

Technical Paper

A Bamboo Site–Species Matching Study in Kenya

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About this Working Paper

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Foreword

The drive to slow down the extraction of woody forest resources in East Africa has provided countries with the opportunity to earnestly seek alternative sources of wood and related composite materials. Bamboo is quickly emerging as one of the priority alternatives under consideration. It is a versatile resource with several documented uses, such as timber substitutes, pulp and paper, fiber and textile, plastic composites, food and beverage, energy, health, and cosmetics. It also has proven potential for soil erosion control, water recharge, and climate change mitigation and adaptation. It can contribute to flagship programs with a focus on small- and medium-scale enterprise development to promote manufacturing, the rehabilitation of degraded landscapes, employment creation, poverty reduction, economic development, and environmental resilience. In this regard, the government of Kenya has gasetted bamboo as a cash crop in order to spur its propagation for environmental conservation and commercial use. The widespread adoption of bamboo is expected to significantly contribute to Kenya's commitment to increasing its forest cover under its 10-year bamboo development strategy and to meeting the Bonn Challenge, the African Forest Landscape Restoration Initiative (AFLRI), the United Nations Sustainable Development Goals (SDGs), the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), the Convention on Biological Diversity (CBD), and the United Nations Framework Convention on Climate Change (UNFCCC).

Currently, Kenya is estimated to have a bamboo cover of approximately 133,000 hectares. This largely comprises the country's indigenous bamboo species, *Oldeania alpina* (syn. *Yushania alpina*). The geographic range of this bamboo species is restricted to highland areas of altitudes 2,400–3,500 meters above sea level, where it grows naturally. The country has imported approximately 22 exotic species of bamboo over the past three decades, and most of them thrive in lower-elevation zones. As the introduction of these exotic bamboo species has been uncoordinated, the areas in Kenya where they are planted have not been recorded, and whether they are grown in the appropriate agro-ecological zones (AEZs) is unknown. This information gap has hampered the country's ability to estimate the existing bamboo resource base and its potential to contribute to environmental resilience and economic development.

This report on bamboo species–site suitability matching for Kenya is expected to identify the exotic bamboo species currently planted in the country and inform actors in the bamboo value chain about the growth performance and suitability of these species for planting in different AEZs. The report captures the origin of each bamboo species, its growth performance in its native range and in different AEZs where it is currently grown in Kenya, and its potential for ecological and socio-economic utilization in different parts of the country. This report is intended to serve as a guide for farmers, foresters, extension agents, and bamboo value chain actors in matching each bamboo species to its most suitable AEZs in Kenya. This is expected to provide the confidence needed by bamboo growers and value chain actors in decision making on bamboo production and its utilization on a commercial scale.

Ali Mchumo
Director General
INBAR

List of Acronyms

AEZs	Agro-ecological zones
CBD	Convention on Biological Diversity
CERP	Coast Eco-Region Research Programme
CHERP	Central Highlands Eco-Region Research Programme
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
CL	Coastal lowland zone
cm	Centimeter
DBH	Diameter at breast height
g	Gram
ha	Hectare
hr	Hours
INBAR	International Bamboo and Rattan Organization
KEFRI	Kenya Forestry Research Institute
KFS	Kenya Forest Service
kg	Kilogram
LH	Lower highland zone
LM	Lower midland zone
m	Meter
mm	Millimeter
m a.s.l.	Meters above sea level
SDGs	Sustainable Development Goals
UM	Upper midland zone
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USD	United States dollars
yr	Year

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Executive summary

Bamboo has been planted in Kenya for about three decades. Most of the planted bamboo comprise exotic species, which have been introduced into the country at various phases. However, their introduction remains uncoordinated, so there is a serious information gap in the existing planted-bamboo resource base, the growth performance of bamboo species in different agro-ecological zones, and their commercial utilization. This has hampered the widespread adoption and scaling up of bamboo species in the county. A bamboo species–site suitability study was carried out in November and December 2020 to match each bamboo species to its most suitable agro-ecological zones in Kenya. The study was supported by the International Bamboo and Rattan Organization under the Dutch–Sino–East Africa Bamboo Development Programme (Phase II). This report outlines the results of the assessment with regard to the origins of the bamboo species planted in Kenya, their growth performance in their native ranges, their performance at different agro-ecological zones in the country, and their potential for ecological and socio-economic utilization in different parts of the country.

The assessment was carried out at 12 representative sites in Kenya. It identified one indigenous and 15 exotic bamboo species. The native bamboo species was *Oldeania alpina* (syn. *Yushania alpina*), while the exotic species were *Thyrsostachys siamensis*, *Phyllostachys aurea*, *Dendrocalamus strictus*, *D. membranaceus*, *D. hamiltonii*, *D. giganteus*, *D. brandsii*, *D. birmanicus*, *D. asper*, *Bambusa tulda*, *B. multiplex*, *B. blumeana*, *B. bambos*, *B. vulgaris* var. *vulgaris*, and *B. vulgaris* var. *vittata*. Four of the 15 exotic bamboo species were solid, whereas *Oxytenanthera abyssinica*, *T. siamensis*, *D. strictus*, and *B. tulda* were semi-solid, and the rest had hollow culms. The soil properties across the 12 sites varied significantly in terms of pH, bulk density, and texture.

The site suitability analysis indicated that *O. alpina* was unsuitable for plantation establishment outside its natural range of 2,300–3,200 meters above sea level. If planted below this range, it did not die, but its height and diameter failed to attain economically viable sizes, and so did its biomass. In this regard, it is recommended that *O. alpina* be planted only for conservation and ornamental purposes outside of its range. The performance of *T. siamensis* in Kenya was slightly lower than that of its native range, but it remained within its expected range, with better

performance in lower-elevation coastal zones, such as Gede and Jilore, than in mid-elevation zones, such as Kehancha. *Phyllostachys aurea*, which was recorded only in Limuru, showed fairly good performance. Given that Limuru had a significantly higher elevation than those areas where *P. aurea*'s native range was found, the performance of this species indicated that it was highly versatile in elevated areas. The performance of *O. abyssinica* in Kehancha, Muguga, Jilore, and Kibwezi showed that it grew well in Kenya's humid zones (Muguga and Kehancha) compared with its native range. The mean height and diameter of *D. strictus* in Jilore, Kibwezi, and Kehancha indicated that its performance was superior in lower-elevation and sub-humid zones, such as Jilore and Kibwezi. The performance of *D. membranaceus* in Gede, Kagumo, and Muguga indicated its suitability for humid low-elevation zones. *Dendrocalamus hamiltonii*, which was found in Mivumoni in Kwale, in Busia, and in Muguga in Kiambu, was likely to perform better in lower-elevation zones with fairly reliable rainfall. On the other hand, the height and diameter recorded for *D. giganteus* in Muguga, Ndakaini, Kairi-ini, and Kehancha showed that the species had a wide range of ecological preferences, with better performance in humid lower-elevation zones, such as LM1–2, as well as in mid-ecological zones, such as UM1–2. *Dendrocalamus brandisii* was reported only in Muguga. The results showed that this species was likely to perform better in low-lying humid zones, such as LM1–2 and UM1–2. *Dendrocalamus asper* was found in Busia Town, Isecheno, Kagumo Gardens, Kairi-ini, Limuru, and Muguga. Its performance indicated its suitability for the humid range of LM and CL zones. *Bambusa vulgaris* var. *vulgaris* had better performance in humid low-lying zones, such as Isecheno and Kehancha, than in other areas, such as Kibwezi, Limuru, and Ndakaini, where it was also encountered. *Bambusa vulgaris* var. *vittata* was the most common bamboo species recorded during the assessment and was found in Busia Town, Gede, Kagumo Gardens, Isecheno, Kairi-ini, Kehancha, Muguga, and Ndakaini. Its performance indicated that it had a wide ecological range. However, there was a variation in the results across sites with similar agro-ecological characteristics, which could be explained by differences in management practices and provenances. *Bambusa tulda* was observed only in Muguga. Nevertheless, its performance indicated its suitability for commercial production in LM1–2 and UM1–2 zones. *Bambusa multiplex* was found only in Limuru and was recommended for LM1–2 and lower-elevation UM1–2 zones. *Bambusa blumeana* showed a fairly wide elevation range with regard to growth performance. Overall, the species was likely to perform well in lower-elevation zones, such as CL2–4, LM1–2, and low-lying UM1–2 zones.

Bambusa bambos performed better in the lowlands and was therefore recommended in CL2–4, LM1–2, and low-lying UM1–2 zones, with proper silvicultural management.

In summary, this report demonstrates the following:

1. Establishment of bamboo trial plots in agriculturally marginal zones, such as LM3–5, to ascertain the suitability of different bamboo species in terms of yield and utilization;
2. Development of guidelines on bamboo silvicultural management and practices;
3. Creation of guidelines for the management of runner-type bamboo, such as *P. aurea*, to manage its potential to become invasive;
4. Capacity building for bamboo growers on standard procedures of bamboo clump management and harvesting to enhance productivity, as well as for other bamboo sector players on the utilization of bamboo for construction and industrial uses to enhance the planting and uptake of bamboo in homestead farming system development and commercial plantations;
5. The need for taxonomy research on bamboo so that researchers can gain a better understanding of bamboo species in Kenya.

1. Background

Bamboo is a perennial plant belonging to the grass family. It is popularly known as *poor man's timber*, denoting its popularity among poor populations as a substitute for expensive wood from trees (Lobovikov et al., 2012). About 1,600 species of bamboo grow in different parts of the world. Most of them grow naturally in tropical and sub-tropical regions at elevations ranging from sea level to 4,000 m above sea level (m a.s.l.). They are mostly found in Asia, Africa, and Latin America and cover a total area of 35 million ha, which accounts for 1% of the global forest area (Food and Agriculture Organization, 2020). In East Africa, bamboo is found in Ethiopia, Kenya, Tanzania, and Kenya and is estimated to cover 2.8 million ha. Global bamboo production and consumption are valued at USD 60 billion, with an international trade of USD 2.5 billion per annum. This supports the livelihoods of around 1.5 billion people.

Bamboo is a highly versatile plant in its adaptability and utility, with great potential for economic development, wealth creation, and environmental resilience (Kaushal et al., 2016). In this regard, growing it offers opportunities for rural communities to strengthen their livelihood, food security, and environmental resilience efforts (Dietz and Kuyah, 2011). There are over 10,000 documented bamboo uses and products, such as timber substitutes, fiber and textiles, plastic composites, food and beverage, and cosmetics. It also has proven potential for the rehabilitation of degraded lands, watershed protection, and climate change mitigation and adaptation (International Bamboo and Rattan Organization [INBAR], 2006). Because of its extensive shallow rhizome–root system and accumulation of leaf mulch, bamboo is an efficient agent for preventing soil erosion and conserving moisture, reinforcing embankments, and creating drainage channels (INBAR, 2010). With its fast growth rate and high annual re-growth after harvesting, it is a major carbon sink, especially when the harvested culms are used as durable products (Nath et al., 2009).

In Kenya, bamboo is an integral part of indigenous forests. The country's only indigenous bamboo species, *Oldeania alpina* (syn. *Yushania alpina*), grows naturally in the highlands at altitudes of 2,200–3,400 m a.s.l. The indigenous bamboo forest covers about 131,040 ha, distributed in mountain ranges and forest areas managed by the national government, such as the Aberdares Range, Mau Forest, Mt. Kenya, Mt. Elgon, and Cherangany Hills (Yuanyuan et

al., 2018). Research to introduce and validate the suitability of different exotic bamboo species in Kenya began in 1986. Twenty-two bamboo species were introduced from Asia. Some of these were *Bambusa brandisii*, *B. vulgaris* var. *vittata*, *B. vulgaris* var. *vulgaris*, *B. bambos*, *B. tulda*, *Dendrocalamus membranaceus*, *D. strictus*, *Dendrocalamus asper*, *Oxytenanthera abyssinica*, and *Thyrsostachys siamensis*. Since then, bamboo growing has taken root in many locations or counties within the country, such as Migori, Vihiga, Busia, Homa Bay, Uasin Gishu, Elgeyo Marakwet, Kirinyaga, Kitui, Laikipia, Nyandarua, Embu, and Tharaka Nithi. In these locations or counties, bamboo is grown as a crop on farm boundaries or via homestead farming, though not on a large scale.

The introduced bamboo has proven its potential to contribute to the economic and social pillars of Kenya's Vision 2030 and the Big Four Agenda, the Bonn Challenge, the African Forest Landscape Restoration Initiative, the United Nations Sustainable Development Goals, the Convention on International Trade in Endangered Species of Wild Fauna and Flora, the Convention on Biological Diversity, and the United Nations Framework Convention on Climate Change, particularly through small- and medium-scale enterprises that promote manufacturing and product development, rehabilitation of degraded landscapes, and provision of housing. In this regard, bamboo was declared a cash crop in Kenya by the former president of Kenya, Uhuru Kenyatta, in 2020, with a view to promoting its widespread adoption for national development. It is now classified as the country's 16th cash crop. This has tremendously raised its profile with many stakeholders, demonstrating hitherto unimaginable interest in the planting of bamboo as a commercial crop. However, despite the presence of about 22 bamboo species for close to three decades in Kenya and gassetting the same as a cash crop, the introductions have been uncoordinated. As a result, the country lacks information about the geographic locations of most introduced species, their suitability to the eco-climatic sites where they have been planted, and their growth performance and yields. This information gap has hindered the widespread adoption of exotic bamboo species, resulting in an inadequate supply of quality planting materials, inadequate know-how about bamboo propagation and management practices, weak marketing systems, and limited information and decision-making tools. The information gap has also hampered the country's ability to estimate the existing bamboo resource base and its potential to contribute to environmental resilience and economic development. It is important to have accurate information on the growth performance, yields, and commercial uses of all

bamboo species planted in different agro-ecological zones (AEZs) in Kenya. This information is essential in assisting bamboo growers, prospective investors, and entrepreneurs in the bamboo sector to accurately project expected returns on investment with a high level of certainty. Thus, this report is not only timely but also highly appropriate in raising the confidence necessary for the widespread adoption of bamboo as a commercial crop in the country.

1.1 Scope of the study

This report outlines the results of a bamboo species–site suitability matching assessment in different AEZs in Kenya, which was carried out in November and December 2020 with the support of the INBAR under the Dutch–Sino–East Africa Bamboo Development Programme (Phase II). Kenya is one of the countries in East Africa where bamboo planting has been promoted for close to three decades now. The assessment was aimed at providing an outlook of the performance of the planted bamboo species in different AEZs in the country. The information was intended to put into perspective the growth performance of the planted bamboo species in Kenya by comparing their performance with that of their native ranges.

Thus, the report captures the origin of bamboo species that are planted on a trial basis or, to some extent, commercially in Kenya, their growth performance in their native ranges, their performance in different AEZs in the country, the reported insect pests and diseases of bamboo in their native ranges, and their potential for ecological and socio-economic utilization in different parts of the country. The findings of the report inform strategies for enhancing bamboo production to improve the environmental resilience and socio-economic well-being of bamboo growers and entrepreneurs in Kenya.

1.2 Objectives of the study

The objectives of this bamboo species–site suitability study were as follows:

1. Undertake a desk review and consult with bamboo sector stakeholders to identify the planting locations of both introduced and indigenous bamboo species
2. Conduct a literature review of the growth performance of both indigenous and introduced bamboo species in their native ranges and introduced landscapes

- a) Undertake site visits to ex-situ conservation sites / research plots / smallholder and large-scale plantation sites to collect data on (i) site parameters and (ii) species identification parameters (primarily culm characteristics, e.g., culm size, spacing, and internode lengths; branching patterns and shapes of culm sheaths; and shoots, nodes, and canopy structures)
3. Document the growth parameters of different bamboo species in different AEZs in Kenya
4. Record the parameters at different culm positions, straightness, and biomass accumulation
5. Analyze the growth performance of bamboo species in different AEZs to examine their relationships with eco-climatic conditions
6. Match bamboo species to suitable AEZs, with a focus on identifying agro-climatic clusters and preparing a list of potential bamboo species for planting in each AEZ
7. Conduct a review, analysis, and identification of bamboo products that are being produced and/or shortlisted for production in the medium and long terms, as well as a matching of the species and sites to end uses
8. Shortlist and narrow down the suitable bamboo species for plantation establishment, in collaboration with resource and technology experts

1.2.1. Expected output

The expected output of the study was a comprehensive report in publishable format covering the following aspects:

- a) Growth performance of indigenous and introduced bamboo species in different AEZs in Kenya
- b) A bamboo species identification guide
- c) A technical guide to support plantation expansion based on species–site matching to end uses
- d) Recommendations to guide bamboo development in the country

1.3 Significance of the study

The gazettement of bamboo as a cash crop has elicited significant interest in bamboo growing in Kenya, especially among bamboo growers and entrepreneurs. However, most of them are

hesitant about which bamboo species to plant in different AEZs, as well as the end uses of bamboo. Many actors are also unclear about the expected returns on investment and specific uses of different bamboo species. The results of this study provide highly important information that serves as a guide to various actors in bamboo value chains regarding the growth performance and expected yields of different bamboo species in different AEZs and the commercial utilization of bamboo in Kenya. The information also serves as an important decision-making tool for bamboo development in Kenya.

2. Origin and growth of native species

This chapter presents a review of the literature on the origin and growth performance of both indigenous and introduced bamboo species within their native ranges.

2.1 Native species growth performance

2.1.1. *Oldeania alpina*

Oldeania alpina (syn. *Y. alpina*) is a native bamboo species in Kenya. It is mainly found in the mountain ranges in Mt. Kenya, Aberdares, Mau escarpment, Cherangani Hills, and Mt. Elgon at elevations of 2,300–3,200 m a.s.l. (Muchiri and Muga, 2013). It grows in single clumps, attaining a mean culm height of 10 m and a diameter at breast height (DBH) of 7.5 cm (Table 1). It has a mean culm stocking density of 19,000–21,000 culms ha⁻¹. This bamboo species is estimated to yield 92–100 t/ha (approximately 9.6 kg dry weight [DW] / culm). It is mainly used for construction and residential fencing. It is also used for making handicrafts, furniture, baskets, toothpicks, and matchsticks.

Table 1. A summary of the growth performance of *O. alpina* in its natural range

Species	<i>Oldeania alpina</i> (syn. <i>Yushania alpina</i>)
Origin	Kenya
Stocking density	19,000–21,000 culms ha ⁻¹
Mean height	10 m
DBH	7.5 cm
Yield	92–100 t/ha

2.2 Exotic species growth performance

2.2.1. *Thyrsostachys siamensis gamble*

Thyrsostachys siamensis is commonly known as monastery bamboo, Thai bamboo, or umbrella bamboo. It is a tropical medium-size bamboo species that originates from China, Laos, Myanmar, Thailand, and Viet Nam. It grows to 5–10 m in culm height and 6 cm in DBH (Table 2). It thrives in river valleys and hilly forested areas at elevations of 500–1,000 m a.s.l. (Banik, 2016). The culms are erect and bright green when young, but they turn yellowish brown upon

maturity, with thick walls (semi-solid stem) and prominent nodes. It is cylindrical and has a triangular blade (Mohamed, 2000). It grows best in areas where the annual temperatures are within 20°C–29°C and the mean annual rainfall is 1,000–2,000 mm. It prefers a soil pH of 6–6.5. Its optimum planting distance is 4 m × 4 m. The culm internodes are thick walled and almost solid near the base but hollow from the middle toward the top. The internodes range from 15 cm to 30 cm long and are separated by slightly thickened prominent nodes, and they have white rings below the nodes. Lower nodes are covered with a circle of rootlets when young, with fine golden-brown hair. The species produces edible shoots. It is also a strong construction-grade bamboo and is suitable for ornamental use in narrow areas that require screening. It is found naturally in dry or semi-evergreen forests with pronounced monsoon climates and poor soils. However, it grows in a wide range of soils, provided they are not waterlogged.



Figure 1. A *Thyrsostachys siamensis* clump

Thyrsostachys siamensis culms are used in house construction, furniture making, and the cottage industries, and they also have general household uses. They are made into chopsticks, broomsticks, handicrafts, fishing rods, paper pulp, and fuel. The species is often used to produce umbrella handles for high-ranking people, as well as for monks and priests. Young shoots are consumed as vegetables and are considered among the best edible bamboo shoots. Because of its elegant appearance, this species is a popular ornamental plant by Buddhist monks around temples. It is also planted in rows as live fences and windbreaks.

Table 2. A summary of the growth performance of *T. siamensis* in its natural range

Species	<i>Thyrsostachys siamensis</i>
Origin	China, Laos, Myanmar, Thailand, and Viet Nam
Stocking density	6,000 culms ha ⁻¹
Mean height	7–13 m
DBH	2–6 cm
Annual yield	1.5 t/ha/yr
Wall thickness	60 mm
Internode length	15–30 cm

2.2.2. *Phyllostachys aurea* A. Rivière & C. Rivière

Phyllostachys aurea A. Rivière & C. Rivière is a running type of bamboo, which is commonly referred to as fish pole bamboo, golden bamboo, monk's belly bamboo, and fairyland bamboo. It is native to China and Viet Nam. Its culms are thin walled and grow to 2–8 m long and 2–3 cm wide (Table 3), with an internode length of 8–10 cm (Borowski et al., 1996). The species has compressed internodes in the lower part of the canes, which have a tortoise shell-like appearance. The canes turn yellow in full or partial sun, and they deepen into a gold-orange color as the plant matures (Mulatu et al., 2016). This species is reported to be invasive, suffocates native plants, and may alter the landscape. It is known to grow at an altitude range of 1,000–2,000 m in China (Dransfield and Widjaja, 1995).

**Figure 2.** A stand of *Phyllostachys aurea*

The species produces young shoots, which can be cooked or eaten raw with little bitterness. It is also a popular garden ornamental, as it is used as a hedge. Its basal culm parts are irregularly

shortened and swollen, which are used and sold as walking sticks, umbrella and fan handles, and various other souvenirs. The straight upper culm parts make excellent plant supports and are used as fishing rods, ski poles, and javelins, as well as for furniture making and construction.

Table 3. A summary of the growth performance of *P. aurea* in its natural range

Species	<i>Phyllostachys aurea</i>
Origin	China and Viet Nam
Stocking density	38,017 culms ha ⁻¹
Mean height	2–8 m
DBH	2–3 cm
Internode length	8–10 cm
Yield	67.78t/ha

2.2.3. *Oxytenanthera abyssinica* (A. Rich.) Munro

This is an African lowland bamboo that grows at elevations of 50–1,500 m a.s.l. (Bystriakova, Kapos and Lysenko, 2004). It has a mean clumping density of 20–100 culms, which could be erect, ascending, or leaning outward. It grows to a height of 5–10 m, a DBH of 3–8 cm, and an internode length of 15–30 cm in its natural range (Table 4). Its basal internodes are solid, while its distal ones are thick walled. Its young shoots are gray-green, with dense, silky, and hairy stems, while its mature shoots are glabrous (smooth) (Embaye et al., 2003). It is found in Ethiopia and extends westward to Senegal and southward to Zimbabwe. It is the hardiest of the three African bamboos (including the African alpine bamboo, *O. alpina*).

Its uses include building poles, furniture, water pipes, arrow shafts, walking sticks, fodder (leaves), baskets, and fencing materials. It is traditionally used for basket weaving, construction, and furniture making. In the southern highlands of Tanzania in the Iringa, Mbeya, and Ruvuma regions, it is tapped for its juice and fermented for the production of a local alcoholic beverage.



Figure 3. *Oxytenanthera abyssinica* clumps

Table 4. A summary of the growth performance of *O. abyssinica* in its natural range

Species	<i>Oxytenanthera abyssinica</i>
Origin	Africa
Stocking density	4,374 culms ha ⁻¹
Mean height	5–10 m
DBH	3–8 cm
Internode length	15–30 cm
Yield	13.63t/ha

2.2.4. *Dendrocalamus strictus* (Roxb.) Nees

This bamboo species is native to India, Laos, Myanmar, Nepal, Pakistan, Thailand, and Viet Nam. It is commonly known as male bamboo, solid bamboo, or Calcutta bamboo. It grows from sea level up to 1,200 m (Kumar et al., 2001). It is a medium-sized bamboo that reaches a height of 8–20 m and a diameter of 2.5–8 cm. Its internodes are 30–45 cm long (Table 5). Its culms are solid when growing under dry conditions and semi-solid when growing under humid conditions. The species has green culms covered with white blooms, and these culms become dull green upon maturity and turn brown upon drying (Mahajan and Nishant, 2006). Its young stems are cooked as vegetables. It is suitable for scaffolding, bridges, poles, agricultural implements, and other large bamboo implements. Its stems can be split and used to make items, such as walking sticks, furniture, and baskets.

Table 5. A summary of the growth performance of *D. strictus* in its natural range

Species	<i>Dendrocalamus strictus</i>
Origin	India, Laos, Myanmar, Nepal, Pakistan, Thailand, and Viet Nam
Stocking density	1,777 culms ha ⁻¹
Mean height	8–20 m
DBH	2.5–8 cm
Internode length	30–45 cm
Yield	50.3 t/ha
Age	5 yr

2.2.5. *Dendrocalamus membranaceus* Munro

Dendrocalamus membranaceus is a native of China, Laos, Myanmar, Taiwan, and Thailand. It is commonly known as white bamboo. It grows below 1,000 m in altitude. The culms are straight and usually grow 20–24 m tall and 6–10 cm wide. Internodes are 22–38 cm long (Table 6) and covered with a white powdery deciduous scurf when young, but they are green upon maturity. Its nodes are strongly ringed, and basal nodes show rootlets (Yang et al., 2012).

Table 6. A summary of the growth performance of *D. membranaceus* in its natural range

Species	<i>Dendrocalamus membranaceus</i>
Origin	China, Laos, Myanmar, Taiwan, and Thailand
Mean height	20–24 m
DBH	6–10 cm
Internode length	22–38 cm

**Figure 4.** A *Dendrocalamus membranaceus* stand

It is used to make bamboo boards, agricultural implements, slat traps, matting, chopsticks, baskets, handicrafts, and props for fruit trees, as well as for construction and furniture making. It is also one of the most promising species for pulp. Its shoots are edible and consumed as vegetables.

2.2.6. *Dendrocalamus hamiltonii* Nees & Arn. Ex Munro

Dendrocalamus hamiltonii is a native of China, India, Laos, Myanmar, Thailand, and Viet Nam. It is commonly known as tama bamboo and grows at elevations of up to 1,000 m a.s.l. (Farrelly, 1984). It is an evergreen clump-forming bamboo with woody culms that are often very pendulous and can grow 12–25 m tall. The culms are 9–20 cm in diameter at the base, with internodes that are 30–50 cm apart and walls that are 12–20 mm thick (Table 7). The culms are dull green and covered with whitish-brown hair, which becomes dull brownish-green when dry.



Figure 5. A *Dendrocalamus hamiltonii* clump

Its young shoots are widely consumed as vegetables. It is also grown as windbreaks in tea plantations. The culms are used for construction (houses and bridges) and for making various household utensils, such as water containers. Split culms are used to make baskets and mats.

Table 7. A summary of the growth performance of *D. hamiltonii* in its natural range

Species	<i>Dendrocalamus hamiltonii</i>
Origin	China, India, Laos, Myanmar, Thailand, and Viet Nam
Stocking density	2,755 culms ha ⁻¹
Mean height	12–25 m
DBH	9–20 cm

Internode length	30–50 cm
Wall thickness	1.2–2.0 cm

2.2.7. *Dendrocalamus giganteus* Munro

Dendrocalamus giganteus is commonly known as giant bamboo. It grows at elevations of up to 1,200 m and is one of the largest and densest clumping bamboo species that is native to Bhutan, China, Myanmar, and Thailand. Its culms typically reach a height of 30 m and have diameters of 10–35 cm and internode lengths of 25–40 cm (Table 8). The culms are straight, thick walled, and grayish green with a powdery appearance. Young shoots are blackish purple in color. The culm sheath is greenish when young and becomes dark brown when mature (Thompson, 2011). It is considered the tallest bamboo in the world.

Table 8. A summary of the growth performance of *D. giganteus* in its natural range

Species	<i>Dendrocalamus giganteus</i>
Origin	Bhutan, China, Myanmar, and Thailand
Mean height	25–35 m
DBH	10–35 cm
Internode length	35–40 cm
Wall thickness	2.0–2.5 cm
Annual yield	20–30 t/ha/yr



Figure 6. A *Dendrocalamus giganteus* clump

Dendrocalamus giganteus is very good for construction and paper production, while its young shoots are consumed as vegetables. Its culms are also used as scaffolding, boat masts, water pipes, vases, buckets, water pitchers, matting, boards, furniture, and water pots. Culm sheaths are used to make hats.

2.2.8. *Dendrocalamus brandisii* (Munro) Kurz

Dendrocalamus brandisii is also known as Velvet Leaf Bamboo, Teddy Bear Bamboo, and Sweet Dragon Bamboo. It is native to China, India, Laos, Myanmar, Thailand, and Viet Nam. It is an evergreen clump-forming bamboo with erect culms that are 19–33 m tall and 13–20 cm wide. It has a wall thickness of 2.5–5.0 cm and an internode length of 30–38 cm (Table 9) (Seethalakshmi et al., 1998). It grows well up to 1,300 m in altitude.

Table 9. A summary of the growth performance of *D. brandisii* in its natural range

Species	<i>Dendrocalamus brandisii</i>
Origin	China, India, Laos, Myanmar, Thailand, and Viet Nam
Mean height	19–33 m
DBH	13–20 cm
Internode length	30–38 cm
Wall thickness	2.5–5.0 cm

It is used for construction and for making boat masts, furniture, farm implements, water pots, baskets, handicrafts, and paper. Shoots are edible and consumed as vegetables.

2.2.9. *Dendrocalamus birmanicus* A.Camus

Dendrocalamus birmanicus is a giant bamboo from China and Myanmar. It is a relatively small-sized species of the genus *Dendrocalamus* with erect culms. It grows to a height of 10 m and a diameter of 8 cm (Table 10).

Table 10. A summary of the growth performance of *D. birmanicus* in its natural range

Species	<i>Dendrocalamus birmanicus</i>
Origin	China and Myanmar
Mean height	10 m
DBH	8 cm

**Figure 7.** A *Dendrocalamus birmanicus* culm

2.2.10. *Dendrocalamus asper* (Schult.) Backer

This bamboo species is native to Bangladesh, China, Malaysia, Myanmar, the Philippines, Taiwan, Thailand, and Viet Nam. It is an evergreen clumping bamboo with a short, thick rhizome and densely tufted, erect stems that can reach a height of 15–30 m and a diameter of 8–20 cm, with an internode length of 40–50 cm and a wall thickness of 1.1–2 cm (Table 11) (Malanit, 2009). It grows from low elevations up to 1,500 m, although it grows best at elevations of 400–500 m. It also grows optimally in areas where the annual daytime temperatures are within the range of 20°C–27°C, but it can tolerate 15°C–34°C. It prefers a mean annual rainfall in the range of 1,800–3,600 mm, but it can tolerate 1,200–4,500 mm (Aguinsatan et al., 2019). It is used as building materials for heavy construction, while its shoots are consumed as vegetables.



Figure 8. A *Dendrocalamus asper* stand

Table 11. A summary of the growth performance of *D. asper* in its natural range

Species	<i>Dendrocalamus asper</i>
Origin	Bangladesh, China, Malaysia, Myanmar, the Philippines, Taiwan, Thailand, and Viet Nam
Stocking density	2,666 culms ha ⁻¹
Mean height	15–30 m
DBH	8–20 cm
Internode length	40–50 cm
Wall thickness	1.1–2.0 cm

2.2.11. *Bambusa vulgaris* var. *vulgaris* Schrad

Bambusa vulgaris var. *vulgaris* is a native of Southeast Asia, particularly the Indochina region. It is one of the most common bamboo species worldwide. It is an erect, evergreen, clump-forming bamboo that grows 10–20 m tall (Wahab et al., 2009), with thin-walled, hollow stems that have a diameter of 4–12 cm, a wall thickness of 0.7–1.5 cm, and an internode length of 20–45 cm (Table 12) (Darwis and Iswanto, 2018). It performs well up to an elevation of 1,200 m a.s.l., but its culms become progressively shorter and thinner as the altitude increases beyond 1,000 m. It grows best in areas where the daytime temperatures are within the range of 22°C–28°C, but it can very well tolerate 9°C–32°C (Amoah et al., 2020). It prefers a mean annual rainfall in the range of 1,200–2,500 mm, but it can tolerate a little less or a little more rainfall. Its stems are not easy to split.

It thrives in a wide range of moisture and soil conditions, but it performs better in permanently humid conditions, such as areas along river banks and lake shores. It also grows in areas with severe dry seasons, where the plants become completely defoliated. In Peninsular Malaysia, it has been noted to grow well in degraded soils containing tin. It produces approximately 2,250 culms ha⁻¹, which translates to an annual yield of 20 t DW/ha. The DW ratios for its culms, branches, and leaves are about 70%, 22%, and 8%, respectively.



Figure 9. A *Bambusa vulgaris* var. *vulgaris* stand

The species is commonly used as fuel and fodder. Its poor stem form and poor working properties (not straight, not easy to split, and not flexible) limit its use in the construction industry. It has a high carbohydrate content, which makes its stems susceptible to attacks by fungi and insects.

Table 12. A summary of the growth performance of *B. vulgaris* var. *vulgaris* in its natural range

Species	<i>Bambusa vulgaris</i> var. <i>vulgaris</i>
Origin	Southeast Asia – Indochina
Stocking density	2,250 culms ha ⁻¹
Mean height	10–20 m
DBH	4–12 cm
Internode length	20–45 cm
Wall thickness	0.7–1.5 cm
Yield	57 t/ha
Age	5 yr
Annual yield	20 t DW/ha

2.2.12. *Bambusa vulgaris* var. *vittata* Rivière & C. Rivière

Bambusa vulgaris var. *vittata* (syn. *Bambusa striata*) is a tropical and sub-tropical clumping bamboo that is native to China and Japan. It is commonly known as painted bamboo. It is one of the most cultivated ornamental bamboos in the tropical world (Liana et al., 2017). The glossy culms of *B. vulgaris* var. *vittata* are bright yellow and randomly marked with narrow and broad green stripes (or rarely light green with yellow stripes). The species has an average height of 10–15 m. The internodes are 10–15 cm long, with an average diameter of 5–8 cm (Table 13). The type of striping on the culms is known to vary across culms within a clump or even within an individual culm (Setiawati et al., 2017). This bamboo species performs well at altitudes of 1,000 m and below (Peprah et al., 2014).



Figure 10. A *Bambusa vulgaris* var. *vittata* stand

Bambusa vulgaris var. *vittata* (syn. *Bambusa striata*) is mostly planted as ornamental bamboo and is used as hedges and for erosion control. Its culms are used as poles in light construction or furniture work. In some parts of the world, it is used to make baskets or TV antenna posts.

Table 13. A summary of the growth performance of *B. vulgaris* var. *vittata* in its natural range

Species	<i>Bambusa vulgaris</i> var. <i>vittata</i>
Origin	China and Japan
Mean height	10–15 m
DBH	5–8 cm
Internode length	10–15 cm

2.2.13. *Bambusa tulda* Roxb

Bambusa tulda Roxb. is a native of China and India. It is commonly known as Indian timber bamboo, spineless Indian bamboo, or Bengal bamboo. It is an evergreen or deciduous clump-forming bamboo with stems 6–20 m tall. Its thin-walled canes are about 5–10 cm in diameter, with an internode length of 36–60 cm and a wall thickness of 1–2.5 cm (Table 14) (Bhattacharya et al., 2006). In its native range, it is found in mixed deciduous forests in plains and valleys and along streams up to elevations of 1,500 m. It grows best in areas where the daytime temperatures are within the range of 22°C –28°C, but it can tolerate 9°C –32°C. It prefers a mean annual rainfall of 1,200–2,500 mm and grows best in fertile, medium-to-heavy soils. It prefers a pH range of 5–6, but it can tolerate 4.5–6.5 (Jha, 2010). It produces an annual yield of about 3 t/ha. It is used extensively by the paper pulp industry in India. Its near-solid culms make very strong timber.



Figure 11. A *Bambusa tulda* clump

Table 14. A summary of the growth performance of *B. tulda* in its natural range

Species	<i>Bambusa tulda</i> Roxb
Origin	China and India
Stocking density	5,244 culms ha ⁻¹
Mean height	6–20 m
DBH	5–10 cm
Internode length	36–60 cm

Wall thickness	1–2.5 cm
Yield	39.1 t/ha
Age	5 yr
Annual yield	3 t/ha

2.2.14. *Bambusa multiplex* (Lour.) Raeusch. ex Schult

Bambusa multiplex (Lour.) Raeusch. ex Schult. is a clumping dwarf bamboo commonly referred to as hedge bamboo. It is a native of China and India (Chen, 2020). It is an evergreen bamboo producing erect yellow/green striped culms with a length of 2–7 m and a diameter of 1–3 cm (Table 15), with an internode length of 20–40 cm (Kawasaki et al., 2017). It grows well at elevations of 200–1,500 m a.s.l.



Figure 12. A *Bambusa multiplex* clump

This species makes excellent hedges and windbreaks and is a common ornamental in gardens. The culms are also used as umbrella handles and fishing poles. In Indonesia and Thailand, it is used for making handicrafts, such as bookcases. Several dwarf cultivars are attractive pot plants.

Table 15. A summary of the growth performance of *B. multiplex* in its natural range

Species	<i>Bambusa multiplex</i> (Lour.) Raeusch. ex Schult
Origin	China and India
Mean height	2–7 m
DBH	1–3 cm
Internode length	20–40 cm

2.2.15. *Bambusa blumeana* Schult.f.

Bambusa blumeana Schult.f. is an evergreen, clumping, spiny bamboo that forms a densely interlocking thicket. It is native to Indonesia and Malaysia. It grows to a height of 15–25 m and has a diameter of 8–15 cm, a wall thickness of 2–3 cm, and an internode length of 25–60 cm. It grows well at an elevation of 300 m a.s.l., but it can grow in areas slightly above 1,000 m a.s.l. (Dierick et al., 2010). It also grows in heavy or poor soils and can tolerate flooding. The species prefers a pH of 5–6.5. It does not grow well in heavy saline soils. It produces a DW of about 143 t/ha (120 t for culms, 18 t for branches, and 5 t for leaves) (Table 16).

Its young shoots are eaten as vegetables, usually boiled and shredded. The culms are used for construction and for making baskets, furniture, parquets, concrete reinforcements, kitchen utensils, chopsticks, hats, and toys. Its culms are also used as firewood. The species is often planted along water courses to prevent soil erosion. It is also planted around farmhouses as windbreaks and in fields as live fences or boundary markers.

Table 16. A summary of the growth performance of *B. blumeana* in its natural range

Species	<i>Bambusa blumeana</i> Schult.f
Origin	China and India
Mean height	15–25 m
DBH	8–15 cm
Internode length	25–60 cm
Wall thickness	2–3 cm
Yield	143 t DW/ha

2.2.16. *Bambusa bambos* (L.) Voss

Bambusa bambos (syn. *Bambusa arundinacea*) is a dense clumping bamboo that is native to Bangladesh, China, India, Laos, Myanmar, Pakistan, Sri Lanka, Thailand, and Viet Nam. It was previously named *B. arundinacea*. Its common name is giant thorny bamboo or Indian thorny bamboo. In India, the species occupies 15% of all bamboo forests.

It is fast growing, with strong woody culms that average 20–30 m in height (the tallest recorded culm was measured at 40 m) and 10–18 cm in diameter. It has an internode length of 20–40

cm. The culms are dark green in color and have very thick walls. The nodes are slightly swollen, with some lower ones producing short aerial roots (Sharma and Nirmala, 2015). Nodes contain a central dominant branch with one or two lateral branches and are often spine like. Thorny lower branches are long and wiry, and they are usually bent toward the ground. The upper leafy branches produce a fan-like plume and bear small spines (Banik, 2015). This species grows best in moist, deciduous forests up to an altitude of 1,250 m and with an annual rainfall of 2,000–2,500 mm (Benton, 2015). It produces about 5,000–8,000 culms ha⁻¹. Its culms yield an average DW of 5 t/ha/yr (Table 17).



Figure 13. A *Bambusa bambos* clump

Bambusa bambos (syn. *Bambusa arundinaceae*) is a multipurpose bamboo species with uses ranging from edible shoots (vegetables) and leaves (forage) to valuable culms for household use and basic construction. It is often planted as a windbreak around farms and along rivers to prevent floods. In rural areas, its culms are used in cottage floors and roofs. These culms are among the best and strongest for house construction, scaffolding, thatching and roofing, furniture making, and basket making, and they can be made into rafters, handicrafts and art objects, bows and arrows, cooking utensils, and fences. The culms are also important raw materials for the paper pulp and plywood industries. The richly and uniformly branched culms are used as ladders. An infusion of the leaves serves as an eyewash and a cure for bronchitis, gonorrhoea, and fever.

Table 17. A summary of the growth performance of *B. bambos* in its natural range

Species	<i>Bambusa bambos</i>
Origin	Bangladesh, China, India, Laos, Myanmar, Pakistan, Sri Lanka, Thailand, and Viet Nam
Stocking density	5,000–8,000 culms ha ⁻¹
Mean height	20–30 m
DBH	10–18 cm
Internode length	20–40 cm
Wall thickness	2–3 cm
Annual yield	5 t DW/ha/yr

3. Materials and methods

This chapter outlines the sites or locations where planted bamboo was assessed in different AEZs in Kenya, as well as the methods used to estimate their growth performance and yield.

3.1 Study sites

The assessments were conducted at 12 sites where both indigenous and exotic bamboo species were planted. The sites were clustered into nine counties representing nine AEZs. These counties were Migori, Busia, and Kakamega in western Kenya; Nyeri, Muranga, and Kiambu in the central highlands of Kenya; Makueni in the semi-arid eastern zone; and Kilifi and Kwale in the coastal lowlands (Table 18).

Table 18. Areas where bamboo species–site suitability assessments were conducted

Site	County	AEZ	Elevation (m)	Annual mean temp (°C)	Annual rainfall (mm)
I. Central highlands					
Limuru tea estates	Kiambu	LH1	2,085	16	1,067
KEFRI-Muguga	Kiambu	LH3	2,070	15.9	954
Ndakaini	Murang'a	UM1	2,056	18	1,800
Kairi-ini	Murang'a	UM1	2,042	19	1,600
Kagumo Gardens	Nyeri	UM2	1,757	18	933
II. Western Kenya					
Isecheno	Kakamega	UM1	1,633	20.5	2,100
Kehancha	Migori	LM2	1,504	21.7	1,400
Busia Town	Busia	LM1	1,227	22.2	1,600
III. Semi-arid eastern Kenya					
KEFRI-Kibwezi	Kibwezi	LM5	945	22.6	659

IV. Coastal lowlands					
Mivumoni	Kwale	CL2	66	27	1,386
Jilore	Kilifi	CL4	85	27	927
Gede	Kilifi	CL4	25	27	1,059

Areas were listed from the highest to lowest elevations to illustrate the variations in AEZs:

- LH = Lower highland zone (LH1 – tea and dairy zone; LH3 – wheat, maize, and barley zone)
- UM = Upper midland zone (UM1 [humid] – tea and coffee zone; UM2 [sub-humid] – mainly coffee zone)
- LM = Lower midland zone (LM1 [humid] – sugarcane zone; LM2 [sub-humid] – marginal sugarcane zone; LM5 – semi-arid livestock and millet zone)
- CL = Coastal lowland zone (CL2 – marginal sugarcane zone; CL4 – cashew nut and cassava zone).

An assessment in Penon in Kaptagat, Elgeyo-Marakwet County, was also planned, but this did not materialize. The bamboo there, which was planted in the early 1990s, was harvested when the plantation area was transformed into a human settlement. The location of each of the 12 bamboo plantation sites is illustrated in Figure 1.

measured for length, DBH, internode length, and wall thickness. The sampled culms were analyzed for signs of disease or pest infestation.

Soil samples were collected to assist in characterizing specific site conditions, particularly with regard to soil chemical and physical properties. The samples were randomly obtained under different clumps of bamboo species. The soils were collected at 0–30 cm depth using a soil auger, and bulked to come up with approximately 500 g of representative samples. The Munsell soil color chart was used to identify the color of soil in the field. The soil samples were packed in tightly closed plastic containers and transported to the Kenya Forestry Research Institute (KEFRI) soil laboratory for physical and chemical analyses. In the laboratory, the soil samples were air dried for three days to remove excess moisture, homogenized using pestle and mortar for grinding, sieved using a 2 mm sieve to remove plant litter and stones, and hereafter given a laboratory working number. Physical analysis focused on soil moisture, bulk density, and soil texture, while chemical analysis focused on pH, electroconductivity, and levels of nitrogen, phosphorus, and potassium. These analyses were conducted using standard laboratory procedures, as described by Okalebo et al. (2002).

Ten insect pests observed onsite were collected in vials and ferried to the KEFRI insect reference collection for identification through microscopy. The types of damages to the bamboo culms were recorded. Disease infestations manifested on foliage and culms were indicated. Labels contained details of the bamboo species, county, clump number, number of affected culms, and date of assessment. The disease severity rating, ranging from low (L) to severe (S), was also recorded.

3.4 Bamboo biomass determination

The sampled culms were cut into small pieces, packed in gunny bags, labeled, and weighed using a suspension balance to determine the fresh weight of each culm. Labels contained details of the bamboo species, county, planting site, clump and culm numbers, date of assessment, and fresh weight. The samples were transported to the laboratory for drying to determine their DWs. The bamboo culms were dried in an oven at 72°C for 36 hr. This was followed by weighing

the culms using a suspension balance to determine their DWs. Drying was done at KEFRI laboratories located nearest to the bamboo planting sites.

3.5 Data analysis

Data on clump radius, culm density, culm length, culm DBH, internode length, and wall thickness were entered into Microsoft Excel and thereafter transferred to Genstat statistical software (version 21). Analysis was done using ANOVA, which entailed assessing the variation in growth performance for each bamboo species across planting sites at a 5% significance level. Post hoc tests were carried out to separate means using the Ryan–Einot–Gabriel–Welsch Multiple Range Test at a 5% significance level (Krull and Craft, 2009; Sokal and Rohlf, 2012; Holt et al., 2013).

3.6 Development of a bamboo species identification guide

This guide was developed using the morphological relationships between the encountered bamboo species. The morphology characteristics considered were culm size, culm color, internode length, nodal characteristics, bamboo spines, leaves, and culm sheath characteristics.

4. Results

This section presents the results of the bamboo species–site suitability assessment. The results include soil properties across sites, the planted bamboo species in Kenya, a morphological identification guide of bamboo species encountered during the survey, the growth performance of bamboo species planted in Kenya, the growth yield of bamboo species planted in different AEZs, and a comparison of the results of each species against its growth performance and yield in its native zone, the uses of each bamboo species, and the identified insect pests and diseases of bamboo in its native range.

4.1 Soil properties across sites

4.1.1. Soil pH

The soil pH in the 12 bamboo planting sites varied significantly ($F_{(1,11)} = 13.92$; $p < 0.001$). Post hoc tests indicated that the variation was caused by the four different soil pH categories of the sites (Table 19).

Table 19. Variations in soil pH across AEZs

Bamboo planting site	AEZ	Soil pH category	pH level
Ndakaini	UM1	Strongly acidic (pH 5.1–5.5)	5.465 ± 0.1102 ^{ab}
Muvumoni	CL2		5.387 ± 0.06 ^{ab}
Kairi-ini	UM1		5.055 ± 0.3134 ^a
Busia	LM1	Moderate acidic (pH 5.6–6.0)	5.916 ± 0.192 ^{abcd}
Kakamega	UM1		5.852 ± 0.048 ^{abcd}
Jilore	CL4		5.705 ± 0.154 ^{abc}
Limuru	LH1		5.517 ± 0.2139 ^{ab}
Kagumo Gardens	UM2	Slightly acidic (pH 6.1–6.5)	6.173 ± 0.1783 ^{bcd}
Kibwezi	LM5	Neutral soil (pH 6.6–7.3)	6.49 ± 0.3075 ^{cd}
Kehancha	LM2		6.674 ± 0.0553 ^d
Gede	CL4		6.608 ± 0.008 ^d
Muguga	LH3		6.546 ± 0.0426 ^d

		$F_{(1,11)} = 13.92; p < 0.001$
		<i>l.s.d.</i> = 0.486

LH = Lower highland zone

UM = Upper midland zone – UM1 (humid) and UM2 (sub-humid)

LM = Lower midland zone – LM1 (humid) and LM2 (sub-humid)

CL = Coastal lowland zone – CL2 (humid) and CL4 (sub-humid)

4.1.2. Bulk density

The 12 bamboo sites recorded significantly different soil bulk densities ($F_{(1,11)} = 13.92; p < 0.001$). The lowest bulk density (0.61 ± 0.01) was recorded in Kakamega (UM1), while the highest (1.63 ± 0.01) was reported in Gede (CL4) (Table 20). It is worth noting that sandy soils tended to have higher bulk densities than clay soils.

Table 20. Variations in soil bulk density across AEZs

Bamboo site	AEZ	Bulk density (g/cm ³)
Kakamega	UM1	0.61 ± 0.01038^a
Kairi-ini	UM1	0.751 ± 0.028^{ab}
Limuru	LH1	0.806 ± 0.02167^{abc}
Muguga	LH3	0.861 ± 0.0877^{abc}
Kagumo Gardens	UM2	0.901 ± 0.06447^{abcd}
Ndakaini	UM1	$0.975 \pm 0.03872^{abcde}$
Kehancha	LM2	$1.032 \pm 0.05557^{abcde}$
Busia	LM1	$1.035 \pm 0.16591^{abcdef}$
Jilore	CL4	1.202 ± 0.03485^{bdef}
Kibwezi	LM5	$1.227 \pm 0.01036^{abcdef}$
Muvumoni	CL2	1.513 ± 0.07422^{ef}
Gede	CL4	1.632 ± 0.01198^f
		$F_{(1,11)} = 8.26; p < 0.001$
		<i>l.s.d.</i> = 0.2806

Source: Field survey data; November 2020

4.1.3. Soil texture

There were significant variations in soil texture across the 12 sites, as exemplified by the proportions of sand, clay, and silt. The proportion of sand varied across the bamboo planting sites ($F_{(1,11)} = 24.94$; $p < 0.001$). Kagumo Gardens had the lowest proportion of sand (8 ± 1.16 %), while Gede had the highest (87 ± 1 %). Similarly, the proportion of clay varied significantly across the 12 sites, with Gede having the lowest proportion ($8.5 \pm 0.5\%$) and Kagumo having the highest (83.33 ± 3.333 %) ($F_{(1,11)} = 17.40$; $p < 0.001$). The proportion of silt also varied significantly across the sites ($F_{(1,11)} = 8.15$; $p < 0.001$). Gede had the lowest proportion ($5 \pm 1\%$), whereas Muguga had the highest (40 ± 1.265) (Table 21).

Table 21. Variations in soil texture across AEZs

Bamboo site	AEZ	% Sand	% Clay	% Silt
Limuru	LH1	22.4 ± 1.939 ^{ab}	54.4 ± 3.709 ^{ce}	23.2 ± 4.499 ^{abcdeh}
Kairi-ini	UM1	22.67 ± 1.764 ^{ab}	54.67 ± 5.333 ^{ce}	22.67 ± 6.766 ^{abcde}
Muguga	LH3	27.2 ± 1.583 ^{ab}	32.8 ± 1.34 ^{abcd}	40 ± 1.265 ^d
Ndakaini	UM1	28 ± 2 ^{ab}	48 ± 6.11 ^{bcde}	24 ± 4.163 ^{abcdeh}
Busia	LM1	30 ± 0 ^{ab}	34 ± 10 ^{abcde}	36 ± 10 ^{cdefh}
Kibwezi	LM5	39 ± 11 ^{bc}	30 ± 10 ^{abc}	31 ± 1 ^{abcdeh}
Kakamega	UM1	43 ± 1 ^{bc}	23 ± 1 ^{ab}	33.5 ± 0.5 ^{acdeh}
Kehancha	LM2	57.67 ± 2.603 ^{cd}	21.67 ± 4.631 ^a	20.33 ± 4.24 ^{abcde}
Muvumoni	CL2	65 ± 23 ^{cde}	23 ± 15 ^{ab}	17 ± 13 ^{abcd}
Jilore	CL4	75.2 ± 6.053 ^{de}	17.2 ± 3.441 ^a	7.6 ± 2.786 ^{ab}
Kagumo Gardens	UM2	8 ± 1.155 ^a	83.33 ± 3.333 ^f	8.67 ± 3.528 ^{abc}
Gede	CL4	87 ± 1 ^e	8.5 ± 0.5 ^a	5 ± 1 ^a
		$F_{(1,11)} = 24.94$; $p < 0.001$	$F_{(1,11)} = 17.40$; $p < 0.001$	$F_{(1,11)} = 8.15$; $p < 0.001$
		<i>l.s.d.</i> = 14.86	<i>l.s.d.</i> = 14.97	<i>l.s.d.</i> = 13.81

Source: Field survey data; November 2020

4.2 Introduced bamboo species

The site-specific study considered 16 bamboo species and two sub-species from nine different AEZs (Table 22). The species included one indigenous and 15 exotic bamboo species. The native bamboo species was *Oldenia alpina* (syn. *Y. alpina*), while the exotic bamboo species were *T. siamensis*, *P. aurea*, *O. abyssinica*, *D. strictus*, *D. membranaceus*, *D. hamiltonii*, *D. giganteus*, *D. brandsii*, *D. birmanicus*, *D. asper*, *Bambusa tulda*, *B. multiplex*, *B. blumeana*, *B. bambos*, *B. vulgaris* var. *vulgaris*, and *B. vulgaris* var. *vittata* (Table 4.2.1). Four of the 15 exotic bamboo species were solid/semi-solid bamboos (*O. abyssinica*, *T. siamensis*, *D. strictus*, and *B. tulda*), while the rest had hollow culms. The list of identified bamboo species was very close to that in the work of Ongugo et al. (2000), who estimated that about 18 exotic bamboo species have been trilled in Kenya since the 1980s. It is worth noting, however, that the country has a few more bamboo species, particularly those that have been introduced by the Dutch–Sino East Africa Bamboo Development Program since 2017 (Otuoma and Mutsami, 2019). Some notable new introductions include *Phyllostachys heteroclada*, *Cephalostachyum pergracile*, *Bambusa polymorpha*, and *Dendrocalamus laonensis*. These new introductions were not featured in the present study because they were hardly two years old in the field, so their yields or biomass could not be determined. For effective yield estimation, the assessment was restricted to bamboo clumps aged five years and above. Some of the species captured in this assessment occupied up to five different AEZs.

Table 22. Bamboo species assessed for suitability in Kenya’s AEZs

No.	Bamboo species	Origin	Planting site (s)	Agro-ecological zone(s)
1.	<i>Oldenia alpina</i>	Native	2	LH1 and UM1
2.	<i>Thyrsostachys siamensis</i>	Exotic	3	LM2 and CL4
3.	<i>Phyllostachys aurea</i>	Exotic	1	LH1
4.	<i>Oxytenanthera abyssinica</i>	Exotic	4	LH3, LM2, LM5, and CL4
5.	<i>Dendrocalamus strictus</i>	Exotic	3	LM2, LM5, and CL4
6.	<i>Dendrocalamus membranaceus</i>	Exotic	3	LH3, UM3, and CL4

7.	<i>Dendrocalamus hamiltonii</i>	Exotic	3	LH3, LM1, and CL2
8.	<i>Dendrocalamus giganteus</i>	Exotic	4	LH3, UM1, and LM2
9.	<i>Dendrocalamus brandsii</i>	Exotic	1	LH3
10.	<i>Dendrocalamus birmanicus</i>	Exotic	1	LH3
11.	<i>Dendrocalamus asper</i>	Exotic	6	LH1, LH3, UM1, UM2, and LM1
12.	<i>Bambusa vulgaris var. vulgaris</i>	Exotic	6	LH1, UM1, UM2, LM2, and LM5
13.	<i>Bambusa vulgaris var. vitatta</i>	Exotic	8	LH3, UM1, UM2, LM1, LM2, and CL4
14.	<i>Bambusa tulda</i>	Exotic	1	LH3
15.	<i>Bambusa multiplex</i>	Exotic	1	LH1
16.	<i>Bambusa blumeana</i>	Exotic	3	LH3, CL2, and CL4
17.	<i>Bambusa bambos/arundinaceae</i>	Exotic	2	LM2 and CL4

4.3 A morphological identification guide for the bamboo species encountered in the survey

1. Clump forming bamboo (sympodial).....2
 Running bamboo (monopodial).....***Phyllostachys aurea***

2. Culms yellow/green with green/yellow stripes.....3
 Culms green in color.....4

3. Erect culms of 10–15 m height, 5–10 cm diameter.....***Bambusa vulgaris var. vitatta***
 Erect culms of 2–7 m height, 1–3 cm diameter.....***Bambusa multiplex***

4. Culms bright green when young and turn yellowish brown upon maturity.....***Thyrsostachys siamensis***

 Culms bright grassy green.....5
 Culms grayish green in color.....8

5. Young culms yellow/brown and silky.....*Oldeania alpina*
 Mature culms **WITH** white rings above the nodal rings.....6
 Mature culms **WITHOUT** white rings above the nodal rings.....7
6. Culms with spineless branches.....*Bambusa tulda*
 Culms with spiny branches.....*Bambusa bambos*
7. Culms with spines.....*Bambusa blumeana*
 Culms spineless.....*Bambusa vulgaris* var. *vulgaris*
8. Culm sheaths persistent.....*Oxytenanthera abyssinica*
 Culm sheaths **NOT** persistent.....
9. Mature culms less than 12 m tall and 10 cm wide.....*Dendrocalamus birmanicus*
 Mature culms **MORE** than 10 m high and 8 cm wide.....10
10. Young internodes covered with peeling whitish bloom.....11
 Young internodes covered with hair12
11. Brown young shoots covered with white blooms.....*Dendrocalamus strictus*
 Green young shoots covered with white blooms.....*Dendrocalamus membranaceus*
12. Below and above the nodal ring white layer prominent.....*Dendrocalamus hamiltonii*
 Below and above the nodal ring white layer **NOT** prominent.....13
13. Young shoots covered with golden brown hair.....*Dendrocalamus asper*
 Young shoots covered with purplish hair.....*Dendrocalamus giganteus*
 Dark-gray young shoots with a dark-brown blade.....*Dendrocalamus brandisii*

4.4 Growth performance of the planted bamboo species

4.4.1. *Oldeania alpina*

Oldeania alpina (syn. *Y. alpina*) was recorded as one of the planted bamboo species in Limuru in Kiambu County and Ndakaini in Murang'a County. A summary of the species' growth performance in Limuru and Ndakaini is presented in Table 23.

Table 23. Summary of the growth performance of *O. alpina* planted in Limuru and Ndakaini

Growth parameter	Limuru	Ndakaini	Statistical result
Clump age (yrs)	5 ± 0	35 ± 0	
Clumps per ha	400 ± 0	25 ± 0	
Clump radius (m)	0.533 ± 0.033	1.167 ± 0.417	<i>p</i> = 0.204
Culms per clump (no.)	15 ± 2	76.67 ± 36.67	<i>p</i> = 0.168
Culm density (no./ha)	6,000 ± 800	1,917 ± 916.7	<i>p</i> = 0.028
Culm diameter (cm)	2.133 ± 0.291	0.917 ± 0.170	<i>p</i> = 0.022
Culm height (m)	3.467 ± 0.393	2.833 ± 0.176	<i>p</i> = 0.215
Wall thickness (cm)	0.65 ± 0.144	0.217 ± 0.017	<i>p</i> = 0.041
Internode length (cm)	23 ± 1	37.93 ± 2.067	<i>p</i> = 0.003

Source: Field survey data; November 2020; Limuru = LH1 and Ndakaini = UM1

The results indicated that *O. alpina* was more productive in Limuru (LH1 – tea/dairy zone) than in Ndakaini (UM1 – coffee/tea zone). This was because Limuru (2,085 m a.s.l.) is located at a relatively higher elevation than Ndakaini (2,056 m a.s.l.). The higher elevation in Limuru is not very far from that of the natural range of *O. alpina* at 2,300–3,500 m a.s.l. Despite growing much taller and larger in Limuru than in Ndakaini, *O. alpina* still had a mean height and diameter that were significantly lower than expected (height = 20 m, diameter = 5–12.5 cm) in its natural range (Clayton et al., 2016).

4.4.2. *Thyrsostachys siamensis*

Thyrsostachys siamensis was recorded in Gede and Jilore in Kilifi County and Kehancha in Migori County (Table 24). There were no significant differences in the species' culm wall thickness at the three sites (*p* > 0.05). The culm density in Gede and Jilore did not differ significantly (*p* > 0.05) from that in Kehancha, which was much higher. However, the culm diameter, height, and internode length differed significantly between the three sites (*p* < 0.05), with Gede recording the largest mean height and diameter, followed by Jilore, while Kehancha recorded the smallest. The culm density, culms per clump, and internode length were higher in Kehancha. The growth performance of *T. siamensis* in Gede and that in Jilore were found to be similar in many aspects because they both involved the same AEZ and similar elevations. However, *T. siamensis* in the three sites did not grow to attain the maximum height (≈ 13 m) and

diameter (≈ 6 cm) as expected of the species at elevations of 500–1,000 m a.s.l. (Banik, 2016). This can be explained by the fact that none of the three *T. siamensis* plantation sites were in this range of altitude; Gede and Jilore had elevations of 25 m and 85 m, respectively, while Kehancha had a higher elevation of 1,504 m.

Table 24. *T. siamensis* growing in Gede, Jilore, and Kehancha, Kenya

Growth parameter	Gede	Jilore	Kehancha	Statistical result
Clump age (yrs)	29 \pm 0	30 \pm 0	11 \pm 0	
Clumps per ha	400 \pm 0	100 \pm 0	400 \pm 0	
Clump radius (m)	2.067 \pm 0.067	1.033 \pm 0.033	1.467 \pm 0.291	$F_{(1,2)} = 8.98$; $p = 0.016$
Culms per clump (no.)	16.67 \pm 0.88	64 \pm 13	144 \pm 18.33	$F_{(1,2)} = 24.57$; $p = 0.001$
Culm density (no./ha)	6667 \pm 353	6400 \pm 1300	57,600 \pm 7332	$F_{(1,2)} = 46.93$; $p < 0.001$
Culm diameter (cm)	3 \pm 0.0577	2.283 \pm 0.142	1.811 \pm 0.1281	$F_{(1,2)} = 26.86$; $p = 0.001$
Culm height (m)	8.667 \pm 0.338	6.533 \pm 0.706	3.5 \pm 0.1072	$F_{(1,2)} = 32.42$; $p < 0.001$
Wall thickness (cm)	0.333 \pm 0.033	0.833 \pm 0.120	0.656 \pm 0.423	$F_{(1,2)} = 0.99$; $p = 0.424$
Internode length (cm)	10.33 \pm 0.333	17.83 \pm 1.167	53.56 \pm 0.444	$F_{(1,2)} = 958.37$; $p < 0.001$

Source: Field survey data; November 2020; Gede = CL4; Jilore = CL4 and Kehancha = LM2

4.4.3. *Phyllostachys aurea*

Phyllostachys aurea was found only in Limuru, a lower highland AEZ suitable for tea and dairy. A summary of the species' key growth performance in Limuru is presented in Table 25.

Table 25. Summary of the growth performance of *P. aurea* in Limuru

Variable	Limuru
Clump age (yr)	5 ± 0
Clump radius (m)	0.3 ± 0
Culms per clump (no.)	N/A (running bamboo)
Culm density (no./ha)	111,111
Culm diameter (cm)	2.15 ± 0.126
Culm height (m)	4.067 ± 0.192
Wall thickness (cm)	0.617 ± 0.017
Internode length (cm)	17.5 ± 1.041

Source: Field survey data; November 2020; Limuru = LH1

4.4.4. *Oxytenanthera abyssinica*

Oxytenanthera abyssinica was recorded in Jilore, KEFRI-Kibwezi, Kehancha, and Muguga. The number of clumps per ha between Jilore and KEFRI-Kabwezi was statistically similar. Kehancha and Muguga also had similar numbers of clumps per ha. The culm wall thicknesses for Jilore, Kehancha, and Muguga were semi-solid, with no statistical difference ($p > 0.05$), whereas the Kibwezi samples were completely solid. The analysis of the height of *O. abyssinica* from the four areas showed that Kehancha samples had the largest height, followed by Jilore, while the heights for Muguga and Kibwezi were similar. The culm diameter was largest in Kehancha, followed by Jilore, while those for Muguga and Kibwezi were similar. Overall, the best growth performance of this species was recorded in samples from Kehancha, except for culms per clump and culm density, which were highest in Muguga, and wall thickness, which was largest in Jilore. The growth performance of this species across the four areas differed significantly, even in areas belonging to the same ecological zones. The four areas that featured *O. abyssinica* were within the elevation range of 50–1,600 m, which is ideal for the good performance of this species, except for the Muguga site, which was at 2,070 m. Therefore, the performance of this species may not be associated with altitude or agro-ecological zoning. The species' growth performance at each of the four sites is summarized in Table 26.

Table 26. Growth performance of *O. abyssinica* in Jilore, KEFRI-Kibwezi, Kehancha, and Muguga

Variable	Jilore	KEFRI-Kibwezi	Kehancha	Muguga	Statistical result
Clump age (yrs)	30 ± 0	6 ± 0	12 ± 0		N/A
Clumps per ha	100 ± 0	100 ± 0	400 ± 0	400 ± 0	N/A
Clump radius (m)	2.2 ± 0.1a	0.3 ± 0a	5.4 ± 1.35b	1.8 ± 0a	$F(1,3) = 10.01$; $p = 0.004$
Culms per clump (no.)	37 ± 3a	6.33 ± 1.33a	77.67 ± 17.05b	95.33 ± 7.33b	$F(1,3) = 18.12$; $p < 0.001$
Culm density (no./ha)	3,700 ± 300a	633 ± 133a	31,067 ± 6,821b	38,133 ± 2,933b	$F(1,3) = 26.11$; $p < 0.001$
Culm diameter (cm)	4.07 ± 0.43b	3 ± 0.12a	6.578 ± 0.2c	2.883 ± 0.04a	$F(1,3) = 48.1$; $p < 0.001$
Culm height (m)	8.48 ± 1.32b	5.47 ± 0.12b	11.5 ± 0.22b	6.12 ± 0.25ab	$F(1,3) = 15.98$; $p < 0.001$
Wall thickness (cm)	1.7 ± 0.3a	* ± *	1.144 ± 0.05a	1.33 ± 0.33a	$F(1,3) = 2.38$; $p = 0.209$
Internode length (cm)	21.33 ± 1.76a	29.33 ± 1.85a	44 ± 1b	27 ± 3.22a	$F(1,3) = 20.86$; $p < 0.001$

Source: Field survey data; November 2020; Jilore and Gede = CL4; KEFRI-Kibwezi = LM5; Kehancha = LM2

4.4.5. *Dendrocalamus strictus*

Dendrocalamus strictus was recorded in Jilore, KEFRI-Kibwezi, and Kehancha. Its culm diameter was different at all three sites, with Kibwezi having the largest diameter, followed by Jilore. There were no significant differences in the species' height at the three sites ($F_{(1,2)} = 4.59$; $p = 0.062$). The internode length was largest in Kehancha, while KEFRI-Kabwezi and Jilore had similar lengths. Kehancha was superior in clump per ha, clump radius, culms per clump, and culm density. The culms of this species were found to be completely solid in Jilore and Kehancha and semi-solid in KEFRI-Kibwezi. This finding deviates from that of Mahajan and Nishant (2006), who recorded that *D. strictus* culms are solid in dry areas and semi-solid in humid areas.

Kehancha and Jilore are generally more humid than Kibwezi. The difference in the growth performance of *D. strictus* could be due to other factors, such as edaphic characteristics. The growth performance of the species at the three sites is summarized in Table 27.

Table 27. Growth performance of *D. strictus* in Jilore, KEFRI-Kibwezi, and Kehancha

Variable	Jilore	KEFRI-Kibwezi	Kehancha	Statistical result
Clump age (yrs)	30 ±	6 ±	11 ±	N/A
Clumps per ha	100 ±	250 ±	400 ±	N/A
Clump radius (m)	0.6 ± 0.1b	0.33 ± 0.017a	0.85 ± 0.05c	$F(1,2) = 15.67; p = 0.004$
Culms per clump (no.)	11.67 ± 0.33a	5.33 ± 0.33a	106.67 ± 6.67b	$F(1,2) = 216.42; p < 0.001$
Culm density (no./ha)	1,167 ± 33.3a	1,333 ± 83.3a	42,667 ± 2,666.7b	$F(1,2) = 240.95; p < 0.001$
Culm diameter (cm)	3.3 ± 0.21ab	4.33 ± 0.64b	2.26 ± 0.14a	$F(1,2) = 6.85; p = 0.028$
Culm height (m)	4.03 ± 0.63a	6.58 ± 1.07a	3.394 ± 0.5687a	$F(1,2) = 4.59; p = 0.062$
Wall thickness (cm)	* ± *	1.35 ± 0.23	* ± *	N/A
Internode length (cm)	28.17 ± 0.17a	28.17 ± 0.33a	47.33 ± 0.33b	$F(1,2) = 1,469.44; p < 0.001$

Source: Field survey data; November 2020

4.4.6. *Dendrocalamus membranaceus*

Dendrocalamus membranaceus was recorded in Gede, Kagumo Gardens, and Muguga. Its culm diameter was largest in Kagumo Gardens and smallest in Gede. Its culm height, wall thickness, and clump radius were largest in Muguga and smallest in Gede. The growth performance of this species is summarized in Table 28.

Table 28. Growth performance of *D. membranaceus* in Gede, Kibwezi, and Muguga

Variable	Gede	Kagumo	Muguga	Statistical result
Clump age (yrs)	29 ± 237	5 ±	±	N/A
Clumps per ha	637 ± 0.03	400 ±	400 ±	N/A
Clump radius (m)	0.53 ± 0.88a	0.92 ± 0.21a	2.33 ± 0.33b	$F(1,2) = 17.12$; $p = 0.003$
Culms per clump (no.)	18.67 ± 4.58a	14.33 ± 1.20a	256.67 ± 6.67b	$F(1,2) = 1236.3$; $p < 0.001$
Culm density (no./ha)	11,97 ± 0.09a	5,733 ± 481a	102,667 ± 2667b	$F(1,2) = 311.54$; $p < 0.001$
Culm diameter (cm)	3.23 ± 0.12a	5.87 ± 0.66b	4.117 ± 0.12a	$F(1,2) = 11.91$; $p = 0.008$
Culm height (m)	6.37 ± 0.03a	7.5 ± 1.57a	9.37 ± 0.09a	$F(1,2) = 2.77$; $p = 0.141$
Wall thickness (cm)	0.53 ± 0.33a	0.8 ± 0.12b	0.98 ± 0.02b	$F(1,2) = 10.43$; $p = 0.011$
Internode length (cm)	23.33 ± a	44.33 ± 0.88b	22.67 ± 2.67a	$F(1,2) = 56.93$; $p < 0.001$

Source: Field survey data; November 2020

4.4.7 *Dendrocalamus hamiltonii*

Dendrocalamus hamiltonii was recorded in Busia Town, Mivumoni, and Muguga. Its culm diameter was largest in Busia Town and smallest in Muguga. Overall, culms from Mivumoni had significantly higher culm heights, internode lengths, clump radiuses, culms per clump, culm diameters, and wall thicknesses than those from Busia Town and Muguga. The results suggest that agro-ecological zoning played a key role in the growth performance of this species. Table 29 summarizes the growth performance of *D. hamiltonii*.

Table 29. Growth performance of *D. hamiltonii* in Busia Town, Mivumoni, and Muguga

Variable	Busia Town	Mivumoni	Muguga	Statistical result
Clump age (yrs)	7 ±	25 ±	±	N/A
Clumps per ha	25 ± 0	100 ± 0	400 ± 0	N/A
Clump radius (m)	0.98 ± 0.07a	2.17 ± 0.17b	0.83 ± 0.03a	$F(1,2) = 46.84; p < 0.001$
Culms per clump (no.)	36.33 ± 0.88a	116.67 ± 6.67b	33 ± 10a	$F(1,2) = 46.36; p < 0.001$
Culm density (no./ha)	908 ± 22a	11,667 ± 667b	13,200 ± 4,000b	$F(1,2) = 8.18; p = 0.019$
Culm diameter (cm)	9.53 ± 0.61b	8.32 ± 0.42b	4.43 ± 0.33a	$F(1,2) = 32.46; p < 0.001$
Culm height (m)	7.07 ± 0.35a	13.9 ± 0.82b	7.83 ± 0.50a	$F(1,2) = 40.08; p < 0.001$
Wall thickness (cm)	1.2 ± 0.06a	1.29 ± 11.57a	1.02 ± 0.13a	$F(1,2) = 1.03; p = 0.411$
Internode length (cm)	32 ± 0.58a	40.67 ± 2.73b	31.67 ± 1.33a	$F(1,2) = 8.17; p < 0.019$

Source: Field survey data; November 2020

4.4.8. *Dendrocalamus giganteus*

Dendrocalamus giganteus was recorded in Kairi-ini, Kehancha, Muguga, and Ndakaini. There were no significant differences in culm height between the four sites ($F_{(1,3)} = 1.22; p = 0.364$). The clump radius was significantly lower in Muguga, while the wall thickness was significantly higher in Kehancha. The growth performance of this species at the four sites is summarized in Table 30.

Table 30. Growth performance of *D. giganteus* in Kairi-ini, Kehancha, Muguga, and Ndakaini

Variable	Kairi-ini	Kehancha	Muguga	Ndakaini	Statistical result
Clump age (yrs)	13 ± 1	14 ± 0	* ± *	35 ± 0	N/A

Clumps per ha	* ± *	400 ± 0	400 ± 0	253.2 ± 24.57	N/A
Clump radius (m)	2.85 ± 0.05b	2.63 ± 0.19b	1.6 ± 0.1a	2.58 ± 0.22b	$F(1,3) = 13.2; p = 0.002$
Culms per clump (no.)	110 ± 20b	41.67 ± 9.91a	63 ± 9ab	62.67 ± 2.67ab	$F(1,3) = 5.69 p = 0.022$
Culm density (no./ha)	0 ± 0a	16,667 ± 3,962b	25,200 ± 3,600b	15,738 ± 930b	$F(1,3) = 14.95; p = 0.001$
Culm diameter (cm)	8.33 ± 1.33a	11.68 ± 0.21ab	8.97 ± 0.61abc	8.55 ± 0.42ac	$F(1,3) = 4.1; p = 0.049$
Culm height (m)	12.5 ± 1.32a	13.2 ± 0.67a	10 ± 1.85a	12.88 ± 1.17a	$F(1,3) = 1.22; p = 0.364$
Wall thickness (cm)	0.9 ± 0.1ab	1.18 ± 0.02b	0.97 ± 0.03ab	0.7 ± 0.15ab	$F(1,3) = 4.57; p = 0.038$
Internode length (cm)	40.5 ± 2.02a	40 ± 1.26a	57.5 ± 1.26b	45.33 ± 0.67a	$F(1,3) = 34.45; p < 0.001$

Source: Field survey data; November 2020

4.4.9. *Dendrocalamus brandisii*

Dendrocalamus brandisii was found only in Muguga. Its growth performance at this site is summarized in Table 31.

Table 31. Growth performance of *D. brandisii* in Muguga

Variable	Muguga
Clump age (yrs)	* ± *
Clumps per ha	400 ± 0
Clump radius (m)	1.45 ± 0.05
Culms per clump (no.)	90.67 ± 29.33
Culm density (no./ha)	36,267 ± 11,733
Culm diameter (cm)	4.53 ± 0.291
Culm height (m)	7.62 ± 0.58

Wall thickness (cm)	1.1 ± 0.15
Internode length (cm)	29.33 ± 3.71

Source: Field survey data; November 2020

4.4.10. *Dendrocalamus birmanicus*

Dendrocalamus birmanicus was recorded only in Muguga. Its growth performance at this site is summarized in Table 32.

Table 32. Growth performance of *D. birmanicus* in Muguga

Variable	Muguga
Clump age (yrs)	
Clumps per ha	400 ±
Clump radius (m)	0.77 ± 0.03
Culms per clump (no.)	56 ± 14
Culm density (no./ha)	22,400 ± 5,600
Culm diameter (cm)	3.18 ± 0.59
Culm height (m)	6.7 ± 1.01
Wall thickness (cm)	0.98 ± 0.02
Internode length (cm)	28.33 ± 2.96

Source: Field survey data; November 2020

4.4.11. *Dendrocalamus asper*

Dendrocalamus asper was recorded in Busia Town, Isecheno in Kakamega, Kagumo in Nyeri, Kairi-ini in Muranga, and Limuru and Muguga in Kiambu. In terms of clump radius, Muguga had the largest, followed by Busia Town, Kairi-ini, Kagumo Gardens, and Limuru, while Isecheno had the smallest. Busia Town had the largest culm diameter and wall thickness, followed by Muguga, Isecheno, Kagumo Gardens, and Limuru, whereas Kairi-ini had the smallest. The mean culm height was largest in Muguga and smallest in Limuru. The average number of culms per clump was largest in Busia Town, Kagumo Gardens, Limuru, Muguga, and Kairi-ini and smallest in Isecheno. The culm density was highest in Limuru, followed by Muguga, Kairi-ini, Isecheno, and Busia Town, while Kagumo Gardens had the lowest. The species' growth performance is summarized in Table 33.

Table 33. Growth parameters of *D. asper* in Busia Town, Isecheno, Kagumo, Kairi-ini, Limuru, and Muguga

Variable	Busia Town	Iseche no	Kagumo Gardens	Kairi- ini	Limuru	Muguga	Statistical result
Clump age (yrs)	7 ± 0	7 ± 0	5 ± 0	8 ± 0	5 ± 0	* ± *	N/A
Clumps per ha	25 ± 0	400 ± 0	25 ± 0	400 ± 0	400 ± 0	400 ± 0	N/A
Clump radius (m)	1.47 ± 0.13b	0.53 ± 0.033a	0.917 ± 0.16667a	1.38 ± 0.02b	0.83 ± 0.03a	2.7 ± 0c	$F(1,5) = 73.59$; $p < 0.001$
Culms per clump (no.)	55.67 ± 9.33c	4.33 ± 0.33a	46.67 ± 9.262c	15.33 ± 0.67ab	40.67 ± 0.67c	31.33 ± 3.67b	$F(1,5) = 12.13$ $p < 0.001$
Culm density (no./ha)	1,392 ± 233.3a	1,733 ± 133.3a	1167 ± 231.5a	6,133 ± 266.7b	16,267 ± 266.7d	12,533 ± 1,466.7e	$F(1,5) = 103.76$; $p < 0.001$
Culm diameter (cm)	13.33 ± 0.33e	7.5 ± 0.29c	5.46 ± 0.58b	3.88 ± 0.25a	4.57 ± 0.28ab	9.98 ± 0.30d	$F(1,5) = 103.19$; $p < 0.001$
Culm height (m)	11.83 ± 0.73cd	9.43 ± 0.69bc	7.32 ± 0.68ab	4.67 ± 0.17a	4.47 ± 0.09a	14.25 ± 1.48d	$F(1,5) = 25.0$; $p < 0.001$
Wall thickness (cm)	1.4 ± 0.2d	0.97 ± 0.03bc	0.84 ± 0.06abc	0.47 ± 0.09a	0.63 ± 0.03ab	1.13 ± 0.07cd	$F(1,5) = 11.9$; $p < 0.001$
Internode length (cm)	31.67 ± 0.88a	39.67 ± 0.33a	37.56 ± 2.512a	37.67 ± 2.19a	31.67 ± 0.88a	34.83 ± 2.62a	$F(1,5) = 3.43$; $p < 0.037$

Source: Field survey data; November 2020

4.4.12. *Bambusa vulgaris* var. *vulgaris*

Bambusa vulgaris var. *vulgaris* was recorded in Isecheno, Kagumo Gardens, KEFRI-Kibwezi, Kehancha, Limuru, and Ndakaini. The growth performance of the species varied across these sites. Kehancha had the largest clump radius, while KEFRI-Kibwezi had the smallest. The number of culms per clump was largest in Ndakaini and smallest in KEFRI-Kibwezi. In terms of culm density, Limuru had the highest density, followed by Kehancha, Kagumo Gardens, Isecheno, and Ndakaini. Again, KEFRI-Kibwezi had the lowest. Isecheno had the largest culm diameter, followed by Limuru, Kehancha, Kagumo Gardens, Ndakaini, and KEFRI- Kibwezi.

There were no significant differences in the mean culm height ($p = 0.22$) between the six sites. However, Kehancha had the tallest culms, while Limuru had the shortest. Culms from KEFRI-Kibwezi had the thickest walls, followed by Isecheno, Kehancha, Limuru, and Kagumo Gardens, while Ndakaini had the thinnest. The average internode length was largest in Kagumo Gardens and smallest in Limuru (Table 34).

Table 34. Growth performance of *B. vulgaris* var. *vulgaris* in Isecheno, Kagumo Gardens, KEFRI-Kibwezi, Kehancha, Limuru, and Ndakaini

Variable	Isecheno	Kagumo Gardens	KEFRI-Kibwezi	Kenhancha	Limuru	Ndakaini	Statistical result
Clump age (yrs)	7 ± 0	5 ± 0	6 ± 0	12 ± 0	10 ± 0	35 ± 0	
Clumps per ha	400 ± 0	400 ± 0	100 ± 0	400 ± 0	400 ± 0	25 ± 0	
Clump radius (m)	1.27 ± 0.02b	0.5 ± 0a	0.37 ± 0.03a	2.97 ± 0.35 ^c	1.63 ± 0.13b	2.9 ± 0.1c	$F(1,5) = 50.0$; $p < 0.001$
Culms per clump (no.)	36 ± 1b	38 ± 0b	8.33 ± 1.67a	50.67 ± 10.73 ^{bc}	67 ± 2c	68 ± 4a	$F(1,5) = 21.76$; $p < 0.001$
Culm density (no./ha)	14,400 ± 400b	15,200 ± 0b	833 ± 166.7a	20,267 ± 4,291.6 ^{bc}	26,800 ± 800c	1700 ± 100a	$F(1,5) = 32.75$; $p < 0.001$
Culm diameter (cm)	8.87 ± 0.67b	4.83 ± 0.17a	4.5 ± 0.29a	5.63 ± 0.24 ^a	5.73 ± 0.65a	4.5 ± 0.36a	$F(1,5) = 14.06$; $p < 0.001$
Culm height (m)	8.1 ± 1.12a	8.57 ± 0.69a	7.07 ± 0.97a	9.41 ± 1.14 ^a	6.7 ± 0.40a	6.97 ± 0.23a	$F(1,5) = 1.64$; $p = 0.2221$
Wall thickness (cm)	1.03 ± 0.03b	0.73 ± 0.03a	1.07 ± 0.07b	1.02 ± 0.044 ^b	0.75 ± 0.03a	0.62 ± 0.02a	$F(1,5) = 22.86$; $p < 0.001$
Internode length (cm)	33 ± 0.58a	44.67 ± 2.91b	33.33 ± 1.20a	36 ± 3.79 ^{ab}	32.83 ± 0.44a	34.33 ± 2.40a	$F(1,5) = 4.07$; $p = 0.022$

Source: Field survey data; November 2020

4.4.13. *Bambusa vulgaris* var. *vittata*

Bambusa vulgaris var. *vittata* (syn. *B. striata*) was recorded in Busia Town, Gede, Isecheno, Kagumo Gardens, Kairi-ini, Kehancha, Muguga, and Ndakaini. Its growth parameters varied at the nine sites. The clump radius was largest in Kehancha and smallest in Gede. Ndakaini had the largest number of culms per clump, followed by Muguga, Kagumo Gardens, Busia Town,

Kehancha, Isecheno, and Gede, while Kairi-ini had the smallest. Muguga had the highest culm density (Table 35). Kagumo Gardens had the largest culm diameter, while Ndakaini had the smallest. Kehancha recorded the largest culm height, followed by Kagumo Gardens, Gede, Busia Town, Isecheno, Muguga, Ndakaini, and Kairi-ini. Muguga culms had the thickest walls.

Table 35. Growth performance of *B. vulgaris* var. *vittata* in Busia Town, Gede, Isecheno, Kagumo Gardens, Kairi-ini, Kehancha, Muguga, and Ndakaini

Variable	Busia Town	Gede	Isecheno	Kagumo Gardens	Kairi-ini	Kehancha	Muguga	Ndakaini	Statistical result
Clump age (yrs)	7 ± 0	29 ± 0	7 ± 0	5 ± 0	8 ± 0	14 ± 0	* ± *	35 ± 0	N/A
Clumps per ha	25 ± 0	400 ± 0	25 ± 0	400 ± 0	* ± *	400 ± 0	400 ± 0	25 ± 0	N/A
Clump radius (m)	1.67 ± 0.06 ^{ab}	0.63 ± 0.03 ^a	1.53 ± 0.08 ^{ab}	1.75 ± 0 ^{ab}	2.07 ± 0.02 ^b	3.87 ± 0.73 ^c	0.97 ± 0.29 ^{ab}	2.08 ± 0.03 ^b	$F(1,7) = 11.86; p < 0.001$
Culms per clump (no.)	67.67 ± 2.19 ^{ab}	25 ± 0.58 ^a	51.67 ± 1.76 ^{ab}	74 ± 0 ^{ab}	23.67 ± 0.67 ^a	60 ± 7.21 ^{ab}	113.33 ± 60.0 ^{9ab}	146.67 ± 23.33 ^b	$F(1,7) = 3.36; p = 0.021$
Culm density (no./ha)	1,692 ± 55 ^a	10,000 ± 231 ^{ab}	1,292 ± 44 ^a	29,600 ± 0 ^{ab}	0 ± 0 ^a	24,000 ± 2,884 ^{ab}	45,333 ± 24.037 ^b	367 ± 583 ^a	$F(1,7) = 3.81; p = 0.01$
Culm diameter (cm)	5.12 ± 0.41 ^{ab}	4.2 ± 0.12 ^a	5.33 ± 0.03 ^{ab}	7.27 ± 1.38 ^b	4.3 ± 0.06 ^a	5.49 ± 0.70 ^{ab}	4.18 ± 0.09 ^a	4.17 ± 0.12 ^a	$F(1,7) = 3.53; p = 0.02$
Culm height (m)	6.5 ± 0.77 ^{ab}	8.03 ± 0.12 ^{ab}	6.5 ± 0.12 ^{ab}	8.57 ± 1.93 ^{ab}	4.83 ± 0.09 ^a	9.23 ± 0.35 ^b	6.42 ± 0.57 ^{ab}	5.98 ± 0.73 ^{ab}	$F(1,7) = 3.24; p = 0.024$
Wall thickness (cm)	1.08 ± 0.03 ^a	0.57 ± 0.03 ^a	1.03 ± 0.03 ^a	1.03 ± 0.03 ^a	0.83 ± 0.09 ^a	1.07 ± 0.07 ^a	2.35 ± 1.35 ^a	0.93 ± 0.23 ^a	$F(1,7) = 1.18; p = 0.367$



Internode length (cm)	24.67 ± 0.93 ^a	31 ± 0.58 ^{ab}	33 ± 0.58 ^b	40.67 ± 2.96 ^c	30 ± 0.58 ^{ab}	30 ± 0.19 ^{ab}	27.17 ± 2.21 ^{ab}	27.67 ± 2.85 ^{ab}	$F(1,7) = 7.9; p < 0.001$
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Source: Field survey data; November 2020

4.4.14. *Bambusa tulda* Roxb.

Bambusa tulda was encountered only in Muguga, a lower highland zone (LH3). It had a mean culm diameter of 2.88 ± 0.10 and a mean height of 3.75 ± 0.53 . Its overall growth performance is summarized in Table 36.

Table 36. Growth performance of *B. tulda* in Muguga

Variable	Muguga site
Clump age (yrs)	* ± *
Clumps per ha	400 ± 0
Clump radius (m)	1.15 ± 0.1041
Culms per clump (no.)	191.7 ± 44.19
Culm density (no./ha)	76667 ± 17676
Culm diameter (cm)	2.883 ± 0.1014
Culm height (m)	3.75 ± 0.5299
Wall thickness (cm)	1 ± 0
Internode length (cm)	26.33 ± 1.167

Source: Field survey data; November 2020

4.4.15. *Bambusa multiplex*

Bambusa multiplex was found only in Limuru, a lower highland zone (LH1). It had a mean culm height of 2.73 ± 0.089 m and a mean culm diameter of 1.8 ± 0.12 cm. Its overall growth performance is summarized in Table 37.

Table 37. Growth performance of *B. multiplex* in Limuru

Variable	Limuru
Clump age (yrs)	5 ± 0
Clumps per ha	400 ± 0
Clump radius (m)	0.5333 ± 0.03333
Culms per clump (no.)	40.67 ± 0.6667
Culm density (no./ha)	16267 ± 266.7
Culm diameter (cm)	1.8 ± 0.1155
Culm height (m)	2.733 ± 0.08819

Wall thickness (cm)	0.6333 ± 0.03333
Internode length (cm)	35.33 ± 3.756

Source: Field survey data; November 2020

4.4.16. *Bambusa blumeana* Schult.f.

Bambusa blumeana was recorded in Jilore, Mivumoni, and Muguga. Muguga was superior in terms of culms per clump, culm density, and wall thickness, followed by Jilore and then Mivumoni. Mivumoni had the largest mean internode length, culm height, and diameter, followed by Muguga and Jilore. The growth performance of this species is summarized in Table 38.

Table 38. Growth performance of *B. blumeana* in Jilore, Mivumoni, and Muguga

Variable	Jilore	Mivumoni	Muguga	Statistical result
Clump age (yrs)	30 ± 0	25 ± 0	**	N/A
Clumps per ha	100 ± 0	100 ± 0	400 ± 0	N/A
Clump radius (m)	1.13 ± 0.07a	1.23 ± 0.27a	1.27 ± 0.13a	$F(1,2) = 0.15; p = 0.86$
Culms per clump (no.)	37.67 ± 7.33a	23.33 ± 3.67a	72.67 ± 7.33b	$F(1,2) = 15.97; p = 0.004$
Culm density (no./ha)	3,767 ± 733a	2,333 ± 367a	29,067 ± 2,933b	$F(1,2) = 73.13; p < 0.001$
Culm diameter (cm)	4.73 ± 0.37ab	5.47 ± 0.37b	3.83 ± 0.37a	$F(1,2) = 4.86; p = 0.056$
Culm height (m)	6.17 ± 0.37a	7.75 ± 1.18a	6.7 ± 0.51a	$F(1,2) = 1.08; p = 0.397$
Wall thickness (cm)	1.17 ± 0.03a	1 ± 0.12a	4.28 ± 1.81a	$F(1,2) = 3.11; p = 0.118$
Internode length (cm)	29.33 ± 0.33a	37 ± 3.06b	26.5 ± 1.89a	$F(1,2) = 6.8; p = 0.029$

Source: Field survey data; November 2020

4.4.17. *Bambusa bambos*

Bambusa bambos (syn. *B. arundinaceae*) was found in Jilore on the Kenyan coast and in Kehancha in western Kenya. Kehancha recorded better growth performance in terms of culm density, culm diameter, and wall thickness. However, Jilore had better performance in terms of

internode length, culm height, culms per clump, and clump radius. This species' growth performance is summarized in Table 39.

Table 39. Growth performance of *B. bambos* in Jilore and Kehancha

Variable	Jilore	Kehancha	Statistical result
Clump age (yrs)	30 ± 0	11 ± 0	N/A
Clumps per ha	100 ± 0	400 ± 0	N/A
Clump radius (m)	2.67 ± 0.17b	1.667 ± 0.09a	$F(1,1) = 27.48; p = 0.006$
Culms per clump (no.)	193.3 ± 16.67b	60 ± 20.03a	$F(1,1) = 26.18; p = 0.007$
Culm density (no./ha)	19,333 ± 1,667a	24,000 ± 8,013b	$F(1,1) = 0.33; p = 0.599$
Culm diameter (cm)	5.83 ± 0.58a	7.4 ± 0.31b	$F(1,1) = 5.74; p = 0.075$
Culm height (m)	12.65 ± 0.87a	11.9 ± 2.01a	$F(1,1) = 0.12; p = 0.749$
Wall thickness (cm)	1.53 ± 0.17a	1.9 ± 0.06a	$F(1,1) = 3.9; p = 0.119$
Internode length (cm)	36.83 ± 0.60b	30 ± 0.58a	$F(1,1) = 67.24; p = 0.001$

Source: Field survey data; November 2020

4.5 Growth yield of the bamboo species planted in Kenya

The growth yield of bamboo is expressed in terms of the biomass accumulation potential of the species (Nigatu et al., 2020). Above-ground biomass was measured to assess the growth yields of different bamboo species across the 12 planting sites. Growth yield was expressed as tons of biomass (DW) / ha, and annual yield as tons of biomass/ha/yr. The growth yield for each bamboo species encountered in this assessment is presented in the section below.

4.5.1. *Oldeania alpina*

Oldeania alpina was recorded in Limuru and Ndakaini. Its growth yield ranged from 2.49 ± 0.96 to 3.31 ± 0.35 t/ha. It was higher in Limuru than in Ndakaini, but the difference was not statistically significant ($p = 0.454$). However, the annual yield was significantly higher in Limuru than in Ndakaini ($p < 0.001$) (Table 40).

Table 40. Growth yield of *O. alpina* in Limuru and Ndakaini

Variable	Limuru	Ndakaini	Statistical result
Yield (t DW/ha)	3.31 ± 0.35 ^a	2.49 ± 0.96 ^a	$p = 0.454$
Annual yield (t DW/ha/yr)	0.66 ± 0.07 ^b	0.07 ± 0.03 ^a	$p < 0.001$

Source: Field survey data; November 2020; DW = dry weight

Both the Limuru and Ndakaini results were much lower than those found by Wimbush (1947), who reported the average air DW of *O. alpina* at 100 t/ha. This could be attributed to the locations of the two sites, which are not within the *O. alpina* growing range. *Oldeania alpina* is a mountainous species growing at elevations of 2,500–3,300 m (Linder and Gehrke, 2008; Muchiri and Muga, 2008; Wimbush, 1945). The differences in yield between the two sites could be attributed to the management practices and other conditions prevailing at each site.

4.5.2. *Thyrsostachys siamensis*

The growth yield of *T. siamensis* ranged from 8.66 ± 2.8 to 18.69 ± 1.25 t/ha. The variation between three sites (Gede, Jilore, and Kehancha) was not significant. The variation in annual yield was also not statistically significant ($F_{(1,2)} = 3.68$; $p = 0.054$) (Table 41).

Table 41. Growth yield of *T. siamensis* in Gede, Jilore, and Kehancha

Variable	Gede	Jilore	Kehancha	Statistical result
Yield (t/ha)	18.69 ± 1.25 ^a	8.66 ± 2.8 ^a	15.31 ± 3.32 ^a	$F_{(1,2)} = 1.4$; $p = 0.28$
Annual yield (t DW/ha/yr)	0.64 ± 0.04 ^a	0.29 ± 0.09 ^a	1.39 ± 0.30 ^a	$F_{(1,2)} = 3.68$; $p = 0.054$

Source: Field survey data; November 2020

4.5.3. *Phyllostachys aurea*

Phyllostachys aurea occurred only in Limuru. Its growth yield was 84.26 ± 18.22 t/ha, while its annual yield was 16.85 ± 3.65 t/ha/yr (Table 42).

Table 42. Growth yield of *P. aurea* in Limuru

Variable	Lumuru
Yield (t DW/ha)	84.26 ± 18.22
Annual yield (t DW/ha/yr)	16.85 ± 3.65

Source: Field survey data; November 2020

4.5.4. *Oxytenanthera abyssinica*

The growth yield of *O. abyssinica* ranged from 0.8 ± 0.49 to 407.1 ± 64.08 t/ha, leading to a significant variation between the four sites where it was planted ($F_{(1,3)} = 14.51$; $p < 0.001$) (Table 43). The variation was caused by a significantly higher yield in Kehancha. The annual yield also varied significantly across sites ($F_{(1,3)} = 15.55$; $p < 0.001$) (Table 4.5.4). Generally, biomass estimations of *O. abyssinica* are scarce (Gurmessa et al., 2016), and this report could arguably be among the first that focused on the biomass yield analysis of this species.

Table 43. Growth yield of *O. abyssinica* in Jilore, KEFRI-Kibwezi, Kehancha, and Muguga sites in Kenya

Variable	Jilore	KEFRI-Kibwezi	Kehancha	Muguga	Statistical result
Yield (t DW/ha)	16.4 ± 5.38 ^a	0.8 ± 0.49 ^a	407.1 ± 64.08 ^b	53.9 ± 11.13 ^a	$F_{(1,3)} = 14.51$; $p < 0.001$
Annual yield (t DW/ha/yr)	0.55 ± 0.18 ^a	0.133 ± 0.08 ^a	33.92 ± 5.34 ^b	1.80 ± 0.37 ^a	$F_{(1,3)} = 15.55$; $p < 0.001$

Source: Field survey data; November 2020

4.5.5. *Dendrocalamus strictus*

The growth yield of *D. strictus* ranged from 1.16 ± 0.36 to 34.8 ± 10.95 t/ha. This extensive range resulted in a significant variation between the sites, with Kehancha recording the highest growth yield ($F_{(1,2)} = 9.14$; $p = 0.003$). A similar trend was observed in the annual growth yield (Table 44). The growth yield recorded in Kehancha exceeded what was reported by Piouceau et al. (2014) in France, where the annual yields of *D. strictus* were 1.4 ± 0.3 and 1.6 ± 0.3 in low and high nutrient concentrations, respectively. However, the study by Piouceau et al. (2014) only investigated one-year bamboo culms.

Table 44. Growth yield of *D. strictus* in Jilore, KEFRI-Kibwezi, and Kehancha

Variable	Jilore	KEFRI-Kibwezi	Kehancha	Statistical result
Yield (t DW/ha)	1.16 ± 0.36 ^a	1.87 ± 0.52 ^a	34.8 ± 10.95 ^b	$F_{(1,2)} = 9.14$; $p = 0.003$
Annual yield (t DW/ha/yr)	0.04 ± 0.01 ^a	0.31 ± 0.09 ^a	3.16 ± 1.00 ^b	$F_{(1,2)} = 8.67$; $p = 0.003$

Source: Field survey data; November 2020

4.5.6. *Dendrocalamus membranaceus*

The growth yield of *D. membranaceus* ranged from 32.8 ± 11.05 to 302.4 ± 31.13 t/ha across three sites. This extensive range resulted in a significant variation between the sites ($F_{(1,2)} = 45.3$; $p < 0.001$). Muguga recorded the highest growth yield, followed by Kagumo Gardens; Gede recorded the lowest. A similar pattern was observed in the annual growth yield (Table 45). The results for both Gede and Kagumo Gardens were comparable to those obtained by Komiya et al. (2001) in Viet Nam. However, the Muguga yield was higher than that obtained by Komiya et al. (2001).

Table 45. Growth yield of *D. membranaceus* in Gede, Kagumo Gardens, and Muguga

Variable	Gede	Kagumo	Muguga	Statistical result
Yield (t DW/ha)	32.8 ± 11.05 ^a	36.5 ± 12.47 ^a	302.4 ± 31.13 ^b	$F_{(1,2)} = 45.3$; $p < 0.001$
Annual yield (t DW/ha/yr)	1.13 ± 0.38 ^a	7.29 ± 2.49 ^{ab}	10.08 ± 1.04 ^b	$F_{(1,2)} = 9.56$; $p < 0.001$

Source: Field survey data; November 2020

4.5.7. *Dendrocalamus hamiltonii*

There was a significant variation in the growth yield of *D. hamiltonii* across sites ($F_{(1,2)} = 31.72$; $p < 0.001$). The lowest yield was 8.72 ± 0.37 t/ha, which was recorded in Busia, while the highest was 194.38 ± 20.27 t/ha, which was recorded in Mivumoni. A similar pattern was observed with the annual yield (Table 46). The results obtained from Busia Town and Muguga were comparable to those obtained from a study in Northeast India on the performance of *D. hamiltonii* (Rao and Saxena, 1995).

Table 46. Growth yield of *D. hamiltonii* in Busia Town, Mivumoni, and Muguga in Kenya

Variable	Busia Town	Mivumoni	Muguga	Statistical result
Yield (t DW/ha)	8.72 ± 0.37 ^a	194.38 ± 20.27 ^b	54.79 ± 17.51 ^a	$F_{(1,2)} = 31.72$; $p < 0.001$
Annual yield (t DW/ha/yr)	1.25 ± 0.05 ^a	7.78 ± 0.81 ^b	1.83 ± 0.58 ^a	$F_{(1,2)} = 32.81$; $p < 0.001$

Source: Field survey data; November 2020

4.5.8. *Dendrocalamus giganteus*

The growth yield for *D. giganteus* ranged from 123 ± 23.74 to 390.3 ± 66.05 t/ha. This extensive range led to a significant variation in the species' growth yield across four sites, with Kehancha recording the highest yield ($F_{(1,3)} = 4.28$; $p = 0.024$). Kehancha also had the highest annual growth yield, but the pattern was not similar for the three other sites (Table 47). The figures for Kehancha closely mirror those reported for the same species at 20–30 t/ha/yr by Truong et al. (2014).

Table 47. Growth yield for *D. giganteus* planted in Kairi-ini, Kehancha, Muguga, and Ndakaini in Kenya

Variable	Kairi-ini	Kehancha	Muguga	Ndakaini	Statistical result
Yield (t/ha)	123 ± 23.74 ^a	390.3 ± 66.05 ^b	197.1 ± 81.64 ^{ab}	173.2 ± 37.77 ^{ab}	$F_{(1,3)} = 4.28$; $p = 0.024$
Annual yield (t DW/ha/yr)	8.97 ± 1.46 ^a	27.88 ± 4.72 ^b	6.57 ± 2.72 ^a	4.95 ± 1.08 ^a	$F_{(1,3)} = 10.58$; $p < 0.001$

Source: Field survey data; November 2020

4.5.9. *Dendrocalamus brandsii*

Dendrocalamus brandsii appeared only in Muguga. Its growth yield is summarized in Table 48.

Table 48. Biomass yield of *D. brandsii* in Muguga in central Kenya

Variable	Muguga
Yield (t DW/ha)	121.2 ± 65.09
Annual yield (t DW/ha/yr)	4.04 ± 2.17

Source: Field survey data; November 2020

4.5.10. *Dendrocalamus birmanicus*

Dendrocalamus birmanicus was encountered only in Muguga. Its growth yield is summarized in Table 49.

Table 49. Growth yield of *D. birmanicus* in Muguga

Variable	Muguga
Yield (t DW/ha)	32.62 ± 15.4
Annual yield (t DW/ha/yr)	1.087 ± 0.5133

Source: Field survey data; November 2020

4.5.11. *Dendrocalamus asper*

The growth yield of *D. asper* ranged from 5.7 ± 1.49 to 175.19 ± 32.20 t/ha across six planting sites. This extensive range resulted in a significant variation in growth yield ($F_{(1,5)} = 25.24$; $p < 0.001$). Although Muguga had a high growth yield, Limuru had the highest annual growth yield (Table 50).

Table 50. Growth yield of *D. asper* in Busia Town, Isecheno, Kagumo Gardens, Kairi-ini, Limuru, and Muguga in Kenya

Variable	Busia Town	Isecheno	Kagumo Gardens	Kairi-ini	Limuru	Muguga	Statistical result
Yield (t/ha)	34.76 ± 9.64 ^a	9.33 ± 1.23 ^a	5.7 ± 1.49 ^a	7.94 ± 0.90 ^a	52.43 ± 9.48 ^a	175.19 ± 32.20 ^b	$F_{(1,5)} = 25.24$; $p < 0.001$
Annual yield (t DW/ha/yr)	4.97 ± 1.38 ^{bc}	1.33 ± 0.18 ^{ab}	1.14 ± 0.30 ^a	0.99 ± 0.11 ^a	10.49 ± 1.90 ^d	5.84 ± 1.07 ^c	$F_{(1,5)} = 16.43$; $p < 0.001$

Source: Field survey data; November 2020

4.5.12. *Bambusa vulgaris var. vulgaris*

The growth yield of *B. vulgaris var. vulgaris* ranged from 2.57 ± 1.22 to 158.04 ± 19.27 t/ha across six plantation sites. Its annual yield ranged from 0.21 ± 0.05 to 13.75 ± 1.79 t/ha/yr (Table 51). These results are higher than those obtained by Piouceau et al. (2014, 2020) in France on the biomass yield of *B. vulgaris var. vulgaris*.

Table 51. Growth yield of *B. vulgaris* var. *vulgaris* in Isecheno, Kagumo Gardens, KEFRI-

Variable	Iseche no	Kagumo Gardens	KEFRI-Kibwezi	Kehancha	Limuru	Ndakai ni	Statistical result
Yield (t DW/ha)	96.2 ± 12.5 ^{ab}	45.25 ± 2.11 ^a	2.57 ± 1.22 ^a	158.04 ± 19.27 ^b	40.27 ± 10.08 ^a	7.18 ± 1.72 ^a	$F(1,5) = 14.45; p < 0.001$
Annual yield (t DW/ha/yr)	13.75 ± 1.79 ^c	9.05 ± 0.42 ^{bc}	0.43 ± 0.20 ^a	13.17 ± 1.61 ^c	4.03 ± 1.01 ^{ab}	0.21 ± 0.05 ^a	$F(1,5) = 15.04; p < 0.001$

Kibwezi, Kehancha, Limuru, and Ndakaini

Source: Field survey data; November 2020

4.5.13. *Bambusa vulgaris* var. *vittata*

The growth yield of *B. vulgaris* var. *vittata* ranged from 6.67 ± 1.7 to 235.12 ± 101 t/ha across eight sites. Its annual growth yield ranged from 0.19 ± 0.05 to 47.03 ± 20.3 t DW/ha/yr (Table 52).

Table 52. Growth yield of *B. vulgaris* var. *vittata* in Busia Town, Gede, Isecheno, Kagumo Gardens, Kairi-ini, Kehancha, Muguga, and Ndakaini

Variable	Busia Town	Gede	Isecheno	Kagumo Gardens	Kairi-ini	Kehancha	Muguga	Ndakaini	Statistical result
Yield (t/ha)	8.04 ± 1.47 ^{ab}	56.32 ± 1.3 ^{abc}	3.9 ± 0.12 ^a	235.12 ± 101 ^{ac}	26.2 ± 1.2 ^{abc}	192.58 ± 25.4 ^{ac}	173.73 ± 66.8 ^{abc}	6.67 ± 1.7 ^{ab}	$F(1,7) = 5.12; p < 0.001$
Annual yield (t DW/ha/yr)	1.15 ± 0.21 ^a	1.94 ± 0.045 ^a	0.56 ± 0.02 ^a	47.03 ± 20.3 ^b	3.28 ± 0.15 ^a	13.756 ± 1.81 ^a	5.791 ± .23 ^a	0.19 ± 0.05 ^a	$F(1,7) = 8.33; p < 0.001$

Source: Field survey data; November 2020

4.5.14. *Bambusa tulda*

Bambusa tulda occurred only in Muguga. Its growth yield was 61.25 ± 9.609 t/ha, while its annual yield was 2.042 ± 0.3203 t DW/ha/yr (Table 53).

Table 53. Growth yield of *B. tulda* in Muguga

Variable	Muguga
Yield (t/ha)	61.25 ± 9.61
Annual yield (t DW/ha/yr)	2.04 ± 0.32

Source: Field survey data; November 2020

4.5.15. *Bambusa multiplex*

Bambusa multiplex occurred only in Limuru. Its growth yield is summarized in Table 54.

Table 54. Growth yield of *B. multiplex* in Limuru

Variable	Limuru
Yield (t/ha)	6.41 ± 0.89
Annual yield (t DW/ha/yr)	1.28 ± 0.18

Source: Field survey data; November 2020

4.5.16. *Bambusa blumeana*

The growth yield of *Bambusa blumeana* ranged from 8.07 ± 2.89 to 45.16 ± 10.11 t/ha across three sites. The annual yield ranged from 0.32 ± 0.12 to 1.51 ± 0.34 (Table 55).

Table 55. Growth yield of *B. blumeana* in Jilore, Mivumoni, and Muguga

Variable	Jilore	Mivumoni	Muguga	Statistical result
Yield (t/ha)	11.6 ± 3.54 ^a	8.07 ± 2.89 ^a	45.16 ± 10.11 ^b	$F_{(1,2)} = 10.21; p = 0.005$
Annual yield (t DW/ha/yr)	0.39 ± 0.11 ^a	0.32 ± 0.12 ^a	1.51 ± 0.34 ^b	$F_{(1,2)} = 9.42; p = 0.006$

Source: Field survey data; November 2020

4.5.17. *Bambusa bambos*

The growth yield of *Bambusa bambos* ranged from 212.6 ± 29.57 to 510.4 ± 145.8 t/ha. Its annual yield ranged from 7.09 ± 0.99 to 46.4 ± 13.26 t DW/ha/yr (Table 56).

Table 56. Growth yield of *B. bambos* in Jilore and Kehancha

Variable	Jilore	Kehancha	Statistical result
Yield (t/ha)	212.6 ± 29.57 ^a	510.4 ± 145.8 ^a	$F_{(1,1)} = 5.51; p = 0.066$
Annual yield (t DW/ha/yr)	7.09 ± 0.99 ^a	46.4 ± 13.26 ^b	$F_{(1,1)} = 12.43; p = 0.017$

Source: Field survey data; November 2020

4.6 Bamboo species uses

4.6.1. *Oldeania alpina*

It is used for fencing (mostly untreated) and the construction of nursery beds, houses (in very remote areas), and baskets. In old times, this species was used for carrying arrows and storing food materials (in hollow cut culms). Today, it is used for making curios, ornamental baskets, toothpicks, lampshades, pen holders, and so on.

4.6.2. *Dendrocalamus giganteus*

It is a key source of fuelwood for households and industries and is used as building materials and scaffolding. It is also used for making toothpicks and furniture and for soil improvement and soil erosion control.

4.6.3. *Dendrocalamus asper*

It is used as fuelwood and for making furniture, scaffolding, and toothpicks. It is also used for construction, soil improvement, and soil erosion control.

4.6.4. *B. vulgaris var. vittata*

It is used as an ornamental and for fencing, construction, furniture making, and soil erosion control.

4.6.5. *Bambusa multiplex*

It is used as a live hedge and an ornamental.

4.6.6. *Phyllostachys aurea*

It is used as a live hedge and an ornamental.

4.6.7. *B. vulgaris var. vulgaris*

It is used as an ornamental and for fencing, construction, and furniture making.

4.6.8. *Bambusa tulda*

It is used as fuelwood and an ornamental, and its culms are used in horticultural farms.

4.6.9. *Dendrocalamus brandsii*

It is used in scaffolding, construction, and fencing and for toothpicks. It has edible shoots.

4.6.10. *Dendrocalamus birmanicus*

It is used for toothpicks and for scaffolding, construction, fencing, furniture making, and environmental conservation.

4.6.11. *Bambusa blumeana*

It is used as fuelwood and for environmental conservation and fencing.

4.6.12. *Dendrocalamus strictus*

It is used for toothpicks and for scaffolding, construction, fencing, furniture making, and environmental conservation.

4.6.13. *Dendrocalamus membranaceus*

It is used for toothpicks and for scaffolding, construction, fencing, furniture making, and environmental conservation.

4.6.14. *Oxytenanthera abyssinica*

It is used as fuelwood and an ornamental and for toothpicks and fencing.

4.6.15. *Thyrsostachys siamensis*

It is used as fuelwood and an ornamental and for toothpicks and fencing.

4.6.16. *Dendrocalamus hamiltonii*

It is used for toothpicks and for scaffolding, construction, fencing, furniture making, and environmental conservation.

4.6.17. *Bambusa bambos*

It is used as fuelwood and toothpicks and for construction, fencing, furniture making, and environmental conservation.

4.7 Insect pests and diseases of bamboo in their native ranges

This study also observed the insect pests and diseases that infested the introduced bamboo species. This information will help bamboo farmers and growers manage clumps scientifically for better yields and management. Bamboos are prone to attacks by various kinds of insects (Paduvil, 2008) and diseases, which lower the quality and quantity of bamboo products. These insects can be broadly divided into those that attack live bamboo and those that attack post-harvested bamboo. In the former category, the major groups include insects that attack foliage and culms. They belong to the insect orders of Orthoptera, Hemiptera, Lepidoptera, and Coleoptera (Koshy et al., 2001). The nature of damage entails foliage feeding, sap sucking, and hole boring on culms and shoots. According to Haojie et al. (1998), culm and shoot borers cause more damage to bamboo clumps than other groups of insects. Scale insects usually secrete honey dew, and the damaged bamboo (leaves, branches, and culms) shows black and white appearance because of the sooty mold fungus that grows on the secretion. Spider mites, Acariformes, cause damage by sucking sap from the leaves. The damaged leaves show discolored stripes and spots that dry up and fall, reducing the growth and vigor of bamboo plants. Thrips feed on foliage sap, making the leaves distorted and spindle shaped.

Leaf rust develops linearly on the leaves. Severe rust infection causes abnormal leaf falls (Mohanani, 2010). Leaf spots reduce the leaf photosynthetic area. Severe infection leads to the yellowing and drying up of foliage. In the case of disease attack, the fungi progress in the tree system, causing the death of vascular bundles, stunting the growth of the tree, and gradually leading to death. Once introduced, pathogens persist in an environment through survival mechanisms, awaiting new hosts or re-infecting the hosts. Climate change could be a factor—a

warming climate has been postulated to increase pest ranges and make plants more susceptible to attacks because of moisture stress.

The most common insect pests were leaf miners, and sap suckers were predominant on young shoots and foliage. Sap-sucking scale insects, whose bodies are covered in a waxy material, formed the bulk of insects on bamboo culms. Spider mites were found sucking sap from the leaves of most bamboo plants assessed. Thrips (Thysanoptera), about 0.5–3 mm in length, were also recorded on *B. bambos* in most of the assessed regions. Leaf rust was microscopically identified on *B. bambos*, *B. vulgaris vulgaris*, *B. vulgaris vitatta*, and *Oxytenthera Sp.* foliage samples collected from Kehancha. Culm borers (Coleoptera) were also identified as insect pests attacking mature culms and culms in unmanaged clumps.

Leaf spot disease, which occurs on mature leaves, was identified in all the foliage samples collected. The disease severity rate ranged from low (L) to medium (M); in particular, it was low in the warmer regions of Kehancha and Busia Town, whereas Kairi-ini and Muguga recorded a moderate severity of leaf rust and leaf spot disease.

5. Bamboo species–site matching

This section of the report provides an analysis of the growth performance of the different bamboo species across the plantation sites in Kenya. Growth performance is compared with the expected scenarios in the species' native ranges. The analysis is intended to offer insights into the likely performance of each bamboo species across Kenya's eco-climatic zones.

5.1 Indigenous bamboo species: growth performance and site suitability

5.1.1. Site suitability analysis for *Oldeania alpina*

The only indigenous bamboo species that was found in Kenya was *O. alpina*. Its mean height, diameter, and stocking density were significantly low, even in elevated zones that were only 200 m below its natural range (Table 57). This resulted in extremely low yields for such sites (2.5%–3.3% of the expected situation in its natural range), which is not viable for economic investment. Therefore, the species is unsuitable for plantation establishment outside its natural range of 2,300–3,200 m a.s.l. If planted below this range, it will not die, but its height and diameter will not attain economically viable sizes. Thus, it can only be planted below its natural range for ornamental and conservation purposes.

Table 57. Site suitability analysis for *O. alpina* in Kenya

Variable	Native range	Performance in plantation sites in Kenya	
	Kenyan sub-alpine zone – Mau Aberdares, Mt. Elgon, and Mt. Kenya	Limuru (LH1)	Ndakaini (UM1)
Elevation (m a.s.l.)	2,300–3,200	2,085	2056
Rainfall (mm)	1,100–2,500	1,067	1,800
Temperature (°C)	13	16	18
Soil pH		5.6–6.0	5.1–5.5
Culm height (m)	10	3.467	2.833
Culm diameter (cm)	7.5	2.133	0.917
Culms per ha (no./ha)	21,000	6,000	1,917

Yield (t/ha)	100	3.31	2.49
Annual yield (t/ha/yr)		0.66	0.07
Relative yield (compared to the native range)	100	3.3%	2.5%
Site suitability		Poor	Poor
Recommendation		Plant for ornamental and conservation purposes only	

Source: Field survey; November 2020

5.2 Exotic bamboo species: growth performance and site suitability

5.2.1. Plantation site suitability analysis for *Thyrsostachys siamensis* in Kenya

The mean height and diameter of *T. siamensis* culms growing in different plantation sites in Kenya were slightly lower than those of its native range, but they remained within the expected range (Table 58). The species tended to perform better in lower-elevation coastal zones, such as Gede and Jilore, than in mid-elevation zones, such as Kehancha. Whereas Kehancha recorded a relatively higher yield than the other plantations in Kenya did, this occurred because of its high stocking density. The culms in Kehancha had not been harvested for a long time. The results suggest that this bamboo species is likely to thrive in coastal lowlands of CL2–4. It performs marginally in low-lying midland zones of LM2–3.

Table 58. Site suitability analysis for *T. siamensis* in Kenya

Variable	Native range	Performance in plantation sites in Kenya		
		Gede (CL4)	Jilore (CL4)	Kehancha (LM2)
Elevation (m a.s.l.)	500–1,000	25	85	1,504
Rainfall (mm)	1,000–2,000	1,059	927	1,400
Temperature (°C)	20°C–29°C	27	27	21.7
Soil pH	6–6.5	6.6–7.3	5.6–6.0	6.6–7.3
Culm height (m)	7–13	8.67	6.53	3.50

Culm diameter (cm)	2–6	3.0	2.28	1.81
Culms per ha (no./ha)	6,000	6,667	6,400	57,600
Yield (t/ha)		18.69	8.66	15.31
Annual yield (t/ha/yr)	1.5	0.64	0.29	1.39
Relative yield (compared to the native range)				
Site suitability		V. good	Good	Fair
Recommendation		CL2–4 and LM2		

Source: Field survey; November 2020

5.2.2. Plantation site suitability analysis for *Phyllostachys aurea* in Kenya

Phyllostachys aurea was recorded in only one plantation site in Kenya—in Limuru, which is a lower highland zone 1 (LH1). Although the elevation here was way above that for the native range, the species' recorded mean height and diameter were within the expected range (Table 59). It also had a significantly higher stocking density, which resulted in a higher yield than that of its native range. The species' high stocking density and its runner nature explain its successful application as a live hedge in Limuru. The results suggest that this species is versatile enough to thrive in most LM, UM, and LH zones. However, its growth habit calls for regular maintenance to ensure that it does not become invasive.

Table 59. Site suitability analysis for *P. aurea* in Kenya

Variable	Native range	Performance in plantation sites in Kenya
	China and Viet Nam	Limuru (LH1)
Elevation (m a.s.l.)	1,000– 2,000	2,085
Rainfall (mm)		1,067
Temperature (°C)		16
Soil pH		5.6–6.0
Culm height (m)	2–8	4.07
Culm diameter (cm)	2–3	2.15
Culms per ha (no./ha)	38,017	90,000

Yield (t/ha)	67.78	68.25
Annual yield (t/ha/yr)		16.85
Relative yield (compared to the native range)		100.1%
Site suitability		Excellent
Recommendation		LM1–2, UM1–3, and LH1–3

Source: Field survey; November 2020

5.2.3. Plantation site suitability analysis for *Oxytenanthera abyssinica* in Kenya

The mean height, diameter, and yield of *O. abyssinica* indicated that the species performed exceedingly better in Kenya's humid zones than did its native range. This happened even in sites with elevations far above the species' recommended range. However, the results also showed that it performed poorly in sub-humid and dry environments in Kenya (Table 60). In this regard, the species is suitable for humid zones that fall within LM2 to LH3.

Table 60. Site suitability analysis for *O. abyssinica* in Kenya

Variable	Native range	Performance in plantation sites in Kenya			
	Ethiopia, Senegal, Tanzania, and Zimbabwe	Kehancha (LM2)	Muguga (LH3)	Jilore (CL4)	Kibwezi (LM5)
Elevation (m a.s.l.)	50–1,500	1,504	2,070	85	945
Rainfall (mm)		1,400	954	927	659
Temperature (°C)		21.7	15.9	27	22.6
Soil pH		6.6–7.3	6.6–7.3	5.6–6.0	6.6–7.3
Culm height (m)	5–10	11.5	6.12	8.48	5.47
Culm diameter (cm)	3–8	6.58	2.88	4.07	3.0
Culms per ha (no./ha)	100	31,067	38,133	3,700	633
Yield (t/ha)	28	40.71	53.9	16.4	0.8
Annual yield (t/ha/yr)		33.92	1.80	0.55	0.13

Relative yield (compared to the native range)		145%	193%	57%	2.9%
Site suitability		Excellent	Good	Good	Poor
Recommendation		LM1–2, UM1–2, and LH3			

Source: Field survey; November 2020

5.2.4. Plantation site suitability analysis for *Dendrocalamus strictus* in Kenya

The mean height and diameter of *D. strictus* indicated that it tended to perform better in lower-elevation and sub-humid zones, such as Jilore and Kibwezi (Table 61). The yield for Kehancha, a humid zone, was significantly higher because of its high stocking density, but its mean height and diameter were lower than those in Jilore and Kibwezi. It is worth noting that bamboo culms at the Kehancha site have not been harvested for well over a decade, while those for Kibwezi and Jilore have been subjected to some level of exploitation on a regular basis. Therefore, this species is suitable for the CL2–4 and LM2–5 zones.

Table 61. Site suitability analysis for *D. strictus* in Kenya

Variable	Native range	Performance in plantation sites in Kenya		
	India, Laos, Myanmar, Nepal, Pakistan, Thailand, and Viet Nam	Jilore	KEFRI-Kibwezi	Kehancha
Elevation (m a.s.l.)	1–1,200	85	945	1504
Rainfall (mm)		927	659	1,400
Temperature (°C)		27	22.6	21.7
Soil pH		5.6–6.0	6.6–7.3	6.6–7.3
Culm height (m)	8–20	4.03	6.58	3.39
Culm diameter (cm)	2.5–8	3.3	4.33	2.26
Culms per ha (no./ha)		1,167	1,333	42,667
Yield (t/ha)		1.16	1.87	34.8
Annual yield (t/ha/yr)		0.04	0.31	3.16

Relative yield (compared to the native range)				
Site suitability		Good	V. good	Good
Recommendation		CL2–4 and LM2–5		

Source: Field survey; November 2020

5.2.5. Plantation site suitability analysis for *Dendrocalamus membranaceus* in Kenya

The growth performance of *D. membranaceus* indicated that it thrived in lower-elevation zones. For instance, the growth performance in Gede at 25 m a.s.l. involved a relatively lower mean culm height and diameter than those in Kagumo and Muguga. There were taller culms and higher stocking rates in the latter than in Gede, but the yields were lower (Table 62). The results showed that the species' DW tended to decrease with an increase in elevation. Therefore, the species is suitable for humid low-elevation zones, such as CL2–4, LM1–2, and UM1–2.

Table 62. Site suitability analysis for *D. membranaceus* in Kenya

Variable	Native range	Performance in plantation sites in Kenya		
	China, Laos, Myanmar, Taiwan, and Thailand	Gede (CL4)	Kagumo (UM2)	Muguga (LH3)
Elevation (m a.s.l.)	1–1,000	25	1757	2,070
Rainfall (mm)		1,059	933	954
Temperature (°C)		27	18	15.9
Soil pH		6.6–7.3	6.1–6.5	6.6–7.3
Culm height (m)	20–24	6.37	7.5	9.37
Culm diameter (cm)	6–10	3.23	5.87	4.12
Culms per ha (no./ha)		1,197	5,733	5,304
Yield (t/ha)		32.8	36.5	15.4
Annual yield (t/ha/yr)		1.13	7.29	0.51
Relative yield (compared to the native range)				
Site suitability		V. Good	Good	Poor

Recommendation	CL2–4, LM1–2, and UM2
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Source: Field survey; November 2020

5.2.6. Plantation site suitability analysis for *Dendrocalamus hamiltonii* in Kenya

The mean height, diameter, and stocking density of *D. hamiltonii* indicated that it thrived in lower-elevation zones in Kenya (Table 63). For instance, in Muguga (LH3), which was at 2,070 m a.s.l., the species had more culms than in the two other sites, but these were smaller in diameter, leading to a relatively lower yield. Similarly, the species in Busia Town (LM1), which was at 1,227 m a.s.l., had a height and diameter comparable to those in Mivumoni, but it had fewer culms, which led to a lower yield. Mivumoni (CL2), which was at 66 m a.s.l., had the tallest culms and the highest yield (Table 63). In this regard, *D. hamiltonii* is likely to perform much better in lower-elevation zones with fairly reliable rainfall, such as CL2–4, LM1–2, and low-lying UM2 zones.

Table 63. Site suitability analysis for *D. hamiltonii* in Kenya

Variable	Native range	Performance in plantation sites in Kenya		
	China, India, Laos, Myanmar, Thailand, and Viet Nam	Busia Town (LM1)	Mivumoni (CL2)	Muguga (LH3)
Elevation (m a.s.l.)	1–1,000	1,227	66	2,070
Rainfall (mm)		1,600	1,386	954
Temperature (°C)		22.2	27	15.9
Soil pH		5.6–6.0	5.1–5.5	6.6–7.3
Culm height (m)	12–25	7.07	13.9	7.83
Culm diameter (cm)	9–20	9.53	8.32	4.43
Culms per ha (no./ha)		908	12,000	15,200
Yield (t/ha)		8.72	194.38	54.79
Annual yield (t/ha/yr)		1.25	7.78	1.83

Relative yield (compared to the native range)				
Site suitability		Good	V. good	Fair
Recommendation		CL2–4, LM1–2, and low-lying UM2 zones		

Source: Field survey; November 2020

5.2.7. Plantation site suitability analysis for *Dendrocalamus giganteus* in Kenya

The results of the assessment suggested that *D. giganteus* had a wide range of ecological preferences. It tended to thrive in humid lower-elevation zones, such as LM1–2, but it also performed well in mid-ecological zones, such as UM1–2. This was evident in its relatively higher mean culm height, diameter, and yield in Kehancha (LM2, which was at 1,504 m a.s.l.), Kairini (UM1, which was at 2,042 m a.s.l.), and Ndakaini (UM1, which was at 2,056 m a.s.l.). The range extended higher up into the lower highland zone (LH3) (Table 64). In this regard, the species can be promoted in most humid zones in Kenya. However, it is expected to provide the best returns in low-lying humid environments. It is also worth noting that the height and diameter recorded in this study were about half of the expected figures for its natural range.

Table 64. Site suitability analysis for *D. giganteus* in Kenya

Variable	Native range	Performance in plantation sites in Kenya			
	Bhutan, China, Myanmar, and Thailand	Kairi-ini (UM1)	Kehanch a (LM2)	Muguga (LH3)	Ndakaini (UM1)
Elevation (m a.s.l.)	1–1,200	2,042	1,504	2,070	2,056
Rainfall (mm)		1,600	1,400	954	1,800
Temperature (°C)		19	21.7	15.9	18
Soil pH		5.1–5.5	6.6–7.3	6.6–7.3	5.1–5.5
Culm height (m)	25–35	12.5	13.2	10	12.88
Culm diameter (cm)	10–35	8.33	11.68	8.97	8.55
Culms per ha (no./ha)		12,000	16,667	25,200	15,738
Yield (t/ha)		123	390.3	197.1	173.2

Annual yield (t/ha/yr)	20–30	8.97	27.88	6.57	4.95
Relative yield (compared to the native range)					
Site suitability		Good	V. good	Good	Good
Recommendation		LM1–2, UM1–2, and LH3			

Source: Field survey; November 2020

5.2.8. Plantation site suitability analysis for *Dendrocalamus brandisii* in Kenya

Dendrocalamus brandisii was reported only in Muguga (LH3), whose elevation was far above that of the species' natural range (Table 65). Although its performance at this site was just about a third of that of its natural range, it recorded a fairly high yield, which indicated that it was likely to perform well at this elevation under good management. The species is likely to perform much better in low-lying humid zones, such as LM1–2 and UM1–2.

Table 65. Site suitability analysis for *D. brandisii* in Kenya

Variable	Native range	Performance in plantation sites in Kenya
	China, India, Laos, Myanmar, Thailand, and Viet Nam	Muguga (LH3)
Elevation (m a.s.l.)	1–1,300	2,070
Rainfall (mm)		954
Temperature (°C)		15.9
Soil pH		6.6–7.3
Culm height (m)	19–33	7.62
Culm diameter (cm)	13–20	4.53
Culms per ha (no./ha)		36,267
Yield (t/ha)		121.2
Annual yield (t/ha/yr)		4.04
Relative yield (compared to the native range)		
Site suitability		Good
Recommendation		LM1–2 and UM1–2

Source: Field survey; November 2020

5.2.9. Plantation site suitability analysis for *Dendrocalamus birmanicus* in Kenya

The researchers were unable to obtain data on the growth performance of *D. birmanicus* in the native range. Therefore, it was difficult to identify a suitable AEZ for this species. The analysis will be done after obtaining more information about the species' performance in its native range. Its site suitability in Muguga is recorded in Table 66.

Table 66. Site suitability analysis for *D. birmanicus* in Kenya

Variable	Native range	Performance in plantation sites in Kenya
	China and Myanmar	Muguga (LH3)
Elevation (m a.s.l.)	N/A	2,070
Rainfall (mm)	N/A	954
Temperature (°C)	N/A	15.9
Soil pH	N/A	6.6–7.3
Culm height (m)	10	6.7
Culm diameter (cm)	8	3.18
Culms per ha (no./ha)	N/A	22,400
Yield (t/ha)	N/A	32.62
Annual yield (t/ha/yr)	N/A	1.087

Source: Field survey; November 2020

5.2.10. Plantation site suitability analysis for *Dendrocalamus asper* in Kenya

The mean culm height and diameter of *D. asper* indicated that it tended to thrive in low-lying humid zones (Table 67). Although the results from Muguga (LH3) suggested that the species can perform well in higher-elevation zones, those from Isecheno, Kagumo, and Kairi-ini (all UM zones) and Limuru (LH1 zone) indicated that the species appeared to struggle in UM and LH zones. In this regard, it is suggested that the species be grown in the humid range of LM1–2 and CL2 zones only.

Table 67. Site suitability analysis for *D. asper* in Kenya

Variable	Native range	Performance in plantation sites in Kenya					
		Bangladesh, China, Malaysia, Myanmar, the Philippines, Taiwan, Thailand, and Viet Nam	Busia Town (LM1)	Isechen o (UM1)	Kagumo Gardens (UM2)	Kairi-ini (UM1)	Limuru (LH1)
Elevation (m a.s.l.)	1–1,500	1,227	1,633	1,757	2,042	2,085	2,070
Rainfall (mm)	1,800–3,600 mm	1,600	2,100	933	1,600	1,067	954
Temperature (°C)	20°C–27°C	22.2	20.5	18	19	16	15.9
Soil pH		5.6–6.0	5.6–6.0	6.1–6.5	5.1–5.5	5.6–6.0	6.6–7.3
Culm height (m)	15–30	11.83	9.43	7.32	4.67	4.47	14.25
Culm diameter (cm)	8–20	13.33	7.5	5.46	3.88	4.57	9.98
Culms per ha (no./ha)		1,392	1,733	1,167	6,133	16,267	12,533
Yield (t/ha)		34.76	9.33	5.7	7.94	52.43	175.19
Annual yield (t/ha/yr)		4.97	1.33	1.14	0.99	10.49	5.84
Relative yield (compared to the native range)							
Site suitability		V. good	Poor	Poor	Poor	Fair	Good
Recommendation		LM1–2 and CL2					

Source: Field survey; November 2020

5.2.11. Plantation site suitability analysis for *Bambusa vulgaris* var. *vulgaris* in Kenya

The mean culm height, diameter, and yield of *B. vulgaris* var. *vulgaris* indicated that it performed better in humid low-lying zones. This appeared to have been the case in Isecheno (UM1) and Kehancha (LM2). However, it tended to struggle in lower-elevation zones with a moisture deficit, as was the case in Kibwezi (Table 68). The species can grow in elevation zones a little higher than its optimal range at 1–1,200 m a.s.l but with reduced vigor, as was observed in Limuru (LH1) and Ndakaini (Table 5.12). The species is suitable for low-lying, humid LM, and UM zones.

Table 68. Site suitability analysis for *B. vulgaris* var. *vulgaris* in Kenya

Variable	Native range	Performance in plantation sites in Kenya					
	Southeast Asia – Indochina	Isecheno (UM1)	Kigumo Gardens (UM2)	KEFRI-Kibwezi (LM5)	Kehancha (LM2)	Limuru (LH1)	Ndakaini (UM1)
Elevation (m a.s.l.)	1–1,200	1633	1757	945	1,504	2,085	2,056
Rainfall (mm)	1,200–2,500	2,100	933	659	1,400	1,067	1,800
Temperature (°C)	22°C–28°C	20.5	18	22.6	21.7	16	18
Soil pH		5.6–6.0	6.1–6.5	6.6–7.3	6.6–7.3	5.6–6.0	5.1–5.5
Culm height (m)	10–20	8.1	8.57	7.07	9.41	6.7	6.97
Culm diameter (cm)	4–12	8.87	4.83	4.5	5.63	5.73	4.5
Culms per ha (no./ha)	2,250	14,400	15,200	833	20,267	26,800	1,700
Yield (t/ha)	57	96.2	45.25	2.57	158.04	40.27	7.18
Annual yield (t/ha/yr)	20	13.75	9.05	0.43	13.17	4.03	0.21

Relative yield (compared to the native range)		169%	79%	5%	277%	71%	13%
Site suitability		V. good	Fair	Poor	V. good	Fair	Poor
Recommendation		LM1–2 and low-lying UM1 zones					

Source: Field survey; November 2020

5.2.12. Plantation site suitability analysis for *Bambusa vulgaris* var. *vittata* in Kenya

The growth performance of *B. vulgaris* var. *vittata* indicated that it had a wide ecological range. Its performance did not seem to be significantly affected by elevation (Table 69). However, the variation in results across sites with similar agro-ecological characteristics suggested that its variation in growth performance may also be explained by differences in management operations and provenances. It appeared to struggle in Busia (LM1), but this was attributed to management practices because it performed extremely well in Kehancha (LM2). These two sites did not differ much in elevation, rainfall, and temperature range. The species also performed well in Gede on the Kenyan coast (CL4). Similarly, it thrived in Kairini (UM1) but struggled in Ndakaini (UM1). Both sites were within the same elevation, rainfall, and temperature ranges. The species registered one of the best performances in Muguga (LH3). Thus, it is realistic to suggest that *B. vulgaris* var. *vittata* is likely to thrive in most AEZs in Kenya if subjected to sound silvicultural operations.

Table 69. Site suitability analysis for *B. vulgaris* var. *vittata* in Kenya

Variable	Native range	Performance in plantation sites in Kenya							
		China and Japan	Busia Town (LM1)	Gede (CL4)	Isecheno (UM1)	Kagumo Gardens (UM2)	Kairi-ini (UM1)	Kehancha (LM2)	Muguga (LH3)
Elevation (m a.s.l.)	1,000	1,227	25	1,633	1,757	2,042	1,504	2,070	2,056
Rainfall (mm)		1,600	1,059	2,100	933	1,600	1,400	954	1,800
Temperature (°C)		22.2° C	27	20.5	18	19	21.7	15.9	18
Soil pH		5.6– 6.0	6.6– 7.3	5.6–6.0	6.1–6.5	5.1–5.5	6.6–7.3	6.6–7.3	5.1–5.5

Culm height (m)	10–15	6.5	8.03	6.5	8.57	4.83	9.23	6.42	5.98
Culm diameter (cm)	5–8	5.12	4.2	5.33	7.27	4.3	5.49	4.18	4.17
Culms per ha (no./ha)		1,692	10,000	1,292	29,600	4,828	24,000	45,333	367
Yield (t/ha)		8.04	56.32	3.9	235.12	26.2	192.58	173.73	6.67
Annual yield (t/ha/yr)		1.15	1.94	0.56	47.03	3.28	13.756	5.791	0.19
Relative yield (compared to the native range)									
Site suitability		Poor	Good	Poor	V. good	Fair	V. good	Good	Poor
Recommendation		Good management in LM1–3, UM1–3, CL2–4, and LH3							

Source: Field survey; November 2020

5.2.13. Plantation site suitability analysis for *Bambusa tulda* in Kenya

Although *B. tulda* had an extremely good yield in Muguga (LH3), the site appeared to be too high for it in terms of elevation (Table 70). This can be seen in the species' culm height and diameter. Thus, the high yield was attributed to its large number of culms. This large number of culms with relatively smaller culm sizes may have been an adaptation to the low temperature in the LH zone. The species may have performed much better in terms of culm size if it were planted in an LM1–2 zone or a low-lying UM1–2 zone. Therefore, this species is suggested for commercial production in LM1–2 and UM1–2 zones.

Table 70. Site suitability analysis for *B. tulda* in Kenya

Variable	Native range	Performance in plantation sites in Kenya
	China and India	Muguga (LH3)
Elevation (m a.s.l.)	1–1,500	2,070
Rainfall (mm)	1,200–2,500	954
Temperature (°C)	22°C–28°C	15.9
Soil pH		6.6–7.3
Culm height (m)	6–20	3.75
Culm diameter (cm)	5–10	2.883
Culms per ha (no./ha)	5,244	76,667
Yield (t/ha)	39.1	61.25
Annual yield (t/ha/yr)	3	2.04

Relative yield (compared to the native range)		156%
Site suitability		Fair
Recommendation		LM1–2 and UM1–2; Marginal for LH3

Source: Field survey; November 2020

5.2.14. Plantation site suitability analysis for *Bambusa multiplex* in Kenya

The mean culm height and diameter of *B. multiplex* in Limuru (LH1) suggested that the species was planted in a significantly higher elevation than did its normal range (Table 71). The species would have likely performed much better in a UM1–2 or LM1–2 zone at an elevation lower than 1,700 m a.s.l. Similar to *B. tulda* above, its high stocking density with relatively smaller culms may have been an adaptation to the low temperature in an LH zone. Therefore, this species is recommended for LM1–2 and lower-elevation UM1–2 zones.

Table 71. Site suitability analysis for *B. multiplex* in Kenya

Variable	Native range	Performance in plantation sites in Kenya
	China and India	Limuru (LH1)
Elevation (m a.s.l.)	200–1,500	2,085
Rainfall (mm)		1,067
Temperature (°C)		16
Soil pH		5.6–6.0
Culm height (m)	2–7	2.733
Culm diameter (cm)	1–3	1.8
Culms per ha (no./ha)		16,267
Yield (t/ha)		6.41
Annual yield (t/ha/yr)		1.28
Relative yield (compared to the native range)		
Site suitability		Fair
Recommendation		LM1–2 and UM1–2

Source: Field Survey; November 2020

5.2.15. Plantation site suitability analysis for *Bambusa blumeana* in Kenya

The results on the mean culm height of this species indicated that it had a fairly wide elevation range with regard to growth performance (Table 72). However, the results on its mean culm diameter suggested that it performed better in lower-elevation zones. The yield recorded in the LH3 zone was significantly higher than that in the CL zone. This was because the culms in the CL zone were subjected to regular harvests, while those in the LH3 research plot were largely intact. For instance, if the stocking densities were similar, the LH3 zone would have yielded less than half the cases in each of the two sites. This implies that yield alone may not be a good indicator of growth performance in this particular case. Overall, this species is likely to perform well in the CL2–4, LM1–2, and low-lying UM1–2 zones.

Table 72. Site suitability analysis for *B. blumeana* in Kenya

Variable	Native range	Performance in plantation sites in Kenya		
		Indonesia and Malaysia	Jilore (CL4)	Mivumoni (CL2)
Elevation (m a.s.l.)	300–1,000	85	66	2,070
Rainfall (mm)		927	1,386	954
Temperature (°C)		27	27	15.9
Soil pH	5–6.5	5.6–6.0	5.1–5.5	6.6–7.3
Culm height (m)	15–25	6.17	7.75	6.7
Culm diameter (cm)	8–15	4.73	5.47	3.83
Culms per ha (no./ha)		3,767	2,333	29,067
Yield (t/ha)	120	11.6	8.07	45.16
Annual yield (t/ha/yr)		0.39	0.32	1.51
Relative yield (compared to the native range)				
Site suitability		Good	Good	Fair
Recommendations		CL2–4, LM1–2, and UM1–2		

Source: Field survey; November 2020

5.2.16. Plantation site suitability analysis for *Bambusa bambos* in Kenya

The results of the assessment confirmed that *B. bambos* performed better in the lowlands. Its mean culm height and diameter at the two plantation sites in Kenya were about half of the figures recorded for its native range, but its stocking density appeared to significantly exceed that in its natural habitat. The high stocking rate partly explains the extremely high yield recorded at its plantation sites in Kenya. Ordinarily, the annual growth rate of 5 t DW/ha/yr from its native range should translate to about 70 t in Kehancha in 14 years and 145 t in Jilore in 29 years, but the yield figures in Kenya were significantly higher than these (Table 73). Therefore, this species is likely to perform well in CL2–4, LM1–2, and low-lying UM1–2 zones.

Table 73. Site suitability analysis for *B. bambos* in Kenya

Variable	Native range	Performance in plantation sites in Kenya	
		Jilore (CL4)	Kehancha (LM2)
	Bangladesh, China, India, Laos, Myanmar, Pakistan, Sri Lanka, Thailand, and Viet Nam		
Elevation (m a.s.l.)	1–1,250	85	1,504
Rainfall (mm)	2,000–2,500	927	1,400
Temperature (°C)		27	21.7
Soil pH		5.6–6.0	6.6–7.3
Culm height (m)	20–30	12.65	11.9
Culm diameter (cm)	10–18	5.83	7.4
Culms per ha (no./ha)	5,000–8,000	19,333	24,000
Yield (t/ha)		212.6	510.4
Annual yield (t/ha/yr)	5	7.09	46.4
Site suitability		Good	V. good
Recommendation		CL2–4, LM1–2, and low-lying UM1–2	

Source: Field survey; November 2020

6. Conclusion and recommendations

6.1. Conclusion

The overall objective of this study was to determine the growth performance and yields of both indigenous and introduced bamboo species currently planted in Kenya. The results of the assessment were used to carry out a species–site suitability analysis for each bamboo species. The expected output of the study was a report identifying each bamboo species according to its most suitable AEZs, which was intended to expand the bamboo resource base in Kenya with a view to accelerating its uptake as a commercial crop.

The study recorded one indigenous bamboo species, *O. alpina*, and 15 introduced species, all performing well. The 15 introduced bamboo species comprised two sub-species.

All 15 introduced bamboo species and the two sub-species demonstrated potential for commercial production in Kenya. However, each species had its unique agro-ecological requirements. Some preferred humid low-lying elevations, others thrived in sub-humid lower-elevation zones, and a few performed well in relatively higher-elevation zones. Several introduced bamboo species were extremely versatile, thriving in a range of AEZs. Table 74 below matches each bamboo species to its most suitable AEZs in Kenya. Considering that most species are capable of stretching their performance beyond their optimal range, the table also provides a column indicating a zone of marginal performance.

Table 74. A summary of bamboo species–site suitability in Kenya

Bamboo species	Zone of optimal performance	Zone of marginal performance
<i>Oldeania alpina</i>	Mountain ranges (LH0) at an elevation range of 2,300–3,200 m a.s.l. - Used for conservation and commercial utilization	Upper midland zones (UM1–2) and lower highland zones (LH1–3) at an elevation range of 1,900–2,200 m a.s.l. - Ornamental and conservation use
<i>Thyrsostachys siamensis</i>	Coastal lowlands (CL2–4) at an elevation range of 1–200 m a.s.l.	Low-lying midland zone (LM2) Elevation range of 1,000–1,500
<i>Phyllostachys aurea</i>	Versatile in most lower midland zones (LM1–2), upper midland zones (UM1–3), and lower highland zones (LH1–3). An elevation range of 1,000–2,100 m a.s.l. - Mostly useful for live hedges, furniture making, and construction	
<i>Oxytenanthera abyssinica</i>	Humid lower midland zones (LM1–2), upper midland zones (UM1–2), and a lower highland zone (LH3) Elevation range of 1,000–2,100 m a.s.l.	Humid coastal lowlands (CL2–4) Elevation range of 1–100 m a.s.l.
<i>Dendrocalamus strictus</i>	Sub-humid low-lying lower midland zones (LM3–5), including coastal lowlands (CL2–4) Elevation range of 1–1,000 m a.s.l.	Lower midland zones (LM1–2) Elevation range of 1,000–1,500 m a.s.l.
<i>Dendrocalamus membranaceus</i>	Humid low-elevation zones (CL2–4, LM1–2) and low-lying upper midland zone (UM2) Elevation range of 1–1,800 m a.s.l.	Lower highland zone (LH3) Elevation range of 1,900–2,100 m a.s.l.
<i>Dendrocalamus hamiltonii</i>	Coastal lowland (CL2–4), lower midland (LM1–2), and upper midland (UM2) zones with reliable rainfall Elevation range of 1–1,800 m a.s.l.	Lower highland zone (LH3) Elevation range of 1,900–2,100 m a.s.l.



<i>Dendrocalamus giganteus</i>	Lower midland (LM1–2) and upper midland (UM1–2) zones with reliable rainfall Elevation range 1,200–2,100 m a.s.l.	Lower highland zone (LH3) Elevation range of 1,900–2,100 m a.s.l.
<i>Dendrocalamus brandisii</i>	Low-lying humid midland zones (LM1–2 and UM1–2) Elevation range of 1,200–1,800 m a.s.l.	Lower highland zone (LH3) Elevation range of 1,900–2,100 m a.s.l.
<i>Dendrocalamus birmanicus</i>		Lower highland zone (LH3) Elevation range of 1,900–2,100 m a.s.l.
<i>Dendrocalamus asper</i>	Humid coastal lowland (CL2) and humid lower midlands (LM1–2) Elevation range of 1–1,500 m a.s.l.	Lower highland zone (LH3) Elevation range of 1,900–2,100 m a.s.l.
<i>Bambusa vulgaris</i> var. <i>vulgaris</i>	Coastal lowland (CL2–4), humid lower midland (LM1–2), and low-lying UM1 zones Elevation range 1–1,650 m a.s.l.	Upper midland (UM2) and lower highland (LH1–3) zones Elevation range of 1,700–2,100 m a.s.l.
<i>Bambusa vulgaris</i> var. <i>vittata</i>	Agro-ecological zones (CL2–4, LM1–5, and UM2). Performance depends on silvicultural management and soil moisture content. Elevation range of 1–1,800 m a.s.l.	Higher upper midland zone (UM1) and lower highland zones LH1–3 Elevation range 1,900–2,100 m a.s.l. and above
<i>Bambusa tulda</i>	LM1–2 and UM1–2 zones Elevation range of 1,200–1,700 m a.s.l.	LH3 zone Elevation range of 1,900–2,100 m a.s.l.
<i>Bambusa multiplex</i>	LM1–2 and lower-elevation UM1–2 Elevation range of 1,200–1,700 m a.s.l.	LH1–3 zones Elevation range of 1,900–2,100 m a.s.l.
<i>Bambusa blumeana</i>	CL2–4, LM1–2, and low-lying UM1–2 zones Elevation range of 1–1,600 m a.s.l.	LH3 zone Elevation range of 1,900–2,100 m a.s.l.
<i>Bambusa bambos</i>	CL2–4 and LM1–2 zones Elevation range of 1–1,600 m a.s.l.	Higher UM1–2 and LH3 zones Elevation range of 1,900–2,100 m a.s.l.

There were a few limitations of the study, which were as follows:

- a) The bamboo species plantation range was extremely narrow, which limited the ability to match the introduced bamboo species to all AEZs in Kenya. Some of the plantations comprised research trials, which were mostly in the CL2 and 4; LM1, 2, and 5; UM1 and 2; and LH1 and 3 zones. Thus, the conclusions may suffer from a tendency of over-generalisation, particularly when projecting the expected scenario in AEZs where bamboo was not planted.
- b) Research plots and farmers' plantations were not subjected to similar silvicultural practices, especially during the initial stages of bamboo growth. Thus, research plots tended to register better yields than farmers' plantations.
- c) The bamboo culms in some farms were hardly harvested. This was common among farmers who contributed their lands to research trials and were therefore unsure of the projects' end dates. In such cases, the farmers feared that harvesting would interfere with the research data. This situation presented a challenge because it resulted in significantly larger culms and higher yields than those in farmers' plantations.

Overall, the results on bamboo performance and yields strongly showed that Kenya has great potential for bamboo development. With focused planting guided by species–site suitability matching, bamboo growth performance and yields are likely to increase significantly.

The study found that the utilization of bamboo is still rudimentary in terms of product portfolio and added value products. This aspect needs to be prioritized in bamboo sector development. Some obvious uses of bamboo remain unexplored. These include scaffolding (which is a major driver of *Eucalyptus* planting in Kenya), roof construction using round poles, and the fabrication of basic household furniture, including tables, benches, and beds. It is hoped that the expansion of bamboo planting, along with the training of contractors and carpenters, will promote its widespread use in the construction sector. During heavy infestations of insect pests, there is also a need for power equipment when spraying systemic chemicals to control thrips, spider mites, and other sap suckers so that the treatments can reach insect pests under webbing. A spreading surfactant, recommended by some labels (including bifenthrin), is added to the chemical of choice because bamboo leaves are difficult to wet. Regular control of insect pests and diseases can help avoid invasions and infections. Spraying the soil with deltamethrin-based

chemicals according to the manufacturer's instructions or with diazinon at 240g/l can be effective in preventing bamboo disease infestation in prone areas.

6.2. Recommendations

1. Establishment of bamboo trial plots in agriculturally marginal zones, such as LM3–5, to ascertain the suitability of different bamboo species in terms of yield and utilization
2. Development of guidelines on bamboo silvicultural management and practices
3. Creation of guidelines for the management of runner-type bamboo, such as *P. aurea*, to manage its potential to become invasive
4. Capacity building for bamboo growers on standard procedures of bamboo clump management and harvesting to enhance productivity, as well as for other bamboo sector players on the utilization of bamboo for construction and industrial uses to enhance the uptake and planting of bamboo in homestead farming system development and commercial plantations
5. Taxonomy research on bamboo so that researchers can gain a better understanding of all bamboo species in Kenya

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Appendices

Appendix 1. Stakeholders engaged during the assessment

- 1) Ms. Nellie Oduor – INBAR Country Coordinator
- 2) Mr. Paul Ongugo – INBAR Kenya Focal Point
- 3) Mr. Naftali Chacha – Bamboo farmer in Kehancha, Migori County
- 4) Ms. Jackline _____ – Project Coordinator, Eco-green, Busia County
- 5) Mr. Moses Wesanza – Deputy Ecosystem Conservator, KFS Kakamega
- 6) Ms. Alice Ingutia – Forest Station Manager, KFS Isecheno, Kakamega Forest
- 7) Mr. _____ – Bamboo farmer, Isecheno, Kakamega Forest
- 8) Mr. _____ – Kaimosi Tea Estate, Vihiga
- 9) Ms. _____ – GreenPot Enterprises, Nyeri
- 10) Mr. _____ – Kagumo Gardens, Nyeri
- 11) Mr. Mahugu – Bamboo farmer, Muranga
- 12) Mr. Robert Gordon – Bamboo farmer, Limuru, Kiambu County
- 13) Mr. Michael Okeyo – Assistant Regional Director, KEFRI- Kibwezi
- 14) Dr. Linus Wekesa – Regional Director, KEFRI CERP, Gede, Kilifi County
- 15) Mr. _____ – Forest Station Manager, KFS Jilore Forest, Kilifi County
- 16) Mr. _____ – African Plantation Capital, Madunguni, Kilifi
- 17) Mr. _____ – Bamboo farmer, Mivumoni, Kwale County
- 18) Dr. Eston Mutitu – Regional Director, KEFRI CHERP, Muguga, Nairobi

Appendix 2. Bamboo assessment tool



**Bamboo
Species–Site
Suitability
Matching in
Kenya**

Please use a separate datasheet for each bamboo species.

BAMBOO SPECIES: _____

1. Site characterization (physiographic features)

Table 1. Site descriptive features

Planting site	
Region / agro-ecological zone	
Bamboo species planted	
Type of plantation (conservation site / research plot / smallholder farm / large-scale plantation)	
Area planted (ha)	
Year planted	
GPS coordinates (WGS84 system – zone and UTM)	
Altitude (m)	
Temperature (min)	
Temperature (max)	
Annual rainfall	
Soil type	
Country of origin / native range	

Soil scientist to add parameters for assessing soil data

2. Species identification parameters (taxonomist to improve this section)

Table 2. Description of species identification features

Bamboo species	
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Branching pattern (monopodial/sympodial)					
Culm size (diameter)					
Culm height					
Straightness of culms					
Culm color (yellow, green, variegated, etc.)					
Culm wall thickness					
Culm sheath characteristics (color, shape, thickness, indumentum, and texture)					
Sheath persistence	Quickly deciduous	Slowly deciduous	Firmly attached	Persistent	
Average distance between nodes (length of the internode)					
Ligule length (very short, short, very long, long, etc.)					
Ligule margin (entire, serrate, and lacerate)					
Ligule outline	Level	Arching	Rising in the centre	Asymmetrical	
Clump density	Strongly tufted	Medium tufted	Loosely tufted		
Average leaf blade size	Length		width		
Leaf blade shape (lanceolate, linear, long-triangular, etc.)					
Leaf blade margin (entire, serrate, lacerate, etc.)					
Transverse venation	Present		Absent		
Oral setae characters	Length	Color	Orientation 1. erect 2. radiating	Straightness 1. angular 2. straight 3. curved	Surface 1. glabrous 2. scabrous
Auricles	Presence		shape		
Spacing between culms					
Clump circumference					
Canopy structure					

3. Survival rate and growth parameters

Table 3. Survival rate and growth performance of the planted bamboo species

Bamboo species	
Date planted	
Number of clumps planted	
No. of surviving clumps	
Survival percentage	
Spacing between clumps	
Clump density (culms per clump)	

4. Species characterization by growth and performance variables

Table 4. Species performance parameters

Culm no. (select three mature culms per clump from three clumps in the site, for a total of nine culms)	H (m)	DBH (cm)	WT (mm)	FW (kg)	DW (kg)	Y (kg)

NOTE: H = height of the mature culm (m), DBH = diameter at breast height (cm), WT = wall thickness (mm), FW = fresh weight of the culm (kg), DW = dry weight of the oven-dried culm (72 h) (kg), Y = yield (kg dry weight).

5. Species performance and yield estimation (to be derived from the data analysis)

Table 5. Bamboo species performance and yield characterization

Aspect	Replicate 1	Replicate 2	Replicate 3
Stand age (years)			
Sample plot (30 m × 20 m)			
No. of clumps			
No. of culms			
No. of culms per clump			
Culm density (plants per ha)			

Clump circumference (m)			
Culm height (m)			
Culm diameter (cm)			
Fresh weight (kg)			
Dry weight (kg)			
Relative water content (%)			
Yield (t DW/ha) based on no. of culms per ha			
Annual yield (t DW/ha/yr)			
Proportion of the annual yield as a comparison with the yield from the best-performing site in the country (%)			
Relative yield performance based on the comparison with the performance of the species in its native range (%)			

DW = Dry weight



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