Leucaena interspecific hybrid ‘KX4-Hawaii’ as a source of agricultural biomass in a water-scarce small island developing state (#103231)

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Leucaena interspecific hybrid 'KX4-Hawaii' as a source of agricultural biomass in a water-scarce small island developing state

Jabarry R. Belgrave [Corresp., 1], **Angela T Alleyne** [1], **Jeff S Chandler** [2], **Francis B Lopez** [2]

[1] The Department of Biological and Chemical Sciences, Univeristy of the West Indies - Cave Hill, Bridgetown, Saint Michael, Barbados

[2] Formerly of The Department of Biological and Chemical Sciences, University of the West Indies, Bridgetown, Saint Michael, Barbados

Corresponding Author: Jabarry R. Belgrave
Email address: jabarry.belgrave@cavehill.uwi.edu

Background. *Leucaena leucocephala* is a useful multipurpose tree species for agroforestry systems, but traditional seeded cultivars often become weedy and invasive. A seedless hybrid cultivar, 'KX4-Hawaii', offers a potential solution to this problem. However, relevant agronomic information and information on the performance of KX4-Hawaii under varying growth conditions is required. The goal of this research was to evaluate 'KX4-Hawaii' as a source of agricultural biomass in Barbados, a small island developing state with limited arable land.

Methods. 'KX4-Hawaii' air layers were imported into Barbados to create stock trees. Air layering was used to create propagation material and a field study was established with a 'KX4-Hawaii' hedgerow planted as a field border. Three plant spacings (50 cm, 75 cm, and 100 cm) were evaluated and data on the growth and biomass yields of the trees were collected at 4-month intervals. Precipitation data were used to investigate climatic effects on 'KX4-Hawaii' productivity.

Results. 'KX4-Hawaii' was successfully propagated via air layers and could be planted directly in the field with irrigation. All recorded growth and biomass yields were correlated with precipitation. However, the woody (lignified stems and branches) biomass was more responsive to precipitation than the green (leaves and green tender stems) biomass and made up a large fraction of the total biomass produced. 'KX4-Hawaii' was productive even under drought conditions and biomass yields per meter of hedgerow increased with closer spacings. Of the tested spacing treatments, 75 cm was optimum for a 4-month pruning interval under the conditions seen in Barbados as it produced similar yields to the 50 cm spacing treatment but would require less propagation material.

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Jabarry Rashad Belgrave[1], Angela Theodora Alleyne[1], Jeff St. Aubyn Chandler[1], Francis Bede Lopez[1]

[1] Department of Biological and Chemical Sciences, The University of the West Indies - Cave Hill Campus, Bridgetown, Saint Michael, Barbados

Corresponding Author:
Jabarry Belgrave[1]
The University of the West Indies - Cave Hill Campus, Cave Hill, Bridgetown, Saint Michael, BB11000, Barbados
Email address: jabarrybelgrave@cavehill.uwi.edu

Abstract

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Introduction

Barbados is a small island developing state located in the Western Atlantic. It has a high food import bill (Madden 2023) and it is in the top 20 most water scare countries worldwide (FAO 2015). The island is only 430 km^2, and arable land coverage is heavily fragmented and has decreased over time such that there were only 7000 hectares in 2021 (The World Bank n.d.) as can be seen in Fig. 1 (Zanaga et al. 2022). Other Caribbean islands have similar conditions, leading to calls for sustainable and climate-smart agriculture in the region so that the limited resources available are efficiently used to improve food security (Central Bank Of Barbados 2023).

Several tropical woody tree species have multiple uses in agroforestry and include such species

Something missing

as *Leucaena*, *Gliricidia*, *Inga*, and S*esbania*, which can be found on the island (Carrington 2007). They have been described as Multipurpose Tree Species (MPTs) for their use as bioenergy sources, food, and fodder, among other uses (Kang et al. 1999; Verheij 2007). Many MPTs are nitrogen fixers and the fixed nitrogen may then be transfered to nearby crops via root exudation, leaf litter, and application of pruned biomass (Kang et al. 1999). Nitrogen-fixing MPTs, such as Leucaena (*Leucaena leucocephala* (Lam.) de Wit), may be used in agroforestry to produce biomass for soil amelioration during crop cultivation and their biomass may be pruned and added to the soil as a mulch or mixed into the soil as a green manure. These soil additions may lead to improvements in soil organic matter, water retention, mineral nutrients, and reductions in nutrient leaching (Kang et al. 1999). Organically improved soils result in more sustainable and resilient agroecosystems (requiring fewer external chemical inputs) particularly to climate change effects such as floods and droughts which influence soil erosion, and water and nutrient availability (Kugedera et al. 2022; Lalljee 2013).

When MPTs are grown in a different location to the crop and the pruned biomass carried to the crop to be applied the process is described as a biomass transfer system. (Kang et al. 1999). However, biomass transfer systems require more human resources to transport the pruned biomass although the MPTs can be grown on less arable land, leaving prime arable land for crop cultivation. Still, biomass transfer systems also eliminate competition between MPTs and crops unlike other agroforestry techniques such as alley cropping. Consequently, research has shown that biomass transfer systems can increase crop productivity. A biomass transfer system using

Better to give authority of all species when introduce first

Leucaena, Gliricidia (*Gliricidia sepium*) and Senna (*Senna siamea*), resulted in higher yields than control or fertilizer treatments, but was uneconomical due to high labor costs and low land availability in Nigeria (Kormawa et al. 1999). Contrastingly, a biomass transfer system in southeast Asia using mountain immortelle (*Erythrina poeppigiana*) to produce beans (*Phaseolus vulgaris*) and maize (*Zea mays*) resulted in greater yields and was more profitable than alley cropping (Prosea Foundation 1997). Also, a biomass transfer system in Hawaii using mulch from Leucaena 'KX2' to produce coffee (*Coffea arabica*) resulted in increased coffee growth and yield and soil carbon and nitrogen contents (Youkhana & Idol 2016).

Higher green (non-lignified leaf and stem) biomass production is helpful for soil nutrient additions, as lower carbon:nitrogen (C:N) ratios result in faster biomass decomposition when biomass is applied to the soil (Kang et al. 1999). Low C:N ratios have also been linked to increased biomass quality and crop yields (Srivastava & Singh 2013; Tian et al. 1995; Vargas-Tierras et al. 2021). However, woody biomass with higher C:N ratios can be used as a mulch that is more resistant to decomposition than green biomass and can reduce soil evaporative water loss for longer periods (Budelman 1988). The configuration of a Leucaena hedgerow can be altered to change the dominant fractions in the pruned biomass to suit the needs of the grower if prior knowledge about its use and responses are available.

Research in Hawaii has found that more frequent pruning and wider spacings increased Leucaena green biomass yields (t/ha) (Guevarr 1976). Contrastingly, later studies reported that wider plant spacings led to decreased green and woody Leucaena biomass yields (Chotchutima et al. 2013; Tuncay & Rüstü 1989). This effect was also reported by Elfeel & Elmagboul (2016) who reported increased green and woody biomass yields (t/ha) overall with closer spacing, but decreased woody biomass content.

'KX4 Hawaii' is a seedless Leucaena interspecific hybrid with high biomass production levels (Brewbaker 2013). Leucaena is considered invasive in Barbados, and farmers are hesitant to grow it because after its introduction to Barbados it escaped and became widespread across the island with a high reproductive output (Carrington 2007; Proverbs 1984). However, these Leucaena are self-pollinated seeded types with a maximum of 45 pods per flower head, each containing 8 - 18 seeds, while flowering and fruiting year-round (Orwa et al. 2009). Therefore, seedless cultivars offer a possible solution to this concern. They are less likely to escape and become invasive, but little information is available on their productivity in an agronomic setting.

The 'KX4-Hawaii' hybrid was released in 2012 and it is a completely seedless and high yielding hybrid of *L. leucocephala ssp. glabrata* and *L. esculenta* (*Mociño et Sesse ex DC) Benth* (Brewbaker 2013). 'KX4-Hawaii' may also have potential to supplant the invasive local Leucaena in Barbados for cut stakes, fish traps, biochar, animal feed, land stabilization, and agronomic purposes (Carrington 2007; Proverbs 1984), without the risk of it becoming feral.

This study sought to evaluate the seedless cultivar of Leucaena (cv. 'KX4-Hawaii'), and the effect of intra-row plant spacing on biomass yields when planted as a hedgerow on a field border in Barbados. Both green and woody biomass yields were considered, as green biomass has applications for animal feeds and soil improvements, while woody biomass has applications for wood production, biochar, and biomass to energy, and Leucaena has been used in these roles locally (Carrington 2007; Proverbs 1984). As Barbados is a small water scarce island, the performance of this cultivar under these conditions needs to be established.

Materials & Methods

Establishment of Leucaena 'KX4-Hawaii'

Forty, 30-cm-long rooted air layers of Leucaena cultivar 'KX4-Hawaii' were imported into Barbados from the University of Hawaii in 2015. These were acclimated in the Biology Gardens at the Cave Hill Campus in plastic nursery pots (33 cm diameter, 25 cm high) filled with a 1:1 ratio of loamy topsoil and construction sand with daily irrigation. The surviving air layers (25) were planted at the Barbados Agriculture and Manufacturing Company's (BAMC) research station at Groves, Saint George, Barbados to establish stock trees. These were spaced 2 m apart and 15 g of triple super phosphate fertilizer was placed in each planting hole.

After the stock trees had been established for 2 years, 240 air layers were created by removing 3 cm wide strips of bark from branches 4 cm to 6 cm in diameter, and cheese cloth containing 125 cm^3 of moist Sphagnum peat moss was applied, before wrapping the wounded portion with plastic wrap. Up to 3 air layers were initiated per branch and the branches were cut after 5 weeks to produce 40 cm long air layers. These were acclimated as was done with the imported 'KX4-Hawaii' air layers and 183 air layers (76.25 %) survived. Further air layers were created (cut after 8 weeks) and these were planted directly in the field without acclimatization in pots to test the feasibility of skipping the nursery stage of propagation. Of the 39 air layers directly planted, 33 survived (84.6 %).

Experimental field plot and planting

Not clear about blocking. How did you block? What is the block arrangement

A field experiment was established at the Barbados Ministry of Agriculture's Graeme Hall complex, in the parish of Christ Church, (13.074379°N 59.573093°W), in 2018. This site is located 11 m above sea level in Barbados` black soil association, characterized by fine textured clays (Ahmad 2011). A randomized block design (with 5 blocks) was used to evaluate the plant spacing (50, 75 and 100 cm) between 'KX4-Hawaii' trees planted as a field border hedgerow.

Single line or multiple line

Each plot was 9 m long and plots were spaced 2 m apart. Due to seasonal variations such as the dry season in Barbados between December and May (Mohan, Clarke, and Chadee 2020), a 4-month pruning interval was chosen so that adequate yields could still be acquired during dry periods when Leucaena biomass production drops (Proverbs 1984). After each pruning a 0.15 % Roundup Ultra herbicide solution (a.i. glyphosate, Bayer AG, Germany) was sprayed to control weeds.

How many plots per block? Are those randomized ?

45 plants per block? What is meant by block 5 having more space?

Experimental blocks 1 - 4 were planted using the 183 acclimated air layers. As more space was available, block 5 was planted using the 39 air layers directly planted in the field. Supplying was done two weeks after planting. The trees were established for several months, with daily drip irrigation for the first month. Then they were pruned to 30 cm to standardize the plants to the same height in September 2018 for blocks 1 to 4 (7 months after planting) and in January 2019 for block 5 (9 months after planting).

Several ? state number

Did you use initial value as covariate?

Biomass Data Collection

There were four prunings (spanning 16 months) until the experiment was prematurely concluded due to COVID-19 lockdowns in Barbados in 2020 (Table 1). Block 5 was established later than the other blocks and data was not collected from this block until May 2019 (13 months after planting). Apart from the first interval (ending January 2019) the amount of precipitation received was low.

does it mean each plot has 4 plants where measurements have benn taken only from w plants? If so explain and say why?

Plant height and canopy width (perpendicular across hedgerow) of two plants in the center of each plot were measured with a meter rule and averaged. Light interception was measured using a LI-190R point quantum sensor and LI 191R line quantum sensor (LI COR, Inc., USA) between 10:00 am and 12:00 am. The line sensor was centered on the ground below a plant in the center of the plot and measurements were only taken if the overhead light was at least 1000 µmol s^{-1} m^{-2}.

Plots were pruned to 30 cm high and biomass samples were taken approximately every 4 months. All pruned biomass from one plant from the center of each plot was used to determine the green biomass (leaves and green tender stems) and woody biomass (lignified stems and branches) yield per plant. Subsamples were oven-dried at 105 °C until constant weight and used to determine the dry mass of the samples.

Data Analysis

Block 2 was not analyzed due to very shallow soil depths in that area of the hedgerow that resulted in plots 4 and 5, and half of plot 6, performing extremely poorly. The 'jamovi' 2.5.3 software with the GAMLj: General analyses for linear models 3.2.7 module was used for mixed model, correlation, and regression analyses (Gallucci 2019). A log10 transformation/back transformation was used during mixed model analyses if the residuals were not normally distributed (canopy light interception and the biomass yield variables), and polynomial contrasts were applied during mixed modelling for trend analysis. The Tukey honest significant difference post hoc test was applied to significant ($p \leq 0.05$) mixed model results for pairwise mean comparisons. The strength of correlations was defined based on Swinscow (1997).

Results

'KX4-Hawaii' growth

During 2019, seasonal variations were observed for some growth parameters Plant height, and canopy light interception were at their highest on the January 2019, and canopy width was highest in September 2019, though not significantly different to January 2019 (Table 2). Plant height, canopy width and canopy light interception were at their lowest in May 2019 during the dry season. Although differences between the mean plant height achieved were significant throughout the sampling period there were no significant differences in canopy width and light interception between the January 2019 and September 2019 sampling dates. There was also no significant difference in canopy light interception between the May 2019 and January 2020 sampling dates, although significantly wider canopies were recorded in January 2020 than in May 2019.

The 75 cm spacing treatment consistently resulted in greater plant heights and canopy light interception (Table 3). The 75 cm spacing treatment was significantly different to the 100 cm spacing treatment in these variables, although it was not significantly different to the 50 cm spacing treatment. Similarly, wider canopy widths were observed with a 75 cm spacing interval. At the 50 cm, 75 cm, and 100 cm spacing intervals the mean canopy widths were 222 ± 10.1 cm, 255 ± 10.1 cm, and 220 ± 10.1 cm, respectively, but the linear mixed model results were not significant ($F = 4.77$, d.f. = 2, $p = 0.060$). There was a quadratic response of plant height ($p = 0.013$), canopy width ($p = 0.023$), and light interception ($p < 0.001$) as plant spacing increased. There was also a linear response of canopy light interception to plant spacing ($p < 0.001$).

‘KX4-Hawaii’ Biomass yields

Green biomass comprised a lower fraction of the total biomass produced by ‘KX4-Hawaii’ (Table 4) and its yields were significantly different to the woody biomass yields at each sampling date apart from May 2019. Yet, overall biomass yields recorded in May 2019 did not differ significantly to those recorded in January 2020. However, the woody biomass yields were significantly different between January and September 2019.

The 75 cm spacing treatment resulted in consistently higher yields per plant, although this was not significant. There were no significant effects of the spacing×date interaction on ‘KX4-Hawaii’ biomass yields and spacing only significantly affected the biomass yields per meter of hedgerow ($F = 6.78$, d.f. = 2, $p = 0.016$). The 50 cm, 75 cm and 100 cm spacing treatments resulted in a mean total biomass production of 2.70 ± 0.43 kg, 2.54 ± 0.40 kg, and 1.43 ± 0.23 kg per meter of hedgerow respectively. Biomass yields per meter of hedgerow decreased with higher spacings and polynomial contrasts indicated a significant linear response of biomass yield per meter to spacing ($p = 0.009$). Notably, the 50 cm and 75 cm spacing treatments did not significantly differ in biomass yields per meter ($p = 0.021$), but both resulted in significantly different biomass yields per meter to the 100 cm treatment.

There was a quadratic response (contrast) of the green/woody biomass ratio to plant spacing ($p = 0.048$) but the mixed model results were not significant ($F = 2.69$, d.f. = 2, $p = 0.085$). However, there was a significant effect of date on the green/woody biomass ratio ($F = 64.13$, d.f. = 3, $p < 0.001$) and the ratio was significantly different between all sampling dates. The green/woody biomass ratio was 0.41 ± 0.03 in January 2019, increasing to 0.83 ± 0.03 in May 2019, and declining to 0.67 ± 0.03 in September 2019 and to 0.524 ± 0.03 in January 2020.

Associations between spacing and precipitation with ‘KX4-Hawaii’ growth and yield

All recorded growth and biomass yield variables were significantly correlated with the cumulative precipitation received during each cutting interval (Table 5), and these correlations were all positive apart from the strong negative correlation with the green:woody biomass ratio (rho = -0.686, d.f. = 43, $p < 0,001$). Notably, the correlation with plant height (rho = 0.757, d.f. = 43, $p < 0.001$) was strong as compared to the moderate correlations with canopy width (rho = 0.581, d.f. = 42, $p < 0.001$) and light interception (rho = 0.434, d.f. = 42, $p = 0.003$). Also, the correlation with green biomass yields was weak (rho = 0.375, d.f. 43, $p = 0.011$) compared to the strong correlation with woody biomass yields (rho = 0.641, d.f. = 43, $p < 0.001$). There were no significant correlations between any recorded variable and the length of the interval between data

collection dates apart from the moderate negative correlation with the green:woody biomass ratio (rho = -0.516, N = 43, $p < 0.001$).
Multiple linear regression modelling of spacing, spacing^2, and the duration of each cutting interval and the amount of precipitation received was not significant when fitted to the green biomass yield per plant (Adjusted $R^2 = 0.100$, d.f. = 4,40, $p = 0.083$) (Table 6). However, the regression model fitted to the woody biomass yield per plant was significant (Adjusted $R^2 = 0.100$, d.f. = 4,40, $p = 0.083$) and spacing ($p = 0.004$), spacing^2 ($p = 0.005$), and precipitation ($p < 0.001$) were significant predictors of woody biomass yield. This model explained 47.9 % of the variation in woody biomass yields. However, the duration of the interval between cuts ($p = 0.508$) was not a significant predictor of woody biomass yield, likely because the intervals only ranged from 113 to 123 days; a maximum difference of 10 days). There was a quadratic response of woody biomass yield per plant to plant spacing (spacing, B = 8.96e-2; spacing^2, B = -5.87e-4), indicating that yield increased initially with spacing before declining. Woody biomass yields also increased with increasing precipitation (B = 2.23e-3).

Discussion

Propagation of Leucaena 'KX4-Hawaii'

Air layering is a low-tech method of propagation with a higher than 90 % success rate for 'KX4-Hawaii' propagation under ideal conditions (Idol et al. 2019), so it was used to produce 'KX4-Hawaii' planting material in this study. However, the survival rates (76.25 % and 84.6 %) achieved were lower than the 90 % success rate reported by Idol et al. (2019). It should be considered that the rooted air layers directly planted in the field, though irrigated initially, were propagated under rain-fed conditions and this may explain the lower success rates. Any differences between these findings and those of Idol et al. (2019) in Hawaii might be due to the use of larger diameter branches for air layering in this study. Idol et al. (2019) also mentioned that adequate soil moisture was needed for the best success rate in producing rooted air layers, and the stock trees used in this work were not irrigated. Furthermore, Hawaii is a volcanic island with volcanic soils, while Barbados' soils are mainly of limestone origin (Ahmad 2011). Additionally, the use of larger diameter branches for air layering in this study may also be reflected in the propagation outcome when compared to Idol et al. (2019). Generally, there is agronomic interest in modern seedless Leucaena cultivars but how these cultivars are multiplied for distribution and planting needs to be considered.

Effects of plant spacing on 'KX4-Hawaii' growth and yield

Overall, the 75 cm spacing resulted in the greatest 'KX4-Hawaii' growth and biomass production on a per-plant basis. Research has shown that Leucaena does not compensate for wider plant spacings by producing more lateral stems (Guevarr 1976). Therefore, when space is no longer a limiting factor, further stem growth that would normally drive a bigger canopy and greater biomass does not occur. Leucaena biomass yield per plant (effects of experimental treatments at the individual plant level) and per unit area or length of hedgerow (yields under a production setting) are both helpful metrics to measure plant productivity in response to experimental treatments. Our results showed that there were no significant effects of plant spacing on the biomass yield per plant, but there were significant effects of plant spacing on the biomass yield per meter of hedgerow. Previous research has shown that Leucaena biomass yield per plant did not significantly increase with intra-row plant spacings above 25 cm (Chotchutima et al. 2013; Tuncay & Rüstü 1989), and 50 cm was the smallest plant spacing used in this current study. As plant spacing did not significantly affect biomass yield per plant, a higher biomass yield per length of hedgerow with smaller plant spacings was due to greater plant densities.

The green:woody biomass ratio responded quadratically to plant spacing and the 75 cm spacing treatment resulted in the lowest green:woody biomass ratio (it had the largest proportion of woody biomass). This was unexpected, as literature sources suggest narrower plant spacings are superior for woody biomass production (Chotchutima et al. 2013; Elfeel & Elmagboul 2016; Prasad et al. 2011). Another factor in the lower biomass yield per area of the 100 cm plant spacing treatment might have been because it took longer for this treatment to form a solid canopy and shade out weeds (if it ever did within 4 months). This allowed more weeds to grow inside the hedgerow, which would lead to interspecific competition that would counteract the lower intraspecific competition due to a lower plant density. *Desmanthus virgatus* and *Bothriochloa pertusa* were common weeds in the `KX4-Hawaii` hedgerow in this study.

The biomass yield per meter of hedgerow responded linearly to plant spacing, with an inverse relationship between plant spacing and biomass yields. The 75 cm spacing treatment can be recommended for ‘KX4-Hawaii’ under similar conditions in the present study as it did not differ significantly from the yields per meter of hedgerow of the 50 cm spacing interval but would require less planting material due to the smaller population produced. Our findings are similar to those by Elfeel & Elmagboul (2016), who also used a 4-month pruning interval across 4 biomass sampling dates. Biomass yields recorded from their first biomass sampling responded quadratically to plant spacing but responded linearly to plant spacing on the subsequent three sampling dates, with the lowest plant spacing (40 cm) having higher biomass yields. On its initial release, KX4-Hawaii’ cultivar was noted for its wood and biofuel production (Brewbaker 2013). However, earlier studies with Leucaena by Guevarr (1976) reported that green biomass comprised the predominant fraction when compared to woody biomass yields. This differed from later studies by Elfeel & Elmagboul (2016) who reported the production of equal proportions of Leucaena green and woody biomass. In the current study, woody biomass made up the predominant fraction of the ‘KX4-Hawaii’ biomass produced. The high woody biomass produced here makes KX4-Hawii a suitable cultivar under these conditions as a biofuel source.

Impacts of climate conditions during the study period

Leucaena can grow with 650 mm of annual precipitation (Orwa et al. 2009; Proverbs 1984) but this amount is not optimal. Leucaena has been shown to respond to water availability (Maslekar 1984; Noulèkoun et al. 2017) and thrives with over 1200 mm of annual precipitation (Orwa et al.

2009). However, there was a drought during the study period 2019 in Barbados (Alleyne 2020; Smith 2020), with the Charnocks weather station receiving only 58 % (736.5 mm) of the climatological average precipitation. This was the lowest amount of precipitation received since 1942 (Alleyne 2020). Barbados' climatological average of 1260 mm of annual precipitation (Layne 2021) falls into a favorable precipitation regime for Leucaena growth. Therefore, there is potential for greater 'KX4-Hawaii' growth and biomass production than that seen in 2019 outside of conditions. Notably, the September 6th to December 31st period in 2018 (580.4 mm) was not dissimilar to the climatological average of 1991-2020 for the September to December period (605.8 mm) (Layne 2021), and this period resulted in the highest woody and total biomass yields when the Leucaena trees were pruned in early January 2019. There were positive correlations between precipitation and all recorded 'KX4-Hawaii' growth and yield variables indicating the potential for higher biomass production. However, 'KX4-Hawaii' was still productive under the drought conditions seen during the study and future dry conditions may not hamper the generation of useful woody biomass for agronomic purposes. Elfeel & Elmagboul (2016) also found that the rate of Leucaena biomass production was seasonal, similar to the correlation between precipitation and biomass yields in the current work. So, lower green biomass production under drought conditions was expected as reduced leaf production and increased leaf senescence in Leucaena are typical under these conditions (El-Juhany & Aref 1999; Rosecrance 1990). However, as woody biomass was more responsive to precipitation than green biomass, it may make up an even larger fraction of the total biomass produced by 'KX4-Hawaii' under the climatological norm in Barbados as seen from the January 2019 results.

Limitations of study and future work

Several constraints were encountered during the study period that were outside the control of the authors. First, Barbados is a small island developing state with limited land availability for agroforestry, and there was limited planting material, so the study was restricted to intra-row plant spacing and the pruning regime was fixed. Second, the study had to be terminated prematurely due to national COVID-19 lockdowns. Hedgerow studies typically are run for at least 2 years and include the effect of pruning management such as that by Mullen et al. (2003). This study lasted 16 months from the first cut to the last pruning. Nonetheless, the study provides valuable information on 'KX4-Hawaii', a new cultivar that has not been significantly studied, on a small island with limited land area and creates a base for future research. Future work will build on this research with experiments of longer durations investigating the effects of pruning management on the cultivar and the application of the biomass produced to the soil.

Conclusions

Propagation of Leucaena 'KX4-Hawaii' via rooted air layers was successful and can be recommended as a low-tech method of propagating this seedless cultivar. A plant spacing of 75 cm was superior to that of 50 cm and 100 cm for promoting 'KX4-Hawaii' growth. It resulted in similar biomass yields per meter of hedgerow to a spacing interval of 50 cm, and greater productivity than the 100 cm spacing treatment, but requires less propagation material to establish. 'KX4-Hawaii' was still productive when pruned approximately every 4 months under drought conditions. Contrary to some other Leucaena cultivars, woody biomass comprised a larger fraction of the total 'KX4-Hawaii' biomass produced with a 4-month pruning interval. Growth and biomass yields were correlated with precipitation, and woody biomass production was more responsive to precipitation. Our current results also suggest that 'KX4-Hawaii' is drought tolerant. To the best knowledge of the authors this is the first attempt at understanding the agronomic behavior of 'KX4-Hawii' outside Hawaii and in another island state. Future work is still required to explore the effects of the pruning regime on biomass yields and the ability of 'KX4-Hawaii' biomass to promote the growth of a test crop when applied to the soil.

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The authors wish to thank Dr. Travis Idol who arranged the transfer of 'KX4-Hawaii' air-layers to Barbados. We would also like to thank Dr. Sandra Bellamy (Barbados Agricultural Management Company) who facilitated the planting of the imported 'KX4-Hawaii' air layers to create stock plants, and Mr. Mark Byer (Barbados Ministry of Agriculture) who facilitated the establishment of this field study. Dr. Adrian Trotman (Caribbean Institute of Meteorology and Hydrology) also assisted this study by the provision of precipitation data for the study period.

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All references are cited - good

Figure 1

Map of Barbados showing land coverage. Arable crop land is indicated in pink. Map © 2024 ESA WorldCover Project at https://viewer.esa-worldcover.org.

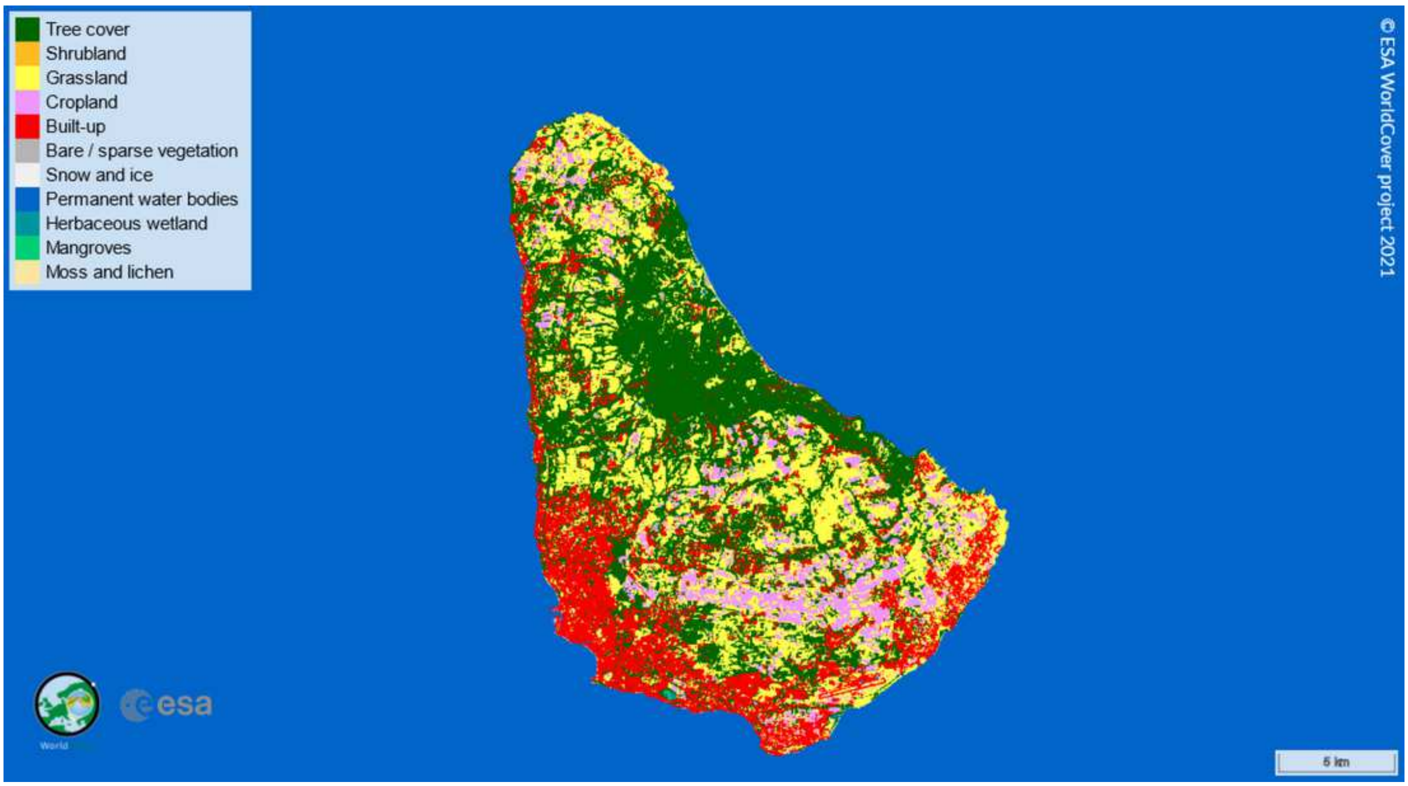

Table 1(on next page)

Data collection dates, and the duration and the amount of precipitation received, for each hedgerow pruning interval.

Measurements activities refer to recording plant height, canopy width and canopy light interception. Sampling activities refer to biomass yield sampling. The precipitation data are from the Charnocks (Grantley Adams International Airport) weather station, which was the station closest to the study site.

Table 1 Data collection dates, and the duration and the amount of precipitation received, for each hedgerow pruning interval.

Pruning	Blocks	Previous Cut	Activity	Date	Duration (Days)	Precipitation (mm)
1 (Jan 2019)	All	2018.09.08	Measurements & sampling	2019.01.06	120	576.0
2	All	2019.01.07	Measurements	2019.05.02	115	150.5
(May 2019)	All	2019.01.07	Sampling	2019.05.04	117	150.5
3	1-2	2019.05.14	Measurements	2019.09.05	116	277.1
(Sep 2019)	3-5	2019.05.12	Measurements	2019.09.05	114	277.4
	1-2	2019.05.14	Sampling	2019.09.07	118	296.9
	3-5	2019.05.12	Sampling	2019.09.07	116	297.2
4	1-2	2019.09.18	Measurements	2020.01.10	114	266.3
(Jan 2020)	3-5	2019.09.09	Measurements	2020.01.10	123	284.7
	1-2	2019.09.18	Sampling	2020.01.09	113	265.1
	3-5	2019.09.09	Sampling	2020.01.09	122	283.5

per year or per duration?

why this previous cut and date in column not matching except pruning 1 and 2

Note: Measurements activities refer to recording plant height, canopy width and canopy light interception. Sampling activities refer to biomass yield sampling. The precipitation data are from the Charnocks (Grantley Adams International Airport) weather station, which was the station closest to the study site.

sample size

Table 2 (on next page)

Leucaena plant height, canopy width, and canopy light interception at each pruning date ± standard error from linear mixed model analyses.

Plant height $F = 167.32$, d.f. = 3, $p < 0.001$. Canopy width $F = 114.70$, d.f. = 3, $p < 0.001$. Canopy light interception $F = 17.61$, d.f. = 3, $p < 0.001$. Means in the same column with a common attached letter are not statistically different based on the Tukey HSD post hoc test ($p \leq 0.05$).

Table 2 Leucaena plant height, canopy width, and canopy light interception at each pruning date ± standard error from linear mixed model analyses.

Time (Sampling Date)	Plant Height (cm)	Canopy Width (cm)	Canopy Light Interception (%)
January 2019	284 ± 6.88 d	273 ± 9.34 c	89.13 ± 2.59 b
May 2019	130 ± 6.09 a	152 ± 8.56 a	69.18 ± 2.01 a
September 2019	259 ± 6.09 c	292 ± 8.56 c	81.28 ± 2.53 b
January 2020	203 ± 6.09 b	213 ± 8.56 b	67.61 ± 2.10 a

Note: Plant height $F = 167.32$, d.f. = 3, $p < 0.001$. Canopy width $F = 114.70$, d.f. = 3, $p < 0.001$. Canopy light interception $F = 17.61$, d.f. = 3, $p < 0.001$. Means in the same column with a common attached letter are not statistically different based on the Tukey HSD post hoc test ($p \leq 0.05$).

sample size?

Table 3(on next page)

Leucaena plant height and canopy light interception for each spacing treatment ± standard error from linear mixed model analyses.

Plant height $F = 4.86$, d.f. = 2, $p = 0.039$. Canopy light interception $F = 17.92$, d.f. = 2, $p < 0.001$. Means in column with a common attached letter are not statistically different based on the Tukey HSD post hoc test ($p \leq 0.05$).

Table 3 Leucaena plant height and canopy light interception for each spacing treatment ± standard error from linear mixed model analyses.

Spacing (cm)	**Plant Height (cm)**	**Canopy Light Interception (%)**
50	211 ± 7.48 ab	81.28 ± 1.91 b
75	238 ± 7.48 b	85.11 ± 2.00 b
100	208 ± 7.48 a	69.18 ± 1.63 a

Note: Plant height F = 4.86, d.f. = 2, $p = 0.039$. Canopy light interception F = 17.92, d.f. = 2, $p < 0.001$. Means in column with a common attached letter are not statistically different based on the Tukey HSD post hoc test ($p \leq 0.05$).

sample size?

Table 4(on next page)

Leucaena biomass yields (dry weight) for each biomass component at each pruning date ± standard error from linear mixed model analyses.

Note: F = 3.86, d.f. = 6, p = 0.002. Means in the same column with a common attached letter are not statistically different based on the Tukey HSD post hoc test (p ≤ 0.05).

Table 4 Leucaena biomass yields (dry weight) for each biomass component at each pruning date ± standard error from linear mixed model analyses.

Time (Sampling Date)	**Biomass**	**Yield/plant (kg)**	**Yield/meter of hedgerow (kg)**
January 2019	Green	0.66 ± 0.08 bc	0.91 ± 0.11 bc
	Woody	1.56 ± 0.18 fg	2.17 ± 0.25 fg
	Total	2.22 ± 0.26 g	3.08 ± 0.36 g
May 2019	Green	0.56 ± 0.06 ab	0.77 ± 0.08 ab
	Woody	0.68 ± 0.07 bc	0.94 ± 0.10 bc
	Total	1.23 ± 0.13 ef	1.71 ± 0.19 ef
September 2019	Green	0.69 ± 0.08 bc	0.96 ± 0.10 bc
	Woody	1.04 ± 0.11 de	1.44 ± 0.16 de
	Total	1.74 ± 0.19 g	2.41 ± 0.26 g
January 2020	Green	0.40 ± 0.04 a	0.56 ± 0.06 a
	Woody	0.78 ± 0.09 cd	1.08 ± 0.12 cd
	Total	1.19 ± 0.13 ef	1.65 ± 0.18 ef

Note: $F = 3.86$, d.f. = 6, $p = 0.002$. Means in the same column with a common attached letter are not statistically different based on the Tukey HSD post hoc test ($p \leq 0.05$).

Table 5 (on next page)

Spearman's rank correlations between precipitation and the recorded growth and yield variables.

1 **Table 6** Spearman's rank correlations between precipitation and the recorded growth and yield variables.

Plant Height (cm)	**Canopy Width (cm)**	**Canopy Light Interception (%)**	**Green Biomass Yield per Plant (kg)**	**Woody Biomass Yield per Plant (kg)**	**Green:Woody Biomass Ratio (kg/kg)**
rho = 0.757 d.f. = 43 $p < 0.001$	rho = 0.581 d.f. = 43 $p < 0.001$	rho = 0.434 d.f. = 42 $p = 0.003$	rho = 0.375 d.f. = 43 $p = 0.011$	rho = 0.641 d.f. = 43 $p < 0.001$	rho = -0.686 d.f. = 43 $p < 0.001$

2

I guess this is pooled data? where growth and other parameters are different in different spacing? What will happen if you analyse within each treatment?

Table 6 (on next page)

Multiple linear regression models of green and woody biomass yields per plant fitted to plant spacing, plant spacing squared, and the duration and the amount of precipitation received for each cutting interval.

R^2 = adjusted R^2 statistic.

1 **Table 7** Multiple linear regression models of green and woody biomass yields per plant fitted to plant spacing, plant
2 spacing squared, and the duration and the amount of precipitation received for each cutting interval.

this says ppt for the given interval?

Variable	Model Fit	Predictor	Estimate (B)	S.E.	t	p
Green Biomass Yield per Plant (kg)	$R^2 = 0.100$ d.f. = 4,40 $p = 0.083$	Intercept	0.82	1.644	0.50	0.620
		Spacing (cm)	3.60e-2	1.60e-2	2.23	**0.031**
		Spacing $(cm)^2$	-2.36e-4	1.07e-4	-2.20	**0.033**
		Precipitation (mm)	4.59e-4	2.36e-4	1.95	0.058
		Interval (Days)	-1.39e-2	1.30e-2	-1.04	0.303
Woody Biomass Yield per Plant (kg)	$R^2 = 0.479$ d.f. = 4,40 $p < 0.001$	Intercept	-4.73	3.01	-1.57	0.124
		Spacing (cm)	8.96e-2	2.96e-2	3.03	**0.004**
		Spacing $(cm)^2$	-5.87e-4	1.96e-4	-2.99	**0.005**
		Precipitation (mm)	2.23e-3	4.31e-4	5.16	**< 0.001**
		Interval (Days)	1.62e-2	2.42e-2	0.67	0.508

3 Note: R^2 = adjusted R^2 statistic.

sample size?