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INVASIVENESS AND BIOMASS PRODUCTION OF *LEUCAENA LEUCOCEPHALA* UNDER HARSH ECOLOGICAL CONDITIONS OF NORTH-CENTRAL NAMIBIA

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Very few agroforestry species perform well in the Cuvelai Basin of north-central Namibia due to the harsh climatic and edaphic conditions. *Leucaena leucocephala* is one of these species and has many ecological and economic benefits but it tends to be invasive. To evaluate the suitability of this species for agroforestry in Namibia, two experiments were conducted at the Ogongo Campus of the University of Namibia. As indication of invasiveness, seed germination and survival of seedlings under different management were monitored for 44 weeks and growth rates of 33-month-old sprouts were used to estimate the potential wood biomass production. Watering and tilling the land gave the highest number of surviving seedlings. Death of seedlings was highest during the dry cold and dry hot months. Height growth rate of sprouts was 1.98 m year^{-1} and sun dried wood production was 15.8 tonnes ha^{-1} year^{-1}. Low temperature, soil surface hard pan and extreme lack of moisture could limit seedling survival and hence invasiveness. Biomass production compares favourably with productivity of *L. leucocephala* grown elsewhere. The likelihood of the species becoming invasive is viewed as high only in cultivated, irrigated areas. *Leucaena leucocephala* could be utilised as an agroforestry species under proper management to minimise chances of it becoming invasive.

Keywords: Potential agroforestry species, Namibian Cuvelai Basin

INTRODUCTION

The Cuvelai Basin extends from southern Angola to the north-central parts of Namibia. The Namibian part of the Cuvelai Basin is situated in the area between the Kavango and Kunene Rivers, consisting of the Etosha Pan, Lake Oponono and the Cuvelai inland delta/drainage, covering a catchment area of about 250,053 km^2 (Kolberg 2002). The area lies within the administrative Regions of Omusati, Ohangwena, Oshikoto and Oshana. These regions are some of the most heavily populated rural areas in Namibia. Combined, they are home to about 40% of the country's 2.2 million people (Namibia Statistics Agency 2012). The basin lies at altitude 1000–1150 m above sea level and receives mean annual total rainfall of 300–500 mm. The area experiences two distinct seasons, i.e. hot, wet summers (November till April), with temperatures as high as 30–36 °C and cool, dry winters (May till August) when temperatures can drop to 6–8 °C. Annual evapotranspiration is between 1680–2500 mm (Mendelsohn et al. 2002). Droughts, sometimes alternating with floods, are common and the soils are infertile.

Typically, the Cuvelai Basin is used for subsistence agropastoralism and numerous individual household settlements and townships. Due to the harsh edaphic and climatic conditions, together with the fact that the basin is home to large human and livestock populations, land degradation is inevitable. Deforestation, driven by conversion of woodlands to crop fields, and cutting of trees for fuel and building materials are on the increase. Depletion of soil nutrients due to continuous cultivation without addition of manure or inorganic fertilisers and shortage of fodder during dry seasons and drought years are probably some of the most challenging problems in the basin. Agroforestry interventions could address some of these challenges, if suitable tree species can be identified. In the past, several exotic agroforestry species (*Eucalyptus* spp., *Azadirachta indica*, *Melia azedarach*, *Leucaena leucocephala*, *Citrus* spp., *Psidium quajava*, *Mangifera indica*, *Casuarina cunninghamiana*, *Morus alba*, *Parkinsonia aculeata* and *Jatropha curcus*) have been introduced to meet the increasing and diverse demands (Erkkila & Siiskonen 1992, Anonymous 2002). However, the introduced species did not perform as expected mainly due to poor management and several of them ended up being invasive (Macdonald et al. 2003, Chamwe 2011). This implies that future introduction of species should be done cautiously and after reasonable amount of research.

Leucaena leucocephala (Mimosaceae) is a multipurpose, perennial shrub/tree legume widely used in agroforestry systems in the tropics and provide numerous products and services, e.g. firewood, poles, flooring parquets, timber, fodder, pulp, biofuel, nitrogen fixing (enhancing soil fertility) and herbicide (National Academy of Sciences 1977, Shelton & Brewbaker 1998, Xuan et al. 2006, Orwa et al. 2009, Devi et al. 2013). The species is particularly attractive for agroforestry purposes due to its fast growth, ease of propagation and drought tolerance. Unfortunately, the species tends to be invasive (Lowe et al. 2000, Macdonald et al. 2003). Invasiveness was judged on the basis of commonness, abundance and detrimental ability (Macdonald et al. 2003). However no data has been provided to show how the species was concluded to be invasive. To avoid prejudice over a potentially beneficial species, more studies need to be conducted as recommended by Lowe (2000). Thus, this study was conducted with two major aims: (1) to gauge the invasiveness of *L. leucocephala* by assessing which husbandry factors may influence seed germination and seedling survival under dry, hot climatic conditions and infertile soils of north-central Namibia and (2) determine the species wood biomass production potential under these harsh conditions.

MATERIALS AND METHODS

Study area

The study was conducted at Ogongo Campus of the University of Namibia in Omusati Region, north-central Namibia in the Cuvelai Basin (Figure 1). The mean total annual rainfall is between 350 and 500 mm. Temperatures show a marked seasonal variation, summer temperatures can go as high as 36 °C and winter temperatures can fall to 6 °C (Mendelsohn et al. 2002). The soil is neutral (pH 6.7), very sandy (93–97% sand) and with a small percentage of clay (3–5%). Contents of macronutrients are generally low (P = 10.6 ppm, K = 202 ppm, Ca = 594 ppm, Mg = 123 ppm, Na = 84 ppm and N = 0.01 ppm).

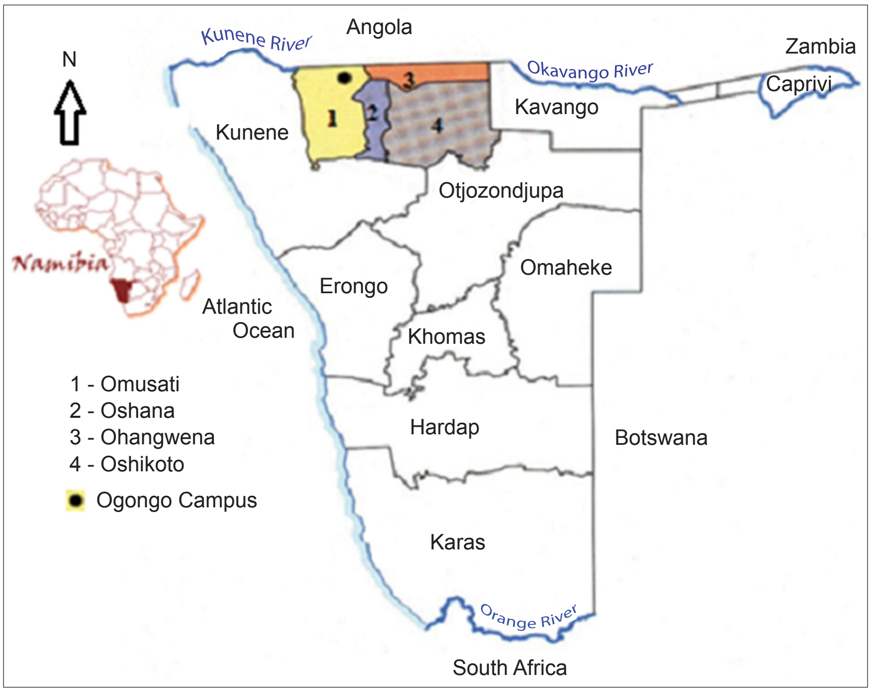


Figure 1 Location of Ogongo Campus in Omusati Region of north-central Namibia

Experimental design

Two experiments were set up. The first was to determine germination of seeds dispersed from an existing *L. leucocephala* hedge (planted in 2002) and the survival of the seedlings under different treatments over a period of 11 months (February 2011 till January 2012). The second experiment was to determine the biomass (volume of green wood and sun-dry weight) production from the same hedge used in the seed germination study. This experiment ran for 33 months (March 2011 till December 2013).

Experiment 1—Seed germination and seedling survival under different treatments

Experimental plots were set along a mature hedge of *L. leucocephala* from which seeds from previous seasons had dispersed and were evident in large numbers on the ground. The distance between the experimental plots and the hedge was set at 2 m in the direction of seed dispersal. Randomised complete block design was used to cater for differences in the number of seeds dispersed on the plots. A total of 16 plots (each 1 m × 1 m), representing four treatments replicated four times were marked on the ground (Figure 2). The treatments were:

(1) Tilling only (T): The plots were tilled using a hoe to loosen the soil. Throughout the experiment period, weeds were subsequently removed from the plots as they appeared.
(2) Tilling + watering (T + W): The plots were tilled and watered and weeds were removed from the plots as soon as they appeared.
(3) Watering + grass cutting (W + GC): The plots were watered and grass and other weeds were regularly cut at the base as soon as they started growing.
(4) Control (C): Plots were not tilled nor watered and no grass cutting was carried out.

Watering was done three times a week, each time using 5 L of water for each plot. The hedge was pollarded to prevent it from producing or dispersing more seeds during the experiment. The number of seedlings germinating and growing in each plot was recorded after every 2 weeks for 44 weeks (14 February 2011 till 6 January 2012), starting 2 weeks after the establishment of plots. Data on average monthly temperature, humidity and rainfall over this period were also collected. Survival of seedlings was recorded monthly to determine how seasons affected seed germination and survival. At the end of the experiment, the average number of seedling survival was recorded and analysis

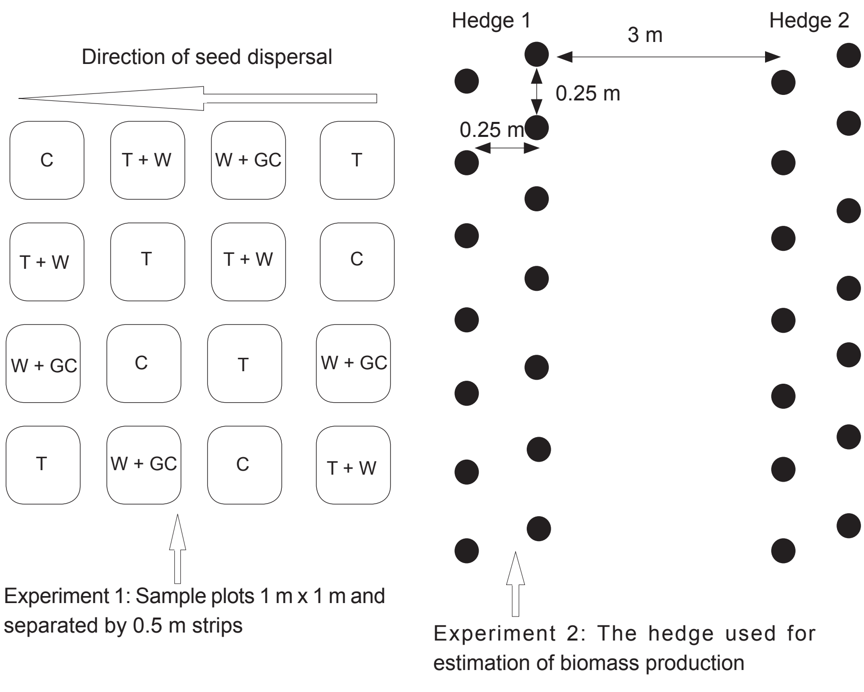


Figure 2 Position of experimental plots in relation to the hedge (seed source); T = tilling only, T + W = tilling + watering and W + GC = watering + grass cutting

of variance (ANOVA) using SPSS software was performed to determine if there were any significant differences between treatments and to assess whether results were influenced by disparity in dispersal of seeds in the plots.

Experiment 2—Estimation of wood biomass production

Data on wood biomass production was collected from a second coppice regeneration of an existing *L. leucocephala* woodlot of about 12 years old consisting of hedges of double rows planted in a zigzag pattern at a spacing of 0.25 m × 0.25 m from plant to plant and a distance of 3 m between the hedges (Figure 2). At the start of the experiment, trees growing in a 10-m long section of the hedge were pollarded at 1 m above ground. Sprouting shoots were allowed to grow for a period of 33 months from March 2011 till December 2013. All sprouts in the 10-m section of the hedge were then cut at the base of sprouting. After cutting, the length and basal, mid-point and tip-end diameters were measured using measuring tape and callipers to the nearest 1.0 and 0.1 cm respectively. Fresh weights were determined for each stem to the nearest 0.5 kg using digital scale. The volume of each stem was estimated using Newton's formula for log volume (Husch et at. 1993). Total volume of green stems from the 10-m hedge was calculated and extrapolated to per hectare basis. The stems were allowed to dry in the sun to constant weights and their sun-dry weight measured.

RESULTS AND DISCUSSION

Seed germination and seedling survival under different treatments

The average number of seedlings that survived under each treatment throughout the 44 weeks are shown in Table 1. Tilling + watering resulted in the highest number of seedling survival (75 seedlings m^{-2}) while control, the lowest (1 seedling m^{-2}). ANOVA revealed a highly significant difference in seedling survival under different treatments ($p < 0.001$).

Duncan's mutiple range test at $p = 0.05$ showed that there was no significant difference between number of seedling survival in control and tilling only. Likewise, watering + grass cutting was not significantly different from tilling only (Table 1). This suggested that tilling land to break the surface hard pan, which characteristically forms in many soil types in north-central Namibia, is important to ensure good growth of seedlings. Overall these results strongly suggest that profuse establishment of *L. leucocephala* seedlings would depend on availability of moisture and tilling to break the hard surface pan. Removing competition from grasses may also enhance establishment though this was not fully investigated. The high survival of seedlings under tilling only and control at the start of experiment and substantial survival through the dry season confirmed the ability of the species to establish and grow well under low rainfall. *Leucaena leucocephala* performs well even in areas receiving total annual rainfall as low as 300 mm (Brewbaker et al. 1985).

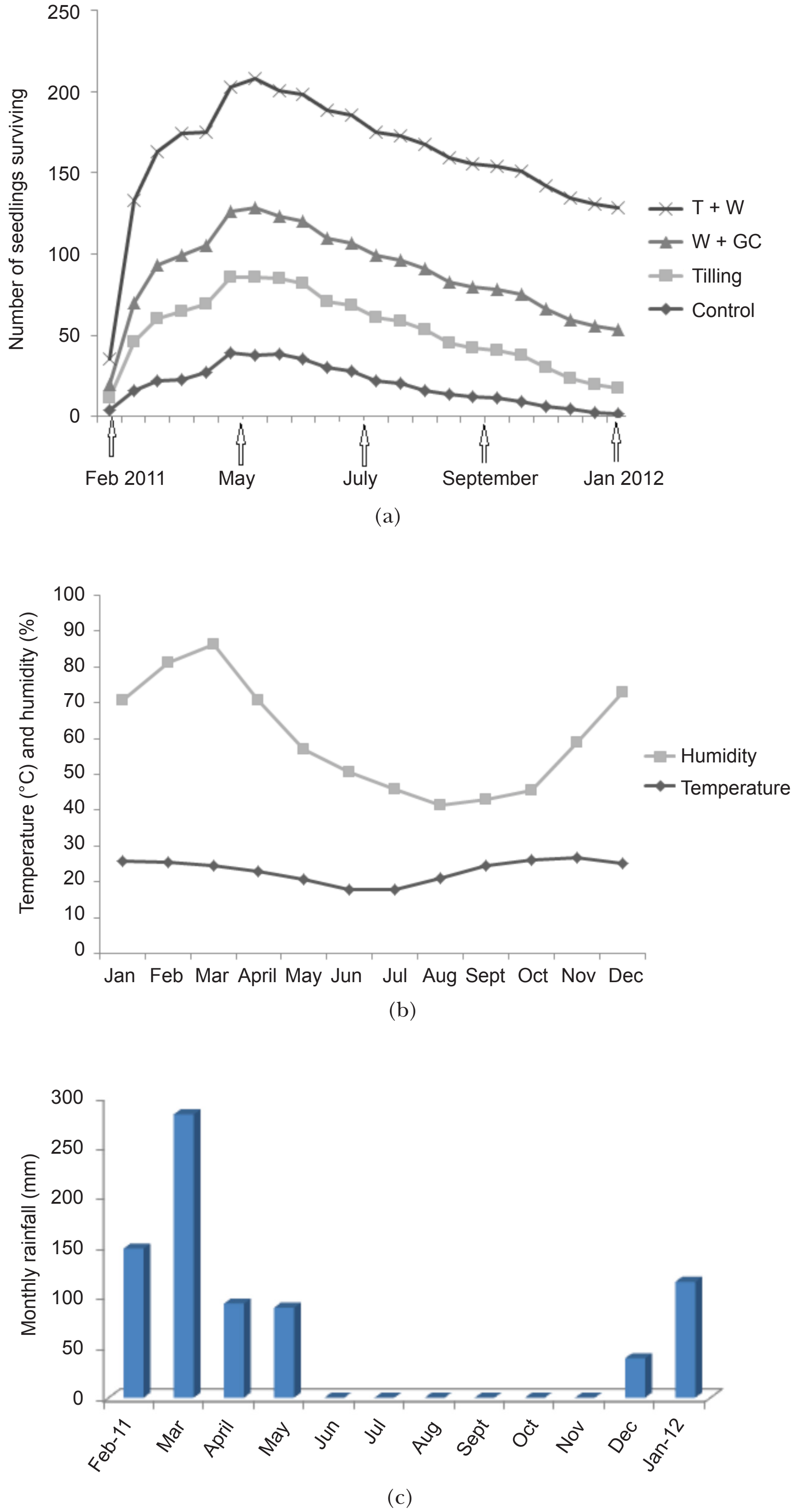
Table 1 Number of seedlings surviving per treatment, 44 weeks after establishing the plots

Treatment	Mean number of seedlings surviving after 44 weeks
Control	1.8 a
Watering and grass cutting	36.3 b
Tilling and watering	75.0 c
Tilling only	15.3 ab

Means having the same letter are not significantly different at p = 0.05 (Duncan's multiple range test)

Seed germination and seedling survival over time

As early as two weeks after setting the experiment, there were more seedlings germinating in the irrigated plots (Figure 3). In general during the hot wet summer (February till May) there was increased germination and survival of seedlings for all treatments. As the rain stopped and temperatures dropped in winter (June till August), there was a huge drop in the number of seedling survival for all treatments. However the decline was more in the plots that were not irrigated. From September till January 2012 (dry hot season), the number of seedlings growing in irrigated plots (tilling + watering and watering + grass cutting) reduced only slightly (Figure 3). However in the non-irrigated plots (control and tillage only), the number of seedlings continued to decrease rapidly. Death of seedlings during the dry cold season was high, confirming observation



Figures 3 (a) Average number of seedlings germinated and survival per treatment in relation to variations in monthly (b) temperature and humidity (Source: www.sasscalweathernet.org) and (c) rainfall; T + W = tilling and watering, W + GC = watering and grass cutting

by Brewbaker (1987) that *L. leucocephala* is not tolerant to frost and its growth is hampered by low temperatures.

Leucaena leucocephala might not be drought tolerant enough to become invasive under these harsh climatic and soil conditions. During the rainy season, the species germinated vigourously in many cultivated parts of the farm but rarely germinating in uncultivated paddocks most probably due to the presence of soil hard pan and competition with grass browsing by livestock. High seedling survival occurred in irrigated crop fields.

As with other semi-arid regions, variation in total annual rainfall from year to year was high (from 700.5 mm in 2011 to 257.7 mm in 2013) with an average of 461.3 mm for the three years (Table 2).

The characteristics of the experimental hedge and dimensions of the wood harvested after 33 months of growth are shown in Table 3. Due to the unique planting pattern (double row and zigzag) of the hedge, it was difficult to make direct comparison of results obtained with biomass data recorded elsewhere. *Leucaena leucocephala* produced an average of 2.58 stems per stump at Ogongo, and the stems achieved average annual height growth and mid-diameter of 1.98 m and 2.93 cm (after 33 months) respectively. This indicated reasonable growth within the range of what has been recorded elsewhere. In Ghana, slower height (1.48 m $year^{-1}$) and diameter (1.12 cm $year^{-1}$) growth was recorded for seedlings. Wood volume production in Ghana was 10.6 m^3 ha $year^{-1}$ at a stocking of 8333 stems ha^{-1} (Mainoo & Ulzen-Appiah 1996). In Waimanalo, Hawaii, the local *Leucaena* variety recorded height growth rate of 0.72 m $year^{-1}$ while that of the introduced giant variety, 1.79 m $year^{-1}$ (Wheeler & Brewbaker 1988). Wood production for the same giant variety was 21.4 m^3 ha $year^{-1}$ at a stocking of 10,000 stems ha^{-1}. In La Ra´bida, Huelva, south-western Spain, growth rates for sprouts of two varieties was much faster, i.e. the Hunduras variety had a height growth rate of 4.08 m $year^{-1}$ and wood volume production of 28.4 tonne ha^{-1} $year^{-1}$ while the variety from India had height growth rate of 4.21 m $year^{-1}$ and wood volume production of 45 tonne ha^{-1} $year^{-1}$ (Lopez et al. 2008). In spite of the difficulty in making direct comparison of these data due to the differing climatic conditions of the study sites, different experimental designs and the fact that sprouts grow faster than seedlings, the figures for Ogongo suggested moderate to high productivity. *Leucaena leucocephala* is also genetically diverse and varietal differences in performance are obvious (Wheeler & Brewbaker 1988). Unfortunately the origin of the Ogongo variety is not known.

Table 2 Total monthly and annual rainfalls (mm) for the years the trees were assessed for wood biomass production

Month	Year			
	2011	2012	2013	Average
January	45.0	115.8	17.9	59.6
February	149.0	102.0	47.3	99.4
March	283.0	63.9	119.6	155.5
April	94.0	1.4	0	31.8
May	90.0	0	0	30.0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	78.4	0	26.1
December	39.5	64.1	72.9	58.8
Total	700.5	425.6	257.7	461.3

(Source: recordings at Ogongo Campus Tree Nursery)

Table 3 Characteristics of the experimental hedge and amount of wood produced in 33 months

Age of hedge	12 years
Age of sprouts	33 months
Spacing	0.25 m × 0.25 m within rows and 3 m between rows
Number of stumps in a 10-m long hedge	40
Average number of stems per stump and (range)	2.58 (1–5)
Average length of stems and (range)	5.46 m (2.63–6.95 m)
Average basal, mid diameter and tip diameter of stems	4.36, 2.93, 0.62 cm
Mean annual height growth per year (estimate based on 33 months)	1.98 m year^{-1}
Mean annual basal diameter growth	1.59 cm year^{-1}
Total volume of green stems harvested from the 10-m long hedge	0.234 m^3
Total sun-dry weight of stems harvested from the 10-m long hedge	0.2612 tonnes
Extrapolated volume of green wood produced at a stocking of 6666 stems ha^{-1}	14.2 m^3 ha^{-1} year^{-1}
Extrapolated biomass (sun-dried weight) production at a stocking of 6666 stems ha^{-1}	15.8 t ha^{-1} year^{-1}

CONCLUSIONS

The results of this study strongly suggested that surface hard pan in soils of north-central Namibia hindered seed germination of *L. leucocephala*. The species spread more in cultivated fields. Survival of seedlings depended on availability of water during the dry spell and the species could become invasive in irrigated fields. High rate of seedling death occurred during winter months. Under the prevailing conditions of poor soils with surface hard pan, long cold dry and hot dry seasons and grazing pressure, this species could not spread freely into the rangelands. However, it may invade water courses and irrigated cultivated fields. Biomass production under these harsh conditions was relatively good. Considering the enormous ecological and economic potential benefits reported for the species, its cultivation should not be discouraged purely out of fear of it being invasive. Rather its cultivation should be promoted and farmers should be trained on how to manage it to prevent uncontrolled spread. Management models that can be emulated exist, for example, the code of practice for growing *Leucaena* in Australia that came into force in 2000 (Anonymous 2009). Giant varieties that combine fast growth, high resistance to psyllid and low seeding rates are available in Australia (Wheeler & Brewbaker 1988). Such varieties could be used where there is fear of the species becoming invasive, rather than the less vigorously growing varieties that are also more invasive by virtue of having high seeding rates.

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