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Environmental adaptation of leucaena in Western Australia – challenges and opportunities

Adaptación ambiental de leucaena en el estado de Western Australia – retos y oportunidades

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Abstract

There is considerable interest from Western Australian (WA) pastoralists on the potential role of leucaena (*Leucaena leucocephala*) in northern WA, where the potential area for dryland production of species of the genus *Leucaena* is high. Although it is highly regarded for animal production in other countries and in Queensland, leucaena is a contentious species since its status as an environmental weed currently precludes it from use on pastoral leases in the Kimberley and Pilbara regions of WA. Development of sterile/seedless forms would overcome risks of spread of the species as a weed. The key environmental constraints to growth of leucaena are likely to be the length of the dry season and low fertility of most soils other than the grey/black cracking clays (vertosols). Psyllid resistance and cool temperature tolerance are likely to be of secondary importance. Opportunities for irrigated production are also emerging and may allow leucaena species to be used in environments previously considered well outside their home-range. It is desirable now to re-examine the diversity of the wider leucaena genus for adaptation to WA conditions generally and for the purpose of selecting elite parent material for use in a sterile/seedless leucaena breeding program. These perennial species that can be under production for 30 to 40 years need to be evaluated in the target environments for at least 3–5 years to fully understand their potential as adult plants.

Keywords: Breeding, climate, shrub legumes, soil, stress, tropics.

Resumen

En el estado de Western Australia (WA), existe un gran interés por parte de los ganaderos en el uso de leucaena (*Leucaena leucocephala*) debido al considerable área potencial para la producción de especies del género Leucaena en tierras de secano. Aunque es muy apreciada para la producción animal en otros países y en el estado de Queensland, leucaena es una especie muy discutida ya que su condición de maleza ambiental excluye actualmente su uso en tierras oficiales arrendadas para explotación pastoril en las regiones de Kimberley y Pilbara en WA. El desarrollo de formas estériles/sin semillas superaría los riesgos de diseminación de la especie como maleza. Las restricciones ambientales clave para el crecimiento de leucaena probablemente sean la duración de la estación seca y la baja fertilidad de la mayoría de los suelos que no sean de arcillas expansivas (vertisoles). La resistencia a los psílidos (insectos de la familia Psyllidae) y la tolerancia de temperaturas bajas son probablemente de importancia secundaria. Existen oportunidades para la producción bajo riego la cual permitiría que las especies de leucaena sean utilizadas en ambientes que antes se consideraban fuera de su área de adaptación. Se considera deseable volver a examinar la diversidad del género *Leucaena* respecto a su adaptación a las condiciones de WA en general y con el fin de seleccionar líneas elite para su uso en proyectos de fitomejoramiento para desarrollar variedades de leucaena estériles/sin semillas. Debido a que estas especies perennes pueden ser productivas durante 30–40 años, se considera que deben evaluarse en diferentes condiciones ambientales durante al menos 3–5 años para comprender completamente su potencial como plantas adultas.

Palabras clave: Clima, estrés, fitomejoramiento, leguminosas arbustivas, suelos, trópico.

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Introduction

Leucaena is a genus of 24 recognized leguminous hardwood species in the mimosoid sub-family, native to tropical regions of Central America (Govindarajulu et al. 2011). The genus is recognized internationally as a source of multipurpose trees, of great significance for timber, forage and green manure (Brewbaker 2016). In Australia, particularly Queensland, considerable public and private investment has been directed towards adoption of leucaena forage systems for the beef industry (Beutel et al. 2018). The most widespread species *L. leucocephala* (Lam.) de Wit has been the focus of breeding efforts over 50 years, particularly centered on the subspecies *glabrata* (Rose) Zárate. All commercial cultivars in Australia have been derived from this species (cvv. Peru, Cunningham, Tarramba and Wondergraze) or interspecific crosses between this species and *L. pallida* (cv. Redlands). These cultivars are well-regarded for their high feed quality (e.g. Garcia et al. 1996; Dalzell et al. 2006) and ability to increase beef production (e.g. Davidson 1987; Pratchett and Triglone 1989; Shelton and Dalzell 2007; Bowen et al. 2016).

There is renewed interest from Western Australian (WA) pastoralists on the potential role of leucaena in northern WA, given the observed benefits to cattle producers in Queensland. However, *L. leucocephala* is a contentious species because it can become a serious environmental weed (e.g. PIER 2002; Walton 2003).

Adaptation of *Leucaena leucocephala*

The agronomic requirements for successful production of *L. leucocephala* have been widely documented (e.g. Dalzell et al. 2006; Brewbaker 2016). It is well adapted to hot and humid climates with mean annual rainfall between 650 and 1,500 mm. Pratchett and Triglone (1989) suggest that it typically requires about 750 mm of rainfall to establish, but once established it can survive on less rain and will persist through drought by shedding its leaves. A recent Australian study (Radrizzani et al. 2016) demonstrated the marked influence of amount of seasonal rainfall and age of the stand on yield of *L. leucocephala.* Yields over a 6–7 month growing season and rainfall-use efficiency were highest in 8-year-old stands [2,128 kg total dry matter (DM)/ha or 4.0 kg DM/ha/mm] and lowest in 38-year-old stands (978 kg total DM/ha or 1.9 kg DM/ha/mm). The reduced yield (a function of fewer stems per plant) and vigor over time were associated with declining soil fertility.

Maximum yields of *L. leucocephala* require daytime temperatures above 30 ºC; if night temperatures drop below 17 ºC, yields are severely reduced (Pratchett and Triglone 1989). Mullen et al. (2003a) suggest subtropical environments with very high maximum temperatures tend to have lower productivity than humid-tropical locations with moderate maximum temperatures. While leucaena species are generally limited ecologically to frost-free ecosystems (Brewbaker 2016), *L. leucocephala* can survive frost, even though leaf and stems may be killed to ground level, recovering in spring with warmer temperatures. Annual biomass production is greatly reduced in these circumstances and the search for enhanced low temperature and frost tolerance remains an important breeding objective.

Leucaena leucocephala is favored by deep fertile soils (Cooksley and Goward 1988) that store adequate soil moisture for the extensive root system to exploit (Poole 2003 cited in Radrizzani et al. 2010). Like most tropical trees, it flourishes in soils that are at least seasonally well-drained and is poorly tolerant of waterlogging and flooding (Brewbaker 2016). Leucaena species have evolved and are largely confined to regions of neutral or alkaline soils. In his review, Brewbaker (2016) describes limiting factors that include acidity per se, associated toxicity of aluminum and manganese, and deficiencies of nutrients including calcium, magnesium and phosphorus. Growth is severely reduced at pH (H_2O) levels below 5.2 and 40–50% Al saturation (Mullen et al. 2003a).

Leucaena leucocephala has high P and S requirements (Ruaysoongnern et al. 1989; Radrizzani et al. 2010) with deficiencies reducing levels of nitrogen fixation, particularly when occurring together. Radrizzani et al. (2010) found that productivity, N_2 fixation and N status of a 31-year-old stand increased with application of P and S fertilizers. Radrizzani et al. (2011; 2016) concluded that leaf analysis could be used with confidence to assess nutrient status, provided the youngest fully expanded leaf was sampled from actively growing plants in the vegetative phase of development that had received rainfall/irrigation in the preceding 28 days and the leaves were <21 days of age. Critical nutrient concentrations derived from this work are in the range of: N (3.5–4.0% DM), P (0.18–0.20% DM), K (0.8–1.0% DM), S (0.20–0.24% DM), Ca (0.25–0.35% DM), Mg (0.16–0.20% DM), Cu (2 ppm) and Zn (8–12 ppm).

Productivity of *L. leucocephala* is strongly influenced by the occurrence of the leucaena psyllid (*Heteropsylla cubana*) with yields reduced by as much as 65% by severe infestations (Mullen and Shelton 2003). Psyllids are small (3 mm) sap-sucking plant lice, which feed from the phloem of developing shoots and young foliage, so that damage is concentrated in these regions (Hughes 1998). A female can lay up to 400 eggs that mature rapidly through 5 nymphal stages in a cycle of about 2 weeks.

Under ideal conditions (warm, calm, moist) for the pest, the population increase can be logarithmic. Populations are lower in cool dry seasons, and heavy rains or sustained drought reduce nymph populations (Brewbaker 2016). Psyllids are not regarded as a serious pest in subhumid areas with 600–800 mm annual rainfall (Shelton and Jones 1995).

Adaptation of the *Leucaena* genus

There may be opportunities to overcome constraints to *L. leucocephala* production through exploiting the wider diversity in the *Leucaena* genus (Shelton and Jones 1995). Twenty-four species have been described ranging from 3 to 25 m in height at maturity and originating from elevations of 100–1,800 m (Hughes 1998; Govindarajulu et al. 2011; Brewbaker 2016). Mullen et al. (2003b) reported a genotype (116 accessions) × environment study with sites in Brisbane (subtropical Australia) and Los Baños (humid-tropical Philippines) that highlighted substantial variation within and between species for DM yield. Main effects were moderated by the influence of seasonal temperatures, rainfall and psyllid pressure as previously discussed. The evaluation of germplasm in the target environment is critical as the authors note that the Los Baños environment presented none of the constraints that commonly limit growth of *L. leucocephala*, such as low temperatures, low rainfall (drought), acid soils and high psyllid pressure. *Leucaena leucocephala* and interspecific hybrids (*L. leucocephala* × *L. diversifolia* and *L. leucocephala* × *L. pallida*) were particularly productive. There was generally a strong relationship between total DM production and edible dry matter (leaf + stem <6 mm in diameter). Other high-yielding accessions at the Brisbane site included representatives of *L. pallida*, *L. diversifolia*, *L. trichandra*, *L. lanceolata* and *L. macrophylla*. Universally low-yielding accessions originated from *L. retusa*, *L. confertiflora* and *L. greggii*. Although *L. collinsii* ssp. *collinsii* established well, it showed only moderate productivity subsequently, but nevertheless was considered a potential species for creating interspecific hybrids (valued for its psyllid tolerance and low levels of condensed tannins and mimosine). A subset of 25 accessions were grown across a range of other tropical and subtropical environments including Kununurra, Western Australia. Top-ranking accessions at Kununurra were similar to those which ranked highly at Los Baños. These assessments were made over a 2–2.5 year period (6–14 month establishment period followed by multiple harvests over the following 12 months). Although establishment growth appears to be positively correlated with post-establishment growth (Mullen et al. 2003a), it is not known whether the relative performance of species (particularly focussing on edible dry matter) would change over the long term. Furthermore, while a strain of *Rhizobium* (CB3060) known for its effectiveness across a range of leucaena species was used in these studies, it is not optimal for all species (Mullen et al. 1998) and poor nodulation and N_2 fixation could also limit the performance of some species. It is imperative that rhizobial effectiveness is accounted for in future species development.

The ability to tolerate regular cutting is an important characteristic for persistence – some accessions of *L. pallida*, *L. trichandra* and *L. collinsii* did not persist with a cutting regime of 3-4 harvests/yr after a 10 month establishment period in the work of Mullen et al. (2003b). These authors also highlighted the issue of the trade-off between the arboreal nature of the 'giant' leucaena (*L. leucocephala* ssp. *glabrata*) and the need for increased management to keep plants at a grazing height. Highly forked (multi-stemmed) forms, particularly after cutting, are desirable, and variability exists within and between species for this trait (Hughes 1998), though it has not been widely researched. *Leucaena confertiflora*, *L. cuspidata*, *L. trichandra*, *L. trichodes* and the 'shrubby' *L. leucocephala* ssp. *leucocephala* are regarded as less arboreal.

In the context of cold tolerance as a desirable trait, cool tolerance needs to be distinguished from frost tolerance (and the frequency of frosts). True frost tolerance exists in *L. greggii* and *L. retusa* (Hughes 1998; Brewbaker 2016). Interestingly, the highland species such as *L. diversifolia*, *L. pallida* and *L. trichandra* show cool tolerance but little frost tolerance and are inferior in frost tolerance to *L. leucocephala* ssp. *glabrata*. There appears to be little variability among species for tolerance to soil acidity though *L. diversifolia* and *L. pallida* appear to be more tolerant of acidity than other species (Brewbaker 2016). Species with the potential to cope with an extended dry season (7–8 months) include *L. retusa* (Brewbaker 2016) and *L. collinsii* ssp. *collinsii* and ssp. *zacapana* and some varieties of *L. pallida* (Hughes 1998).

An analysis of psyllid resistance has been reported by Mullen et al. (2003c) utilizing the genotype × environment study in Australia and the Philippines previously described. There was considerable variation in psyllid resistance both between and within some species, notably *L. trichandra*, *L. diversifolia*, *L. collinsii* and *L. pallida*. *Leucaena collinsii* ssp. *collinsii*, *L. confertiflora*, *L. esculenta*, *L. pueblana*, *L. retusa*, *L. greggii* and *L. matudae* were highly resistant in both countries, while *L. leucocephala*, *L. lempirana*, *L. involucrata* and *L. multicapitula* were highly susceptible in both countries. There was little variation for psyllid resistance within *L. leucocephala*.

Any development of alternative leucaena species needs to take account of both nutritive value and palatability for animal growth together with animal health (Hughes 1998; Stewart and Dunsdon 1998). The 24 species of leucaena can be divided on the basis of average concentrations of the mild toxin (non-protein amino acid) mimosine into a low group (~2% DM) and a high group (~4% DM) (Brewbaker 2016). The low group includes *L. collinsii*, *L. diversifolia*, *L. esculenta*, *L. greggii*, *L. pallida* and *L. pulverulenta*. Variation for in vitro dry matter digestibility (IVDMD) occurs between and within species, among tissues sampled, and among samples in different seasons and growing conditions (Stewart and Dunsdon 1998; Brewbaker 2016). Species with desirable IVDMD (>70%) include *L. collinsii*, *L. leucocephala*, *L. macrophylla*, *L. salvadorensis*, *L. trichodes*, *L. diversifolia*, *L. multicapitula*, *L. retusa* and *L. shannonii*. Stewart and Dunsdon (1998) developed forage quality indices for a range of leucaena taxa (each represented by only a single accession) based on a combination of laboratory analysis (crude protein and digestibility), biomass and palatability using pen-fed sheep. While this was a relatively limited study, high-scoring species included *L. leucocephala* ssp. *glabrata*, *L. collinsii* ssp. *zacapana*, *L. shannonii* ssp. *shannonii* and *L. diversifolia*, with *L. leucocephala* ssp. *glabrata* and *L. diversifolia* notable for their superior animal preference. Condensed and total tannins also vary widely between species (lowest in *L. collinsii*), and high levels appear to reduce dry matter digestibility in the rumen (Stewart and Dunsdon 1998). Clearly, more research to understand and exploit the variability in nutritive value within and between the entire range of leucaena species is required.

A short history of leucaena in Western Australia

Commercial sowings of leucaena in WA have been limited. The notable exception was on the black cracking clay soils of the Ord River Irrigation Area (ORIA) in the 1980s to early 1990s, where *L. leucocephala*, predominantly cv. Cunningham (Bolam et al. 1998), was successfully grown (~1,400 ha). High beef production of 1,400–1,500 kg liveweight gain/ha/yr was measured on leucaena-pangola grass (*Digitaria eriantha*) pastures in the ORIA under flood irrigation (Davidson 1987; Pratchett and Triglone 1989). Davidson (1987) reported a liveweight gain per head of 237 kg over 12 months and Bolam et al. (1998) reported individual growth rates of up to 690 g/hd/d under irrigation in the dry season. A series of grazing trials on the Frank Wise Institute at Kununurra evaluated different stocking rates, different row configurations (including close row spacing as cattle were eating predominantly *L. leucocephala*) and meat quality (Pratchett and Triglone 1989; Pratchett et al. 1992). Beef production appeared to increase over time providing stands were not over-grazed in the establishment years (particularly for close row spacings).

The commercial plantings of *L. leucocephala* in the ORIA have subsequently been replaced by forestry (sandalwood) and horticultural crops due to more favorable economics rather than through problems associated with agronomy or productivity (Brann 2008). However, as a result of management practices, overland water flow in the wet season and/or over-watering with flood irrigation, seeds of *L. leucocephala* have entered the waterways of the Ord River and it is now a weed of riparian zones (Walton 2003).

We are not aware of any other commercial plantings of leucaena species in the Kimberley, or elsewhere in WA. *Leucaena leucocephala* has been planted for shade around homesteads and roadhouses in the Kimberley, Pilbara and Gascoyne and is present in highly disturbed environments like town sites (Walton 2003). The Western Australian Herbarium (1998) describes *L. leucocephala* as an alien species, which is present in the central and northern Kimberley, Murchison and Pilbara. The vast majority (>98%) of grazing land in northern WA is under pastoral lease and a diversification permit from the Pastoral Lands Board is required to grow any non-indigenous plants. The approval process includes a weed risk assessment. *Leucaena leucocephala* has been assessed as a 'very high' environmental weed risk for both the Pilbara and Kimberley (Randall 2018) and is currently not approved for use on pastoral leases in these regions. This outcome aligns with widespread findings on the weed potential of *L. leucocephala*. For example, Lowe et al. (2000) include *L. leucocephala* in a list of 100 of the world's worst invasive alien species. Richardson and Rejmánek (2011) include *L. leucocephala* as 1 of only 6 trees or shrubs known to be invasive in 10 or more regions of the world (12 regions including Australia). Randall (2012) reports it as a weed of the natural environment, escaping from cultivation, and an invasive species in Australia. In contrast with Queensland where the issues with weediness are largely attributed to *L. leucocephala* ssp. *leucocephala* (Walton 2003), in WA the weed issue is with naturalized *L. leucocephala* ssp. *glabrata*. Recent observations by the authors in northern WA are of individual plants with high seed production and often with seedling recruitment.

Potential role for *Leucaena* species in WA

The potential role for leucaena-based pastures in northern WA is unclear, even if the weed risk could be reduced, such as through the development of a sterile or seedless cultivar. There are questions about its adaptation to environments outside the ORIA and the agronomic practices and soil amelioration that would be required to increase productivity. All species of leucaena are permitted into WA, but *L. leucocephala* and *L. lanceolata* have been assessed as very high weed risks in the Kimberley and Pilbara regions and their use is problematic.

The environment in northern WA

The rangelands of northern Western Australia cover a broad range of climatic zones and soil types, predominantly spanning latitudes 16–24° S. The average annual rainfall (AAR) varies from >1,100 mm in the north Kimberley to <300 mm in the southern Pilbara (Figure 1).

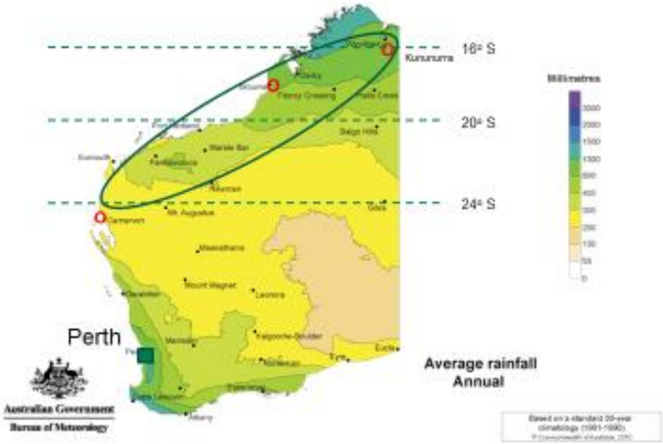

Figure 1. Target environment for leucaena in WA (circled). Source: Bureau of Meteorology, Australian Government.

Based on a modified Köppen climate classification system the Kimberley is predominantly categorized as 'Tropical–savanna', while the southern section of the Kimberley and the Pilbara are classified as 'Grassland–hot with winter drought' (BoM 2001; 2014). The regions have a distinct wet season from October–December to February–April and a dry season with little or no precipitation from March–April through to November–December.

Annual rainfall is increasing in the Kimberley. CSIRO (2009) determined that the recent climate period of 1996–2007 in the central Kimberley was 31% wetter than the historical period of 1930–2007. Wet season rainfall is highly variable, influenced in part by the strength of monsoon systems and the occurrence of sporadic cyclones. Wet season temperatures are also high, with average daily maximum temperatures typically ranging between 33 and 39 °C (BoM 2016). Dry season temperatures are milder with average daily maximum temperatures between 24 and 33 °C and average daily minimum temperatures between 12 and 18 °C. Inland regions can experience night temperatures as low as 5 °C.

The dominant soil types include grey/black cracking clays (vertosols) along the major river systems (flood plains), areas of red earths (red kandosols) in the north Kimberley and large areas of red-brown sandy soils (red-orthic tenosols), especially in the west Kimberley and Pilbara. A summary of the main soil groups by rainfall classes (>1000 mm, 800–1,000 mm and 600–800 mm AAR) for the Kimberley Region, the most likely dryland target, is provided in Table 1. The soil groups are broad categories and there is substantial variation within each group, which influences their agronomic potential (Schoknecht and Pathan 2012). For example, in the La Grange area in the west Kimberley Smolinski et al. (2016) identified 5 variations within 'Cockatoo sands' which are red-brown sands (colloquially known as 'Pindan' sands). They report the topsoil in these soils as relatively uniform (i.e. red-brown sands to loamy sands), so differences relate mainly to changes in texture down the soil profile. The subsoil texture varies considerably, which affects the plant-available water holding capacity (e.g. PAWC 50–108 mm in the top metre of soil; Smolinski et al. 2016).

Most of the soils in northern WA are inherently infertile with very low phosphorus, potassium and soil organic carbon levels (Table 2). Pindan sands have a very low cation exchange capacity (CEC) of 2 meq/100g in the topsoil, while the soil phosphorus retention index (PRI) is also low (typically <7) and positively correlated with soil clay content.

Table 1. A summary of the areas of the main soil groups (,000 ha) by average annual rainfall (AAR) for the Kimberley Region, Western Australia.

AAR (mm)	Loamy earths	Loamy duplexes	Sandy duplexes	Deep sands	Cracking clays	Non-cracking clays	Sandy earths	Total
>1,000	257	203	158	515	59	5	104	1,301
800–1,000	396	34	103	753	557	20	352	2,215
600–800	399	67	145	1,222	762	53	555	3,203

Table 2. Indicative properties of the dominant soil groups in the Kimberley Region, Western Australia.

Soil group	Clay content (0–10 cm; %)	Org. C (%)	Surface pH (1:5 water)	Phosphorus (Colwell; ppm)	Potassium (Colwell; ppm)
Loamy earths	7–13	0.2–0.9	6.0–6.9	<2–3	20–180
Loamy duplexes	10	0.7	6.7	<2	170
Deep sands	4–12	0.15–0.5	5.8–7.0	<2	20–30
Cracking clays	40–65	0.4–0.9	6.8–8.5	2–10	100–300
Sandy earths	5–10	0.2–0.6	5.7–6.9	<2	15–50

Opportunities for northern WA

The potential area suitable for dryland sterile leucaena in northern WA is high. There are about 5.4 M ha of soils within the 600–1,000 mm rainfall zone (Table 1), of which about 40% would potentially be suitable for leucaena. However, unlike eastern Australia, the proportion of cleared/arable land for leucaena establishment is currently very small, perhaps only in the thousands of hectares (outside the ORIA). Flood plains of the larger river systems and the grasslands of old marine sediments have less woody vegetation, but can be inundated for long periods in years when wet season rainfall is above average. Site selection in these environments would be critical. In addition, freehold land represents less than 2% of the area and General and Special lease tenure represents less than 1%, with the remainder under national parks and pastoral lease (not all pastoral lease is actively managed for cattle production). Any intent to establish a sterile leucaena on pastoral lease would still require regulatory approval through both diversification and clearing permits.

While land (often comprising Pindan sand) is now being developed with irrigation (Ash et al. 2017; MacLeod et al. 2018), the potential area for irrigated leucaena will be limited by the availability of water as well as any soil constraints and competition from other land uses (e.g. horticulture, broad-acre crops, forestry and fodder species). The maximum area for irrigated sterile leucaena production is likely to be <10,000 ha.

In WA the key environmental constraints are likely to be the length of the dry season and low fertility of most soils other than the grey/black cracking clays (vertosols). We have also observed significant plant losses from termites (including *Mastotermes darwiniensis*) in field trials and these could pose a further constraint on some soils. Management of other grazing herbivores such as wallabies will also be required. Psyllid resistance and cool temperature tolerance are likely to be of secondary importance. While existing commercial cultivars of *L. leucocephala* are currently not approved for use on pastoral lease, it is desirable now to re-examine the diversity of the wider leucaena genus for adaptation to WA conditions generally and for the purpose of selecting elite parent material for use in a sterile/seedless leucaena breeding program. These perennial species that can be under production for 30–40 years need to be evaluated in the target environments for at least 3–5 years to fully understand their potential as adult plants.

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(Note of the editors: All hyperlinks were verified 17 April 2019.)

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