *Bradyhizobium* (Khasa *et al.* 1990) (Figures 5,6 & 7). We failed to find natural ectomycorrhizal associations in plantations of *Racosperma* in Zaire whereas this was reported with *Thelephora* spp. elsewhere (Dart *et al.* 1991) or with *Pisolithus* spp. (Amadou Ba, personal communication 1992).

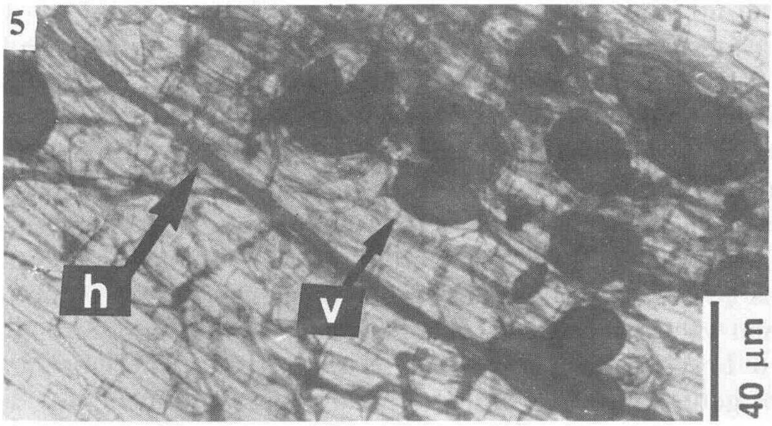

Figure 5. Intercellular vesicles (v) and hyphae (h) in an endomycorrhizal root of *R. auriculiforme*

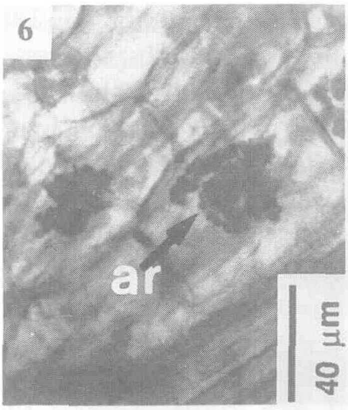

Figure 6. Arbuscules (ar) in an endomycorrhizal root of *R. auriculiforme*

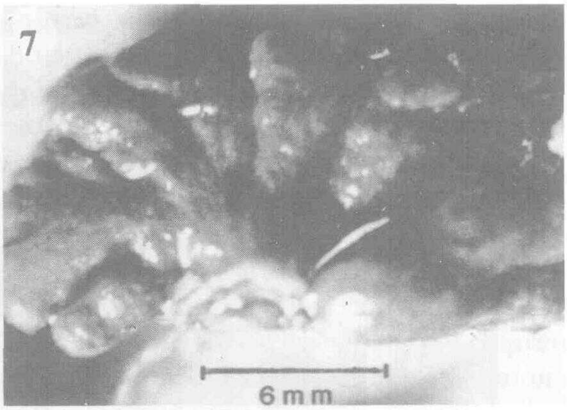

Figure 7. Nodules of *R. auriculiform* induced by wild *Rhizobium* (*sensu lato*) showing a branched form

Reddell and Warren (1987) stressed on the potential benefits of artificially inoculating *Acacia sensu lato* with mycorrhizal fungi as did Roughley (1987) for inoculation with either *Rhizobium* or *Bradyrhizobium.* Following *in vitro* inoculation of *R. auriculiforme* and *R. mangium*, only *Bradyrhizobium* spp. strains formed effective N_2-fixing nodules (Galiana *et al.* 1990). Inoculation with the ectomycorrhizal fungus *Boletus suillus* (L. ex. Fr.) stimulated plant growth of *R. auriculiforme* as well as P and N uptake, as compared to controls (Osonubi *et al.* 1991). However, growth reduction occurred after inoculation with a mixture of *Glomus* and *Acaulospora* (Osonubi *et al.* 1991). Positive effects were recorded on the biomass accumulation and the nutrient uptake in *R. auriculiforme* seedlings under the influence of triple inoculants (*Rhizobium* + *Glomus fasciculatum* + *Bacillus megaterium*), followed by double and single inoculants (Mohammad & Singh 1988). According to these authors, the combination *Rhizobium* + *Glomus fasciculatum* was the most effective among dual inoculants. Height growth of *R. auriculiforme* was equally stimulated, resulting in higher total N and P in the seedlings, after dual inoculation of *Glomos fasciculatum, G. marginata*, or *Scutellispora persica* with *Rhizobium* whereas only both *Glomus* species were effective for *R. mangium* (Dela Cruz *et al.* 1988). Therefore, in the sites where indigenous efficient strains of mycorrhizal fungi and *Rhizobium* (*sensu lato*) are lacking, screening and inoculation in the nurseries with more efficient and competitive strains may increase forest productivity. Moreover, the appropriate selection of the best tree genotypes well adapted to particular site conditions is likely to render the whole process more efficient.

Insect and pathogenic interactions occur in nurseries, such as those involving the nematodes, stem borer insects or insects which cut seedlings (Figures 8 & 9), and the presence of *Oidium* fungus (Figure 10). However, the damage caused by these types of pest is generally negligible. In plantations, *R. auriculiforme* seems to be more susceptible to stem borers (Figure 8) while *R. mangium* is more susceptible to heartrot and also to stem borers during drought. The presence of ants living on branches in symbiosis with the trees may protect them against phytopathogenic organisms and assure better growth (Wiersum & Ramlan 1982). We also noticed in one site in Zaire (Muanda), an unidentified spider species which builds nests with phyllodes of *R. auriculiforme,* resulting in yellowish phyllodes that could severely impair growth. In other countries, *Sinoxylon* species were reported as important pests that cause serious damage in *Racosperma* plantations (Hutacharern & Choldumrongkul 1989).

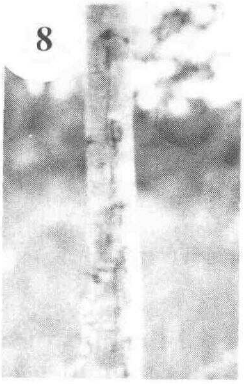

Figure 8. Gommous hole of *R. auriculiforme* due to stem borer insects

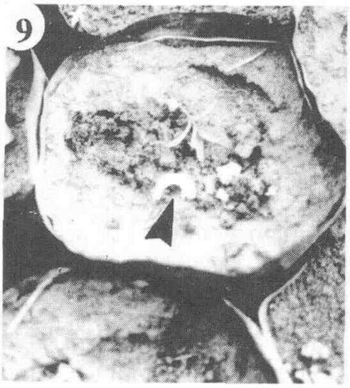

Figure 9. An insect pest which damages seedlings of *Racosperma* at the nursery stage

Figure I 0. *Oidium* fungus covering phyllodes of *Racosperma* at the nursery stage

Silviculture

Seeding is the most popular way to propagate both species (National Academy of Sciences 1980, National Research Council 1983). Because of the seed-coat dormancy in *Racosperma* the seeds should be pre-treated in order to speed up and obtain uniform germination (Khasa 1993b). Soaking seeds in concentrated sulphuric acid for 15 or 30 *min* and then rinsing them for 15 *min* with tap water, produced the best results for laboratory testing as well as for operational application (Doran & Gunn 1987, Khasa 1993b). Boiling water from which the heat source is removed and in which the seeds are placed and soaked until the water is cool (12 - 24 *h*) seems the most suitable and economical method to break seed coat dormancy for social forestry programmes at the village level in Zaire (Khasa 1993b). Newly-germinated seedlings grow well in shady conditions for a limited time and full sunlight is required for their full development. Direct seeding with two to three pre-treated seeds placed in each planting hole represents an attractive reforestation strategy but it requires extensive site preparation and post-seeding maintenance of the small germinating seedlings. Generally, the survival rate is low if weed competition is not appropriately controlled (Gerkens & Kasali 1988). Growing seedlings in black polyethylene bags during three months in nursery resulted in survival rate higher than 90%, and this method was very successful in establishing good stocking of planting trees in the grassland areas (Khasa 1993a) (Figures 11, 12 & 13). The planting spacings used for fuelwood plantations are 2.5 × 2.5 *m* and 2 × 3 *m*. Vegetative propagation is still at an experimental scale but early results with cuttings are encouraging (Khasa *et al.* 1994a). Even if frequent at stand fringes, sexual natural regeneration is scarce in exotic stands but takes place readily after the stands have been cut-over (Khasa, unpublished results).

Figure 11. Preparation of containerized seedlings using black polyethylene bags

Figure 12. Representative average growth of *R. auriculiforme* provenance #16355, reaching about 1.2 *m* at 9 months in a provenance trial on the Bateke Plateau, Zaire

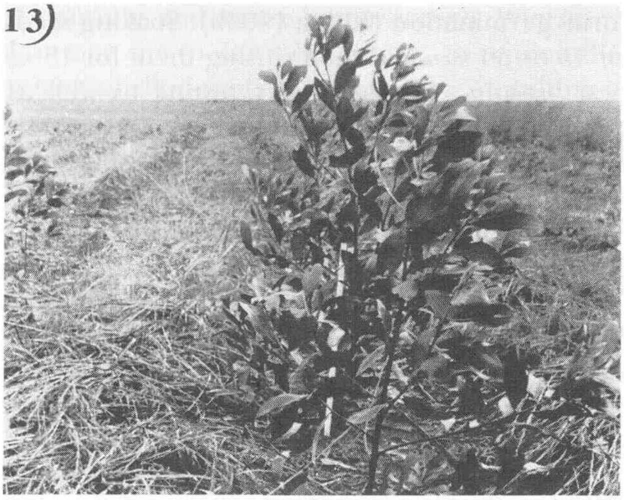

Figure 13. Representative average growth of *R. mangium* provenance #13460, reaching about 1.0 *m* at 9 months in a provenance trial on the Bateke Plateau

The mean annual increment of *R. auriculiforme* on very poor and acidic soils of the Bateke plateau is 12 m^3 ha^{-1} y^{-1} at 7-year rotation (Gerkens & Kasali 1988). The productivity can be improved by more intensive management and by using propagules of genetic superiority. In early evaluation of *R. auriculiforme* and *R. mangium* provenance trials in Zaire (Khasa 1993a), *R. auriculiforme* showed higher plasticity than *R. mangium*, and therefore, more stability across the sites. It grew well from 110 to 1300 *m* of altitude. In the sites where *R. mangium* was physiologically suited, such as Bateke plateau, some provenances were outperforming those of *R. auriculiforme* (Khasa 1993a). However, *R. mangium* was the least salt-tolerant species and did not thrive in saline soils at 6 *km* from the Atlantic coasts with 100% mortality (Khasa 1993a). In this site, two putative hybrids, showing morphological characters intermediate between these two species, grew well. They showed fine branching and apical dominance which may lead to good stem form as compared to pure *R. auriculiforme* trees which generally show crooked stems.

Uses

As exotics, both species have a great potential in the tropics because they are suitable for firewood, charcoal, pulpwood, timber, tanning, fodder, honey production, green manure, agroforestry, erosion control, windbreaks, shade, and ornamentation (Turnbull 1986, 1987, 1991). In Zaire, *R. auriculiforme* has been selected as the main plantation species for large-scale biomass production of fuelwood. *R. auriculiforme* is also planted along the streets in cities as an ornamental tree. Because of its poor stem form (Figure 14), it is not suitable for timber production.

Alternately, *R. mangium* has a good stem form suitable for timber production (Figure 15). As specific gravity and quality of fibre make possible the production of kraft and soda anthraquinone pulps (see Pinyopusarerk 1990), these species could be intercroped in blocks with *Pinus* spp. and *Eucalyptus* spp., which have been retained by the National Forestry Action Plan of Zaire for pulp production (Anonymous 1990). Local textile and cigarette industries could also use bark products of *Racosperma* such as tannins and soga dye for preparation of yellow and brown colours (see Pinyopusarerk 1990). The adhesive properties of bark extract of *R. mangium* may also be attractive for local particleboard manufacture (Mohd Nor *et al.* 1989, Rahim & Wan Asma 1990).

Figure 14. A 10-year-old stand of *R. auriculiforme* on the Bateke plateau for which the seed origin is unknown. This typical poor stem form is generally observed in plantation. Trees usually reach about 15 *m* in height and 18 *cm* in diameter at breast height at 10 year old

Figure 15. A 10-year-old stand of *R. mangium* in the arboretum of Centre Forestier de Kinzono on the Bateke plateau for which the seed origin is unknown. The stem form and growth characteristics of *R. mangium* are generally superior to those of *R. auriculiforme*

In Zaire, a promising agroforestry system with *Racosperma* includes the intercropping of *R. auriculiforme* and *Manihot esculenta* Crantz (Hanns Seidel Foundation, unpublished results). This system combines high productivity with the ability to improve soil fertility (Chakraborty & Chakraborty 1989). However, stunting and reduced yield were observed when leguminous crops such as *Arachis hypogaen* and *Vigna unguiculata* were cultivated after a forest fallow of *R. auriculiforme* (HVA-Holland Agro Industries bv, unpublished results). These results may be explained by either antagonistic relationships among soil minerals, toxicity, or allelopathic effects. Further research is needed to clarify these observations. Similarly, seed germination and growth of *Tamarindus indica* was allelopathically inhibited in soil which has been previously used for germination and growth of *R. auriculiforme* (Setiadi & Samingan 1978). Aqueous extracts of bark and leaf of *A. nilotica*, mostly tannins, inhibited seed germination of arable crops but with differing intensity, tomato being the most sensitive and sunflower the least (Swaminathan *et al.* 1989).

Contrary to *R. auriculiforme*, *R. mangium* has only been recently introduced into Zaire and the first research trials were established in 1989 (Khasa 1993a). For the present, no information is available on the potential use of *R. mangium* in agroforestry. However, a rehabilitation trial of littoral soils for the regeneration of old coconut palm groves was successfully implemented in Ivory Coast with this species (Dupuy & Kanga 1990).

By increasing reforestation activities throughout the country particularly in agroforestry systems, *Racosperma* species may not only contribute to maintaining or increasing soil fertility, but may also provide at the village level various products and other environmental benefits. By simultaneously or sequentially using best suited companion arable crops and/or animals on the same piece of land, the benefits of integrating *Racosperma* species into Zaire agroforestry programmes should be maximized.

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