Promising high-value hardwood plantation tree species for the dry tropics of Queensland.

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Introduction

To date, there has been little commercial timber plantation establishment activity in Queensland's dry tropics. This is a result of the harsh climate, poor soils, competition with other industries (eg. sugar, cattle) and a lack of understanding of appropriate species and silvicultural practices for this region (Bristow, 2004). Most activity, in this region has focussed on tree establishment for non-timber purposes such as land rehabilitation, fodder, stock shelter and windbreaks. In the past 15 years a number of small research trials investigating a wide range of native and exotic tree species have also been established. Early successes and some promising results from these operational and research plantings have lead to an increase in confidence in a few selected species, with a growing number of small private timber plantations established in the dry tropics region over the past seven years.

For the purposes of this paper, the dry tropics of Queensland are defined as areas north of the tropic of Capricorn which receive ≤1200 mm Mean Annual Rainfall (MAR). This includes most of tropical Queensland, excluding a large section of northern Cape York Peninsula, and the eastern coastal ranges and lowlands southwards to Ingham. Smaller wet tropics areas also occur in the coastal Mackay / Whitsunday and coastal Yeppoon / Byfield regions in the south (Bureau of Meteorology, 1989). Climatic conditions in the Queensland dry tropics are characterised by two distinct wet and dry seasons, with most rainfall occurring between December and March, followed by an extended dry season (mean monthly rainfall <40 mm) for up 8 months (Gentilli, 1972). In the tropics, annual rainfall variability is very high, and this has often resulted in consecutive years of severe drought (<50% MAR), with native forest dieback an occasional outcome. Relative humidity is also very low over the dry season and, combined with relatively warm and clear winter conditions, contributes significantly to plant desiccation over this period. Soils of the dry tropics are characteristically poor, and include a wide range of shallow lithosols (skeletal soils), strongly duplex sodosols, and infertile deep sands. Better quality soils are generally restricted to the western slopes of the coastal ranges or as alluvial deposits within the larger creek and river catchments, including some areas of fertile cracking clay soils in the inland regions.

The aim of this paper is summarise the most significant results from a number of key operational and research tree plantings in the dry tropics region. From these results, the most promising high-value plantation species for the dry tropics will be identified and discussed.

Agroforestry Emerges

In Queensland's dry tropics, there is little evidence of tree establishment activities until about the late 1980s. From this time, the first early plantation establishment and research activity was mainly focussed on tree establishment for non-timber purposes such as rehabilitation, fodder, stock shelter and windbreaks. The first large taxa evaluation trials were established in the dry tropics by the Queensland government as part of an Australian Centre for International Agricultural Research (ACIAR) project and focussed on a range of fuel wood, fodder and agroforestry species with application to southern Africa. Within the ACIAR series, two trials were established at Southedge, Mareeba (731 and 737ATH) in 1989/90 and one trial was established at Hillgrove station, Charters

Towers (732ATH) in 1989. These trials contained a wide range of taxa and included 22 *Acacia* species, 13 *Eucalyptus* species, 3 *Grevillea* species, 1 *Corymbia*, 2 *Casuarina*, 1 *Melaleuca* and 1 *Sesbania* species. Overall management of these trials was good, however none of the trials were irrigated. Over the past 15 years, droughts, fires and stock grazing have resulted in high tree mortality and disappointing growth rates. An inspection of the best performing trial from this series (731ATH) at Mareeba in September 2004, revealed only a few species, which had demonstrated acceptable long-term survival and moderate growth rates. These species were *Corymbia citriodora* subsp. *citriodora* (CCC or lemon-scented gum), *Eucalyptus camaldulensis* (river red gum), *E. cloeziana* (Gympie messmate) and *E. raveretiana* (black ironbox).

From the late 1980s the first plantings of *Khaya senegalensis* (African mahogany) were established in the Townsville and Burdekin regions. These trees were mainly established for shade purposes in parks, schools, road median strips and in private residences. It appears that almost all the seed for these trees was sourced from "Darwin street trees". At the Burdekin Agricultural College at Clare, a number of larger blocks were also established as wide-spaced agroforestry woodlots. In many cases, the survival and early growth of these plantings has been very impressive. In one case, a tree diameter of 76.3 cm was recorded for a 15-year-old park tree. In all the successful plantings, irrigation was applied for at least the first few years and in many cases has been on-going for the life of the trees. A major problem with these trees however, is their tendency to regularly produce multiple leaders and consequently a very short merchantable log length. In most cases where no form pruning has been conducted, log lengths are generally <3 m.

Tree Care Salinity Trial

In the early 1990s, the Queensland government initiated the Tree Care Program, with an aim to facilitate and promote the establishment of trees in the rural landscape. A research component within this program allowed for the establishment of a small number of trials within the lower Burdekin region where salinity has been emerging as a problem since the 1980s (Sun and Dickinson, 1993). Trials were established in both saline and non-saline areas to identify appropriate species and silvicultural techniques to help promote tree planting in this area. The first large trial (805 ATH) was established on a salt affected area at the Kalamia Sugar Mill near Ayr in 1991. This trial was established to identify suitable species for saline site rehabilitation and investigated 18 taxa including *Acacia aulacocarpa, A. auriculiformis, Casuarina cristata, C. cunninghamiana, C. equisetifolia, C. glauca, Eucalyptus alba, E. camaldulensis, E. tereticornis, E. tessellaris, Melaleuca bracteata, M. leucadendra* and *M. quinquinervia*. The trees were established as 5-tree line plots in 28 replicated blocks, with these blocks allocated to low, moderate or high salt classes, based on soil chemical analysis.

At the most recent measurement at age 13 years, in areas where salt levels were high (>110 ms/m), best performance was recorded for *C. glauca*, *C. cristata, C. cunninghamiana* and *M. leucadendra*. On areas where salt levels were low (<60 mS/m), most species (except *A. aulacocarpa, E. alba, E. tessellaris*, and *M. quinquinervia*) did very well and benefited from a shallow water-table at <3 m depth on this site. It is interesting to note that in trial results summarised at age 2 years (Sun and Dickinson, 1995), *E. camaldulensis* was the best performer on all salt classes with survival >97 % and excellent growth of 4.4 m (height) and 4.1 cm (DBH). By age 13 years however, survival was <35 % and growth (particularly DBH) had been surpassed by the best performing taxa.

Tree Care High-value Species Trial

The first large high-value species trial (810a ATH) was established to study the performance of a wide range of high-value timber species on a non-saline area of the Burdekin catchment, was planted at the Burdekin Agricultural College at Clare in late 1992. Within this trial, twenty-nine taxa were investigated as 5 tree line plots, in a replicated block design with 6 replicates. Initial tree spacing was 3.5 m x 3.0 m or 952 trees/ha. The species investigated are shown in Figure 1 and included 1 *Agathis*, 1 *Araucaria,* 1 *Azederachta,* 1 *Cedrela,* 2 *Corymbia,* 16 *Eucalyptus,* 1 *Flindersia,* 1 *Grevillea,* 1 *Khaya,* 2 *Paulownia* and 2 *Pinus* species. Early silvicultural management was good, with the tree rows ripped and mounded prior to planting, followed by fertilisation, weed control to age 18 months and early form/branch pruning. Trees were flood irrigated to an age of 3 years.

Over the past 12 years, this trial has experienced regular droughts and has had little maintenance since the irrigation was discontinued at age 3 years. The outcomes from this trial do however, provide a very good indication of tree species resilience at this site and it is likely that the roots of the larger trees have entered the underground water table at an estimated 6-8 m depth. The results from this trial were first analysed at age 2 years (Sun and Dickinson, 1997). Recently this trial was remeasured for the parameters of height, DBH and survival % in June 2004, at a tree age 11.5 years (Figure 1).

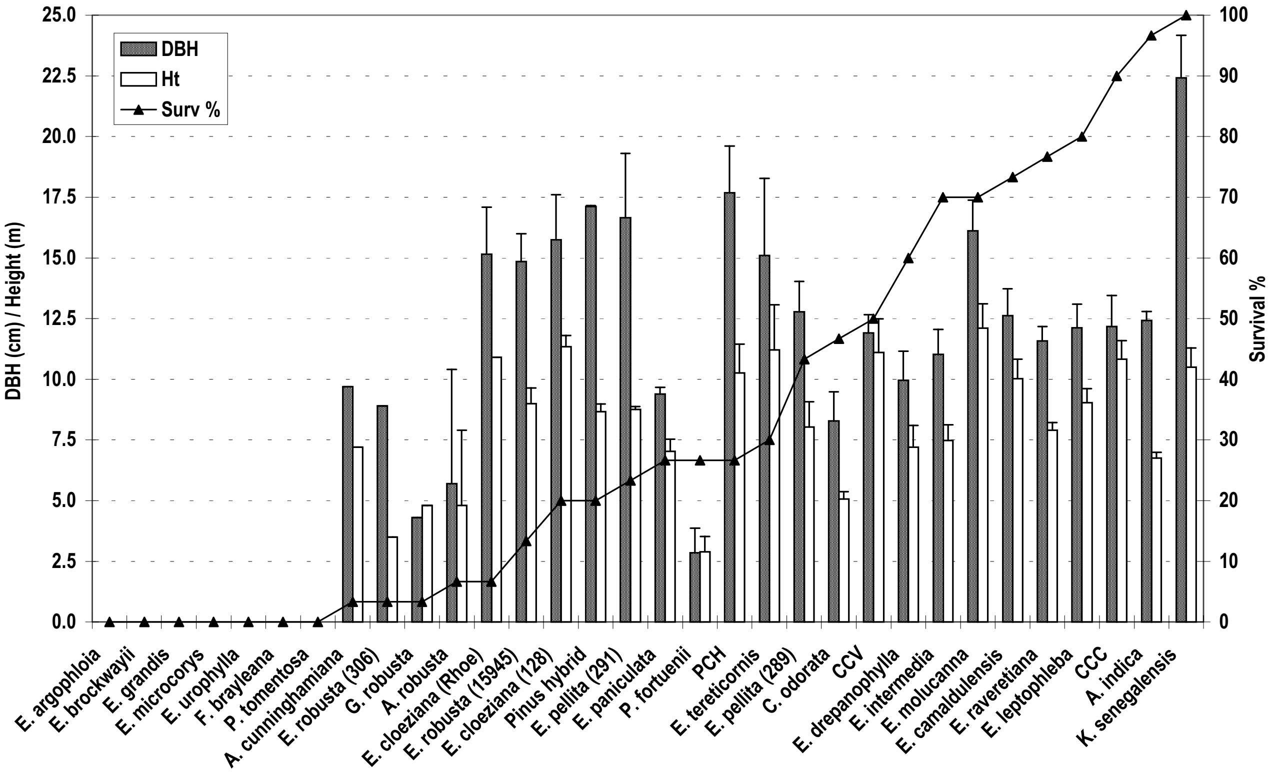

Figure 1: DBH, height and survival % for high-value species trial at Clare at age 11.5 years.

Surprisingly, after 11.5 sub-optimum years, one species had still maintained a survival of 100%, *Khaya senegalensis*. The superior ability of this species to survive once established appears to be characteristic of this species, as observed in numerous other plantings in similar dry environments. The only other species to maintain greater than 90% survival were *Azederachta indica* (neem) and CCC. Other species greater than 70% survival were *E. intermedia* (pink bloodwood), *E. moluccana* (grey box), *E. camaldulensis, E. raveretiana* and *E. leptophleba*. Survival was generally poorest in the species endemic to higher rainfall regions such as *Flindersia brayleyana* (Queensland maple), *Agathis robusta* (kauri pine), *Grevillea robusta* (silky oak), *E. grandis* (rose gum), *E. microcorys* (tallowwood) and *E. urophylla* (Timor gum). *E. argophloia* (western white gum) and *E. brockwayii* from dryer but cooler regions to the south also had very poor survival.

DBH growth was highest in the *Khaya senegalensis* trees with an average of 22.5 cm. This growth rate is quite good, particularly taking into account the minimal management after age 3 years and with 100% survival and no thinning, these trees remain at a high tree stocking/ha. When the best 40% of trees are selected, average DBH for these trees is 28.3 cm and may have been higher if pre-commercial thinning of the poorest trees had been conducted at an early age. After *Khaya senegalensis,* a group of species had moderate DBH growth of between 15.1–17.5 cm and included

Pinus caribea var. *hondurensis* (PCH or Caribbean pine), the PCH x *P. elliotii* hybrid, *E. pellita* (red mahogany), *E. moluccana, E. cloeziana* and *E. tereticornis* (forest red gum). Diameter growth of all other species was quite poor. Height growth was generally low in most species, with only a few achieving mean heights of >10 m. These included *K. senegalensis*, PCH, *E. moluccana, E. cloeziana, E. tereticornis*, CCC and *Corymbia citriodora* subsp. *variegata* (CCV or spotted gum).

Private Forestry Plantations

In the mid to late 1990s, more private forestry blocks were being put in the ground, with timber production emerging as a main reason for tree establishment. In the Townsville, Charters Towers, lower Burdekin and Bowen regions, numerous small but well managed *K. senegalensis* plantations were established, almost all with trickle irrigation systems. As with the original plantings in the late 1980's, seed was sourced primarily from street trees, however these now included the maturing local "Townsville" trees, as well as the original "Darwin" trees. In these plantations, weed control has been good and form/branch pruning has been conducted up to 6 m, in some cases utilising cherry pickers. In most examples, these plantations were established at higher initial stockings of 666–1000 trees/ha and have/will be pre-commercially thinned to 400 trees/ha. These plantations represent the first "well managed" *K. senegalensis* plantations in this region and are providing useful information to guide the establishment of future plantation expansion. Permanent growth plots have now been established in a number of these plantations and these will be monitored over the plantation life to give greater knowledge of the effects of site and management on *K. senegalensis* productivity. On two selected *K. senegalensis* plantations, stem taper, bark thickness and log volume measurements have also been undertaken and for the first time a series of volume equations have now been developed, specifically for this species.

Interest in alternative plantation species was also emerging over the mid to late 1990s and this lead to establishment of previously untested species such as *Santalum album* (Indian sandalwood). At this stage, sandalwood development in the dry tropics region (excluding Cape York) is minimal and has been hindered by difficulties with managing sandalwood/host health, and the high susceptibility of sandalwood to fire damage. Other new taxa to emerge were a variety of eucalypt hybrids, primarily *E. grandis* x *E. camaldulensis* (G x C hybrid). The G x C hybrid appears to do very well on most sites at an early age, but can suffer from drought and insect attack as the trees increase in size. The need to investigate new species and to demonstrate good silvicultural principles to prospective farm foresters lead to the development of a new NHT Project "Demonstrating Farm Forestry in the Dry Tropics".

NHT Demonstration of Farm Forestry Trials

Demonstration plantings were established on seven sites in the dry tropics in 2002 and included plantings at Ayr, Charters Towers, Georgetown, Normanton and Walkamin. The largest trial was established at Charters Towers and included *Acacia victorii* (royal wattle), CCC, *C. odorata* (Mexican cedar), *E. argophloia, E. camaldulensis, K. senegalensis, S. album* and 4 clones of the G x C hybrid and 3 clones of the *E. grandis* x *E. urophylla* hybrid (G x U hybrid). The taxa were established in a randomised complete block design with plots 6 rows x 10 trees in size and replicated 3 times. Most trees were established in February 2002 at a tree spacing of 4 m x 2.5 m (1000 trees/ha). The *S. album* trees were established one year later in February 2003. The trial has been well managed with good site preparation prior to planting, followed by good weed control and trickle irrigation. This trial was recently measured for DBH and survival % at age 2.3 years (Figure 2). Unfortunately, due to their small size, the *S. album* trees were not measured at this time.

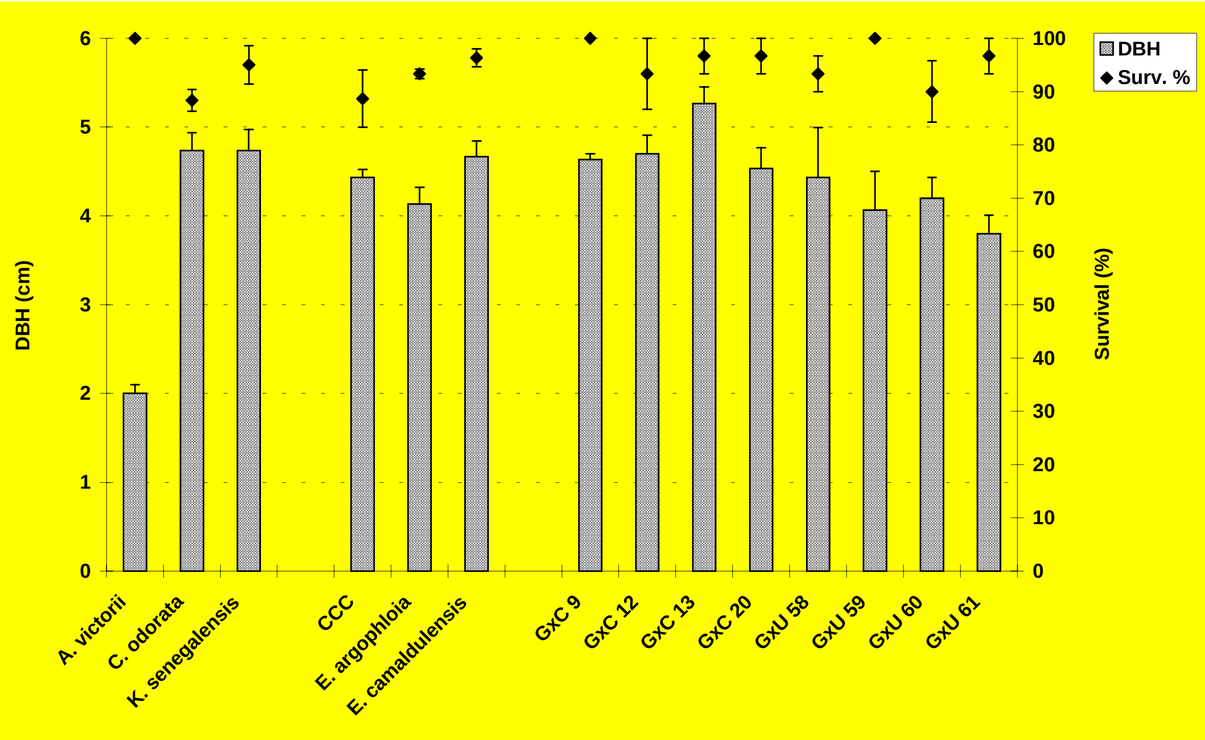

Figure 2: DBH and survival % for NHT trial at Charters Towers at age 2.3 years.

For all taxa in this study, early tree survival at age 2.3 years is very good at ≥90 %. This is not surprising given the intensive management conducted on this site, which has included regular irrigation and good weed control. It is interesting to note however, that a number of individuals of *C. odorata* were quite stressed and have evidence of sunburn damage on the northern side of the tree stems. A number of individuals of the G x C and G x U hybrid were also looking stressed and have evidence of early borer attack on the tree stems. These health symptoms have been observed in older plantings of these taxa in the dry tropics and may also result in accelerated tree mortality over future years. Longer term measure data will be required to confirm these predictions.

Diameter growth of most species has been quite good at 3.8–5.3 cm DBH at age 2.3 years. The exception is *Acacia victorii*, which has a shrub-like growth habit and is mainly grown for its seed as a bush-food product. As with tree survival, it is anticipated that more pronounced growth differences will become evident as longer term measure data is collected and the species adaptability to these sites as larger trees is confirmed.

Hardwoods Queensland *Corymbia* Hybrid Trials

The newest taxa to emerge with potential for dry tropics plantings are the *Corymbia* hybrids, locally developed by the Department of Primary Industries and Fisheries (DPI&F), via controlled pollination crosses between *Corymbia torelliana* (CT or cadaghi) and CCV, CCC and *Corymbia henryi* (CH or broad-leaved spotted gum) (Nikles *et a*l, 2000; Lee *et al*, in press). The oldest trial plantings in north Queensland are located at Davies Creek (Mareeba), Walkamin and Mount Garnet, with early results looking very promising. In the largest trial at Walkamin (524/2b HWD) planted in March 2001, CT x CCC and CT x CCV hybrids were established in addition to control plots of CCC, CCV and CT for comparison. Taxa treatments were investigated as 4–8 tree line plots, in a replicated block design with 2–9 replicates depending on taxa nursery numbers. Initial tree spacing was 4 m x 2.25 m or 1111 trees/ha. This trial has been well managed but not irrigated. Unfortunately, a severe fire in spring, 2002, damaged the western corner of this trial, compromising 4 of the 9 replicates. In a recent measurement at age 3.25 years, the results of the 5 undamaged replicates have been analysed, and are illustrated in Figure 3.

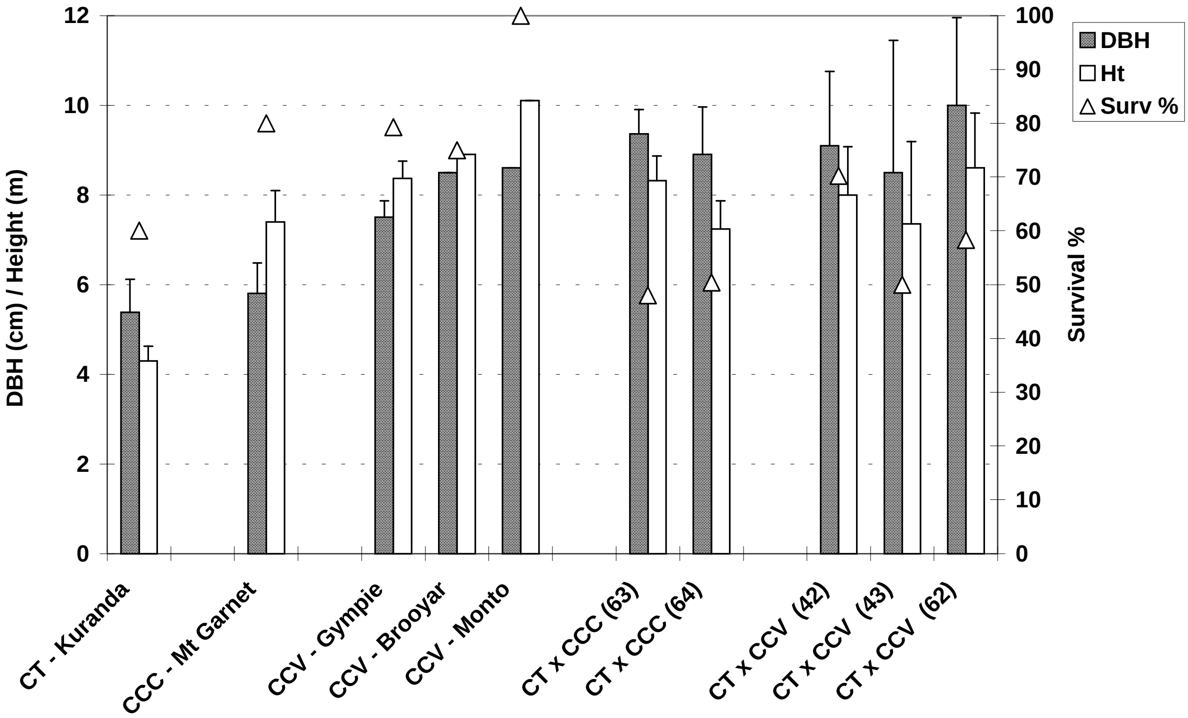

Figure 3: DBH, height and survival % for *Corymbia* hybrid trial at age 3.25 years.

The results from this trial are a very good example of the potential of these new hybrids, but also the variability, which can be expected when dealing with hybrid seed from untested parents. The best average DBH growth was observed in both the CT x CCC and CT x CCV hybrids. The standard error bars however, indicate the large variability in DBH measured between hybrid plots across this site, particularly in the CT x CCV hybrids. High variability is to be expected when dealing with the combination of genes between two inter-specific parents, where gene incompatibility or gene complementarity is poorly understood. Outcomes can be very good, but also very poor. Hybrid incompatibility can also contribute to poor field survival, with high mortality observed among the 5 hybrid taxa investigated on this site. High mortality was first observed in the nursery, with unusually large numbers of deformed and weak individuals culled among hybrid seed lots. After planting, signs of hybrid incompatibility may continue to emerge over the next few growing seasons, resulting in weak individuals eventually failing under field conditions.

Among the other taxa investigated on this site, the three CCV taxa performed well, with good DBH growth at age 3.25 years. Unfortunately, due to the exclusion of 4 replicates because of the 2002 fire, CCV (Brooyar and Woondum) were represented by only one replicate (thus no error bars). The DBH growth of the single taxa of CCC and CT was quite poor. Among most taxa, (all 5 hybrids, CCV and CCC) height growth was good and there was little difference observed. As would be expected however, CT had the poorest height growth, which is generally characteristic of this species as it has poor apical dominance when grown in the open or in plantation situations.

The results from this trial are the first stage in a hybrid development program. The crosses represented here are from a limited genetic base and should be viewed as a small example of the potential of the CT x CCC and CT x CCV hybrids for these dry tropics regions. Further testing with a much greater genetic base and with significantly more individuals has been initiated over the past few years. Many of the trees have been planted in the 2003 and 2004 planting seasons. The next step in this improvement process is to monitor these individual hybrids over the next 3–5 years to identify individuals with exceptional (longer-term) growth and timber qualities. When identified, these individuals may then be cloned vegetatively to produce the next generation of plantation material with no variability and uniform (and exceptional) growth rates.

Conclusions

At present, long-term results (to 15 years) confirm that *Khaya senegalensis* is undoubtedly the high-value plantation species with greatest promise for plantation establishment in the dry tropics of Queensland. This species has demonstrated good survival and growth on a diverse range of sites, soil types and management systems. Where site quality is high or intensive management applied, growth rates have been exceptional. Silvicultural practices, necessary to maintain acceptable growth rates, include good weed control and irrigation. Poor growth has been observed in mainly non-irrigated sites or where irrigation has been prematurely halted. On some sites however, it appears that where ground-water levels are within reach of the tree roots (eg 6–8 m), trees can maintain good growth rates without long-term irrigation. Irrigation is not a normal management operation for commercial forestry plantations, however due to the anticipated high value of *K. senegalensis* timber for cabinetwood or veneer products its use may be economically justified.

The great promise of *K. senegalensis* has been achieved with expected inferior genetic material of unknown origin. This is reflected in the high variability observed in growth and straightness amongst individuals, but particularly for merchantable bole length. It is anticipated that some of these faults can be improved quite quickly through traditional tree improvement techniques. It is recommended that the genetic improvement of this species is a high priority for plantation development in the dry tropics region.

Other species which survive well, but generally have only poor to moderate growth rates in the dry tropics include CCC, CCV, *E. moluccana*, *E. cloeziana* and *E. raveretiana*. All species are highly drought tolerant and on high quality soils or where local climatic conditions have been relatively favourable, numerous good individual trees exist. This is particularly the case with CCC, where good trees are occasionally observed in windbreaks, parks or street plantings. On certain sites (eg. riparian areas), *E. camaldulensis* and *E. tereticornis* have also demonstrated good survival and occasionally very good growth rates. However, these species do appear to be highly site specific and can be prone to severe insect attack and unacceptable mortality when planted off-site. For all these *Eucalyptus* and *Corymbia* species, where irrigation has been applied, tree growth and survival has been much better. However the timber value of these species is generally moderate and it would appear uneconomic to conduct such intensive management.

Where cabinetwood species have been grown in the dry tropics (eg. *Cedrela odorata*, *Flindersia brayleana*, *Paulownia*) it appears that irrigation is generally not sufficient to maintain these species in these harsh climates for the duration of the rotation. As these trees have poor drought tolerance and are highly reliant on irrigation for survival, they quickly succumb when the irrigation is halted or reduced. For certain species such as *Cedrela odorata*, the continuous exposure to sunlight and low humidity can be very damaging and sunburn damage to the trunk is often very severe. Where *Paulownia* has been trialed, trees never seem to develop apical dominance, exhibiting severe multiple stem coppicing each spring, after being deciduous over autumn and winter.

Among new generation hardwood plantation candidates, the *Corymbia* hybrids appear to have the most potential for plantation development in the dry tropics region after *K. senegalensis*. By combining good drought tolerance, form and straightness from the CCV or CCC parent, with the higher growth potential and leaf area of the CT parent (plus hybrid vigour), excellent hybrid individuals have been created. While these results are still relatively recent (<4 years), they demonstrate great promise for the establishment of *Corymbia* hybrid combinations in the dryer regions of north Queensland. Through greater development of the genetic base of these hybrids and through long-term and rigorous screening of the hybrid progeny of these crosses, it is likely that a number of exceptional individuals will be identified. Using advanced propagation techniques, these can be cloned and potentially provide the genetic base for a highly successful clonal forestry program. It is possible that the combination of drought tolerance and improved growth rates may make these hybrids the first realistic plantation choice for large-scale, non-irrigated plantations in the dry tropics region.

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