Hindawi
International Journal of Forestry Research
Volume 2023, Article ID 8859316, 10 pages
https://doi.org/10.1155/2023/8859316

Research Article

Species-Site Suitability Assessment of Bamboo and Its Detailed Study in Different Agroecological Zones of Kenya

Tarun Kumar Lohani,[1] **Gordon Sigu**,[2] **Nellie Oduor**,[3] **Selim Reza**,[3] **and Jayaraman Durai**[4]

[1]*FHWRE, Arba Minch University, P.O. Box 21, Arba Minch, Ethiopia*
[2]*Kenya Forestry Research Institute (KEFRI), P.O. Box 20412-00200, Nairobi, Kenya*
[3]*International Organization of Bamboo and Rattan (INBAR), P.O. Box 1000, Addis Ababa, Ethiopia*
[4]*International Bamboo and Rattan Organization (INBAR), Beijing, China*

Correspondence should be addressed to Tarun Kumar Lohani; tklohani@gmail.com

Received 28 April 2023; Revised 5 September 2023; Accepted 12 September 2023; Published 19 September 2023

Academic Editor: Ranjeet Kumar Mishra

The site suitability assessment of Bamboo in Kenya was studied for diverse agroecological zones (AEZs) comprising one indigenous and fifteen exotic bamboo species in nine different AEZs of Kenya. Three bamboo clumps from each species that were at least five years old were assessed to accurately capture data on growth performance and yield. Soil samples collected at 0–30 cm depth from different areas varied considerably. The proportion of soil varied across the bamboo planting sites ($F_{(1,11)} = 24.94$; $p < 0.001$), soil pH in the planting sites varied significantly ($F_{(1,11)} = 13.92$; $p < 0.001$), and soil bulk densities had different results ($F_{(1,11)} = 13.92$; $p < 0.001$). The lowest bulk density (0.61 ± 0.01) was recorded in Kakamega (UM1), while the highest (1.63 ± 0.01) was reported in Gede. Data on characteristics of clumps and internode length and wall thickness integrated through GenStat statistical software using ANOVA entail a huge variation in growth performance for each bamboo species across planting sites. Morphological characters were also studied in detail. The mean height, diameter, and stocking density were comparatively lower even in elevated zones that were only 200 m below its natural range. This resulted in an extremely low yield, which is not viable for economic investment. The species is unsuitable for plantation establishment outside its natural range of 2300 m–3200 m above the sea level (a.s.l.). Plantation below this range will not dissipate but will not attain a healthy growth. The primary use will be restricted for ornamental and conservation purposes such as scaffolding, roof construction, and fabrication of basic household furniture.

1. Introduction

Bamboo is an imperishable product that belongs to the lawn family. It is popularly known as “the poor man’s timber,” denoting its fashionability among poor populations as a cover for precious wood from trees [1]. There are more than 1,600 species of bamboo comprising 75–107 subfamilies growing across the world [2–4]. Most of them grow naturally in the tropical and subtropical regions nearly 4,000 m a.s.l. [5, 6]. They are substantially set up in Asia, Africa, and Latin America and cover a total area of 37 million hectares, which accounts 1% of the global timber area [7]. Global bamboo product and consumption is valued at 60 b$, with a transnational trade of 2.5 b$ per annum, supporting 1.5 billion people [8]. In eastern Africa, 2.8 million hectares of area is covered with bamboo across Ethiopia, Uganda, Tanzania, and Kenya [9]. Bamboo is a highly versatile plant in its adaptability and utility with a great potential for economic development, wealth creation, and environmental resilience [10], providing opportunity to rural communities to strengthen their livelihood, food security, and environmental resilience efforts [9]. There are over 10,000 proved bamboo uses and products [11]. These include timber backups, fiber and cloth, plastic mixes, food and libation, energy, health, and cosmetics. It has also a proven eventuality in the recuperation of demoralized lands, watershed protection, and climate change mitigation and adaption [12]. On account of its expansive shallow rhizome-root system and accumulation of splint mulch, bamboo serves as an effective agent in precluding soil erosion, conserving humidity, and underpinning of embankments and drainage channels [13, 14]. With its fast growth rate and high periodic development after harvesting, major carbon emission control strategies are needed, especially when the congregated culms are used as sturdy products [15].

In Kenya, bamboo has been an integral part of indigenous timbers. The country's only indigenous bamboo species *Oldeania alpina* (K. Schum.) Stapleton grows naturally in the highlands in Mt. Kenya, Aberdares, Mau escarpment, Cherangani hills, and Mt. Elgon at an elevation of between 2300 and 3200 m a.s.l. [16]. It covers about 131,040 hectare (ha) distributed in mountain ranges and forest areas managed by the national government [17]. It grows in single clumps attaining a mean culm height of 10 m and a diameter at breast height (DBH) of 7.5 cm with a mean culm stocking density of 21,000 culms/ha. The bamboo species is estimated to yield 100 tons per ha (approximately, 9.6 kg of dry weight per culm). It is mainly used for construction and residential fencing and for making handcraft, furniture, baskets, tooth picks, and match sticks [18]. Twenty-two bamboo species were introduced from Asia [9]. Some of the introduced bamboo species include *Bambusa brandisii, Bambusa vulgaris var. vittata, Bambusa vulgaris var. vulgaris, Bambusa bambos, Bambusa tulda, Dendrocalamus membranaceus, Dendrocalamus strictus, Dendrocalamus asper, Gigantochloa aspera, Oxytenanthera abyssinica,* and *Thyrsostachys siamensis* [19]. Since then, bamboo growing has taken root in many counties within the country, similar as Migori, Vihiga, Busia, Homa Bay, Uasin Gishu, Elgeyo Marakwet, Kirinyaga, Kitui, Laikipia, Nyandarua, Embu, and Tharaka Nithi. In these counties, bamboo is grown as a crop on the granges though not on a large scale.

Bamboo seedlings imported from Asia and planted in Kenya has great eventuality to contribute to profitable and social pillars of Kenya's Vision 2030. The big four agenda are the Bonn Challenge, AFR100, Sustainable Development Goals (SDGs), the Convention on International Trade in Endangered Species (CITES), the Convention on Conservation of Biological Diversity (CBD), and UN Framework Convention on Climate Change (UNFCCC) through MSMEs that promote manufacturing and product development; recuperation of demoralized geographies, and provision of affordable ecologically friendly scenario [20]. Despite having about 22 bamboo species for close to three decades in Kenya and gazetting the same as a cash crop, there is a huge gap between planning and execution. The country lacks information about the specific geographic locations of most introductions, their suitability to the ecoclimatic sites where they have been planted and their growth performance and yield. This information gap has hindered widespread adoption of the exotic bamboo species, resulting in inadequate supply of quality planting material, inadequate knowhow about bamboo propagation and sustainable management, weak marketing systems and limited information, and decision-making tools. Moreover, the information gap has impeded the country's ability to estimate the existing bamboo resource base and its potential to contribute to environmental resilience and economic development. Therefore, it is important to collate accurate information on the site-suitability matching on adaptation potential and growth performance and yield of all bamboo species planted in different AEZs in Kenya [21]. This information is essential in assisting bamboo growers and prospective investors in the bamboo sectors to accurately project the expected and guaranteed return. This research, in turn, provides a strong platform to commercialize the bamboo farming which in due course will support the larger community for their alternative livelihood options.

2. Materials and Methods

2.1. Area under Study. Kenya spreads over an area of 582,647 km^2, of which over 10620 km^2 consists of natural lakes. The country is located in Eastern Africa, lapping the ambit between latitudes 40 N and 40 S and longitudes 340 E and 410 E, bounded by Ethiopia and Sudan on the north, Somalia and the Indian Ocean in the east, Uganda in the south, and by Tanzania towards the west. The country geographically is divided into two larger corridors; one conforming 1/3rd of the elevated lands forming the southwestern of the country and the remaining 2/3rd forming a bow of low mesas and plains. The land rises gradationally westward from a narrow littoral plain in a series of mesas, terminating in an upland area that crosses by the Great Rift Valley and includes the country's loftiest point, Mount Kenya (5199 m a.s.l.). The northern and northeastern regions of the country correspond substantially of thirsty plains. The rainfall varies unpredictably, but utmost of the corridor of the country enjoys two wet and two dry seasons. Its mounds are temperate and its littoral zones are hot and sticky; low lying areas are generally hot. The rainfall throughout the country ranges from 250 mm in the northern areas to about 2,000 mm in the western region with an average periodic rainfall of 680 mm. The high rainfall zone, which receives more than 1,000 mm annually, is the productive agrarian land (Figure 1).

The assessment was conducted in twelve sites where both indigenous and exotic bamboo species had been planted. The sites were clustered in nine counties representing nine different AEZs. The counties included Migori, Busia, and Kakamega in western Kenya; Nyeri, Muranga, and Kiambu in the central highlands of Kenya, Makueni, in the semiarid eastern zone, and Kilifi and Kwale in the coastal lowlands (Figure 1).

2.2. Study Design. The flow diagram of the entire process has been presented in Figure 2. A sample of nine representative counties was selected for the species-site suitability assessment of the introduced bamboo species. Representative sites were selected in each county. The selection criteria involved picking a site with the most diverse bamboo species. Bamboo clumps that were at least five years in age were assessed (Figure 3).

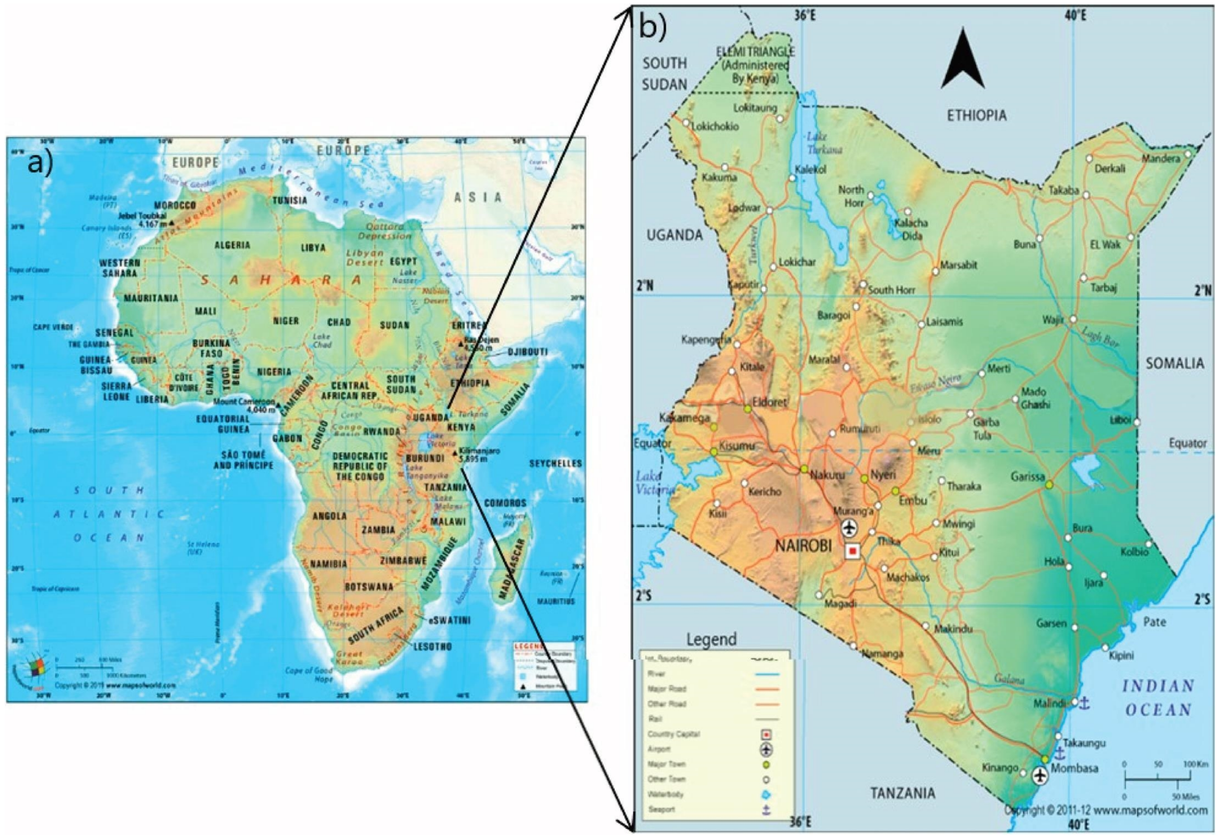

Figure 1: (a) Map of Kenya in Africa and (b) study area.

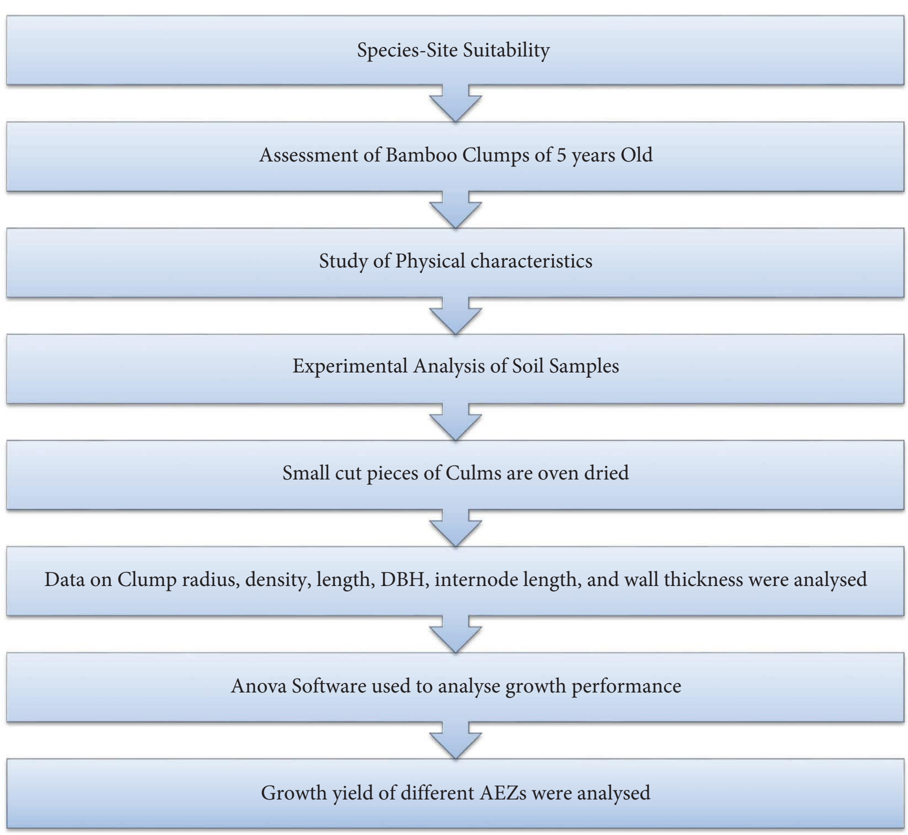

Figure 2: Flow diagram of the process.

(a) (b) (c) (d)

Figure 3: Bamboo clumps after 5 years: (a) *Oldenia alpina*, (b) *Bambusa vulgaris*, (c) *Dendrocalamus giganteus*, and (d) *Oxytenanthera abyssinica*.

This was done in order to accurately capture the growth yield. For each bamboo species, three clumps were randomly selected for assessment. Within a clump, three culms were selected for in-depth analysis of growth parameters with a view to providing data on growth performance and yield. From the sampled culms, insect pest and disease infestation were assessed through the direct observation method.

2.3. Data Collection. Bamboo species were identified by their botanic names. The number of culms per clump was evaluated, followed by measuring the clump radius in metres. Three representative culms were harvested from each clump. The harvested culms were measured for length, DBH, and internode length and wall thickness. The sampled culms were analysed for signs of disease or pest infestation.

Soil samples were collected to assist in characterizing the specific site conditions, particularly in regards to soil chemical and physical properties [22]. The samples were randomly collected under different clumps of bamboo species. Soil samples of 500 g were collected from a depth of 0–30 cm using an auger. The Munsell soil colour chart was used to identify the colour of the soil in the field. Samples were stored in tightly closed plastic containers and transported for physical and chemical analysis. They were air dried for 3 days to remove excess moisture, homogenized using pestle and mortar for grinding, and sieved using a 2 mm sieve to remove plant litter and stones. Physical analysis included soil moisture, bulk density, and soil texture. Chemical analysis included pH, electrical conductivity (E.C.), and levels of nitrogen, phosphorus, and potassium [23].

Ten insect pests observed onsite were collected in vials and brought to the laboratory for microscopic analysis. The type of damage on the bamboo culm was recorded. Disease infestations manifested on foliage and culms was recorded. Labels containing details of bamboo species, county, clump number, number of affected culms, and date of assessment were recorded. The diseases were rated from low (L) to severe (S).

2.4. Bamboo Biomass Determination. The sampled culms were cut into small pieces, packaged in gunny bags, labelled, and weighed to determine the fresh weight of each culm before transported to the laboratory. The labels contained details of the bamboo species, county, planting site, clump and culm numbers, date of assessment, and fresh weight. The bamboo culms were dried in the oven at 72°C for 36 hours followed by weighing the culms to determine the dry weight [24].

2.5. Data Analysis. Records on the clump radius, culm density, culm length, culm DBH, and internode length, and wall thickness were entered in Microsoft Excel and thereafter transferred to GenStat statistical software version 21 for analysis. Analysis was done using ANOVA, and it entailed assessing variation in growth performance for each bamboo species across planting sites at 5% significance level [25]. Post hoc tests were carried out to separate means using the Ryan–Einot–Gabriel–Welsch multiple range test (REGWQ) at 5% significance level [26].

3. Results

The results cover soil properties across sites, planted bamboo species, morphological identification guide of bamboo species encountered during the survey, growth performance of bamboo species, growth yield of bamboo species planted in different AEZs and a comparison of results of each species against the growth performance and yield in its native zone, uses of each bamboo species, and identified insect pests and diseases of bamboo in their native range [27].

3.1. Soil Properties across Sites

3.1.1. 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 fact that the sites had four different pH categories (Table 1).

3.1.2. Bulk Density. The twelve bamboo sites recorded 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 2). Sandy soils have higher bulk density than clay soils.

3.1.3. Soil Texture. There was a significant variation in soil texture across the 12 sites depending on the proportions of sand, clay, and silt. The quantity of sand varied across the bamboo planting sites ($F_{(1,11)} = 24.94$; $p < 0.001$). Kagumo Garden has the lowest proportion of sand ($8 \pm 1.16\%$) while Gede had the highest ($87 \pm 1\%$). Similarly, the proportion of clay varied significantly across the 12 sites and Gede had the lowest ($8.5 \pm 0.5\%$) and Kagumo had the highest ($83.33 \pm 3.333\%$) ($F_{(1,11)} = 17.40$; $p < 0.001$). The proportion of silt also varied considerably across the sites ($F_{(1,11)} = 8.15$; $p < 0.001$), where Gede had the lowest proportion ($5 \pm 1\%$) whereas Muguga had the highest (40 ± 1.265) (Table 3).

3.2. Planted Bamboo Species in Kenya. Sixteen bamboo species and two subspecies from nine different AEZs were identified. The species included one indigenous and fifteen exotic bamboo species (Table 4). Four of the fifteen exotic bamboo species were solid/semisolid bamboos (*O. abyssinica*, *T. siamensis, D. strictus*, and *B. tulda*) while the rest had hollow culms [28]. It is worth noting, however, that the country has a few more bamboo species, particularly recently added by the Dutch-Sino Bamboo Project in East Africa since 2017. Some of the notable new introductions include *Phyllostachys heteroclada, Cephalostachyum pergracile, Bambusa polymorpha*, and *Dendrocalamus laonensis.* Since those species have not completed their desired age (five years) for analysis, hence they have not been included (Table 4).

3.3. Growth Performance of Planted Bamboo Species

3.3.1. Oldeania alpina. Oldeania alpina was recorded as one of the planted bamboo species in Limuru in Kiambu County and Ndakaini in Murang'a County (Figure 4).

Summary of species' growth performance in Limuru and Ndakaini is presented in Table 5.

The results indicated that *O. alpina* was more productive in Limuru (LH1: tea/dairy zone) than in Ndakaini (UM1: coffee/tea zone). This was attributed to the fact that Limuru (2,085 m a.s.l.) was located at relatively higher elevation than Ndakaini (2,056 m a.s.l.). The higher elevation in Limuru was not very far from the natural range of *O. alpina* of 2300–3500 m above the sea level. Despite growing much taller and larger in Limuru than Ndakaini, *O. alpina's* mean height and diameter were still significantly lower than the expected situation (height = 20 m and diameter = 5.0–12.5 cm) in its natural range [29] (Table 6).

4. Discussion

The soil pH level varies from 5.055 to 6.674. Kairi-ini has the lowest pH value which depicts highly acidic behavior, whereas Kehancha has the highest pH which concludes a neutral soil characteristic [30, 31]. Neutral soil is most favorable for bamboo plantations and the growth rate as per their quality are the best across Kenya [32]. High porous and high permeable soils are considered as the most favorable soil [33] for bamboo plantation. Bamboo plants require a slightly acidic pH soil for the best possible health and growth. pH lying between 4.5 and 6.0 is considered as good for healthy bamboo growth. The bulk density of soil is lowest in Kakamega (0.61 g/cm^3) and highest in Gede (1.632 cm^3). Higher bulk density portrays low soil porosity and soil compaction [34]. Compact soil restricts deep rooting and ceases the plant growth [35]. Kakamega, Kairi-ini, Limuru, Muguga, Kagumo Garden, and Ndakaini are favorable sites

Table 1: Variation in soil pH across AEZs.

Bamboo planting sites	AEZs	Soil pH category	pH level
Ndakaini	UM1	Strongly acidic (pH 5.10–5.50)	5.47 ± 0.11
Muvumoni	CL2		5.39 ± 0.06
Kairi-ini	UM1		5.055 ± 0.31
Busia	LM1	Moderately acidic (pH 5.60–6.00)	5.91 ± 0.19
Kakamega	UM1		5.86 ± 0.05
Jilore	CL4		5.71 ± 0.15
Limuru	LH1		5.52 ± 0.21
Kagumo Garden	UM2	Slightly acidic (pH 6.10–6.50)	6.17 ± 0.18
Kibwezi	LM5	Neutral soil (pH 6.60–7.30)	6.49 ± 0.31
Kehancha	LM2		6.68 ± 0.06
Gede	CL4		6.61 ± 0.01
Muguga	LH3		6.55 ± 0.04
$F_{(1,11)} = 13.92$; $p < 0.001$; l.s.d. = 0.49			

LH = lower highland zone. UM = upper midland zone: UM1 (humid) and UM2 (subhumid). LM = lower midland zone: LM1 (humid) and LM2 (subhumid). CL = coastal lowland zone: CL2 (humid) and CL4 (subhumid).

Table 2: Variation in soil bulk density across AEZs.

Bamboo sites	AEZs	Bulk density (g/cm^3)
Kakamega	UM1	0.61 ± 0.01
Kairi-ini	UM1	0.75 ± 0.03
Limuru	LH1	0.81 ± 0.02
Muguga	LH3	0.86 ± 0.09
Kagumo garden	UM2	0.90 ± 0.06
Ndakaini	UM1	0.98 ± 0.04
Kehancha	LM2	1.03 ± 0.06
Busia	LM1	1.04 ± 0.17
Jilore	CL4	1.20 ± 0.03
Kibwezi	LM5	1.23 ± 0.01
Muvumoni	CL2	1.51 ± 0.07
Gede	CL4	1.63 ± 0.01
$F_{(1,11)} = 8.26$; $p < 0.001$; l.s.d. = 0.28		

Table 3: Variation in the soil texture across AEZs.

Bamboo sites	AEZ	% Sand	% Clay	% Silt
Limuru	LH1	22.4 ± 1.94	54.4 ± 3.71	23.2 ± 4.50
Kairi-ini	UM1	22.67 ± 1.76	54.67 ± 5.33	22.67 ± 6.77
Muguga	LH3	27.2 ± 1.58	32.8 ± 1.34	40 ± 1.27
Ndakaini	UM1	28 ± 2	48 ± 6.11	24 ± 4.163
Busia	LM1	30 ± 0	34 ± 10	36 ± 10
Kibwezi	LM5	39 ± 11	30 ± 10	31 ± 1
Kakamega	UM1	43 ± 1	23 ± 1	33.5 ± 0.5
Kehancha	LM2	57.67 ± 2.60	21.67 ± 4.63	20.33 ± 4.24
Muvumoni	CL2	65 ± 23	23 ± 15	17 ± 13
Jilore	CL4	75.2 ± 6.05	17.2 ± 3.44	7.6 ± 2.79
Kagumo Garden	UM2	8 ± 1.16	83.33 ± 3.33	8.67 ± 3.53
Gede	CL4	87 ± 1	8.5 ± 0.5	5 ± 1
		$F_{(1,11)} = 24.94$; $p < 0.001$ l.s.d. = 14.86	$F_{(1,11)} = 17.40$; $p < 0.001$ l.s.d. = 14.97	$F_{(1,11)} = 8.15$; $p < 0.001$ l.s.d. = 13.81

for bamboo cultivation as far as the density of soil is considered. Regarding the soil texture, sandy soils are better than any other category of soils [36]. Locations such as Kakamega, Kehancha, Muvumoni, and Jilore have high soil texture in comparison to the other locations and hence can be considered more advantageous. Bamboo species available in different AEZs of Kenya are native; still many species have been imported from other countries/continents. The exotic bamboos are solid to semisolid in nature which is considered as good to excellent quality [37]. The maximum use of *O. alpine* has been recorded in the entire country since they are available in plenty and have high quality. They are mostly

Table 4: List of bamboo species that were assessed during the nationwide bamboo-species site suitability assessment in different AEZs in Kenya.

Nos.	Bamboo species	Origin	Planting site(s)	Agroecological zones (AEZs)
1	*Oldenia alpina*	Native	2	LH1 and UM1
2	*Thyrsostachys siamensis*	Unfamiliar	3	LM2 and CL4
3	*Phyllostachys aurea*	Unfamiliar	1	LH1
4	*Oxytenanthera abyssinica*	Unfamiliar	4	LH3, LM2, LM5, and CL4
5	*Dendrocalamus strictus*	Unfamiliar	3	LM2, LM5, and CL4
6	*Dendrocalamus membranaceus*	Unfamiliar	3	LH3, UM3, and Cl4
7	*Dendrocalamus hamiltonii*	Unfamiliar	3	LH3, LM1, and CL2
8	*Dendrocalamus giganteus*	Unfamiliar	4	LH3, UM1, and LM2
9	*Dendrocalamus brandsii*	Unfamiliar	1	LH3
10	*Dendrocalamus birmanicus*	Unfamiliar	1	LH3
11	*Dendrocalamus asper*	Unfamiliar	6	LH1, LH3, UM1, UM2, and LM1
12	*Bambusa vulgaris var. vulgaris*	Unfamiliar	6	LH1, UM1, UM2, LM2, and LM5
13	*Bambusa vulgaris var. vitatta*	Unfamiliar	8	LH3, UM1, UM2, LM1, LM2, and CL4
14	*Bambusa tulda*	Unfamiliar	1	LH3
15	*Bambusa multiplex*	Unfamiliar	1	LH1
16	*Bambusa blumeana*	Unfamiliar	3	LH3, CL2, and CL4
17	*Bambusa bambos/arundinaceae*	Unfamiliar	2	LM2 and CL4

Figure 4: Culms of *Oldeania alpina.*

Table 5: Summary of the growth performance of *O. alpina* planted in Limuru and Ndakaini.

Growth parameters	Limuru	Ndakaini	Statistical result (p)
Clump age (yrs)	5 ± 0	35 ± 0	
Clumps per ha	400 ± 0	25 ± 0	
Clump radius (m)	0.53 ± 0.03	1.167 ± 0.417	0.20
Culms per clump (no.)	15 ± 2	76.67 ± 36.67	0.17
Culm density (no. per ha)	$6{,}000 \pm 800$	$1{,}917 \pm 916.7$	0.03
Culm diameter (cm)	2.13 ± 0.29	0.917 ± 0.17	0.02
Culm height (m)	3.47 ± 0.39	2.833 ± 0.18	0.22
Wall thickness (cm)	0.65 ± 0.14	0.217 ± 0.017	0.04
Internode length (cm)	23 ± 1	37.93 ± 2.07	0.01

Limuru = LH1 and Ndakaini = UM1.

Table 6: A summary of species-site suitability analysis for different bamboo species currently planted in Kenya.

Bamboo species	Zone of optimal performance	Zone of marginal performance
Oldeania alpinae	Mountain ranges (LH0) of altitude 2,300–3,200 m a.s.l. (i) Used for conservation only	Upper midland zones (UM1-2) and lower highland zones (LH1-3) of altitude 1,900–2,200 m a.s.l (i) Ornamental and conservation use
Thyrsostachys siamensis	Coastal lowlands (CL2-4) of altitude 1–200 m a.s.l.	Low-lying midland zones LM2 Altitude: 1,000–1,500
Phyllostachys aurea	Versatile in most of lower midland zones (LM1-2), upper midland zones (UM1-3), and lower highland zones (LH1-3). Altitude: 1,000–2,100 m a.s.l. (i) Mostly useful as a live hedge	—
Oxytenanthera abyssinica	Humid lower midland zones (LM1-2), upper midland zones (UM1-2) and lower highland zones (LH3) Altitude: 1,000–2,100 m a.s.l.	Humid coastal lowlands CL2-4 Altitude: 1–100 m a.s.l.
Dendrocalamus strictus	Subhumid low-lying lower midland zones (LM3-5), including coastal lowlands (CL2-4) Altitude: 1–1,000 m a.s.l.	Lower midland zones LM1-2| Altitude: 1,000–1,500 m a.s.l.
Dendrocalamus membranaceus	Humid low elevation zones (CL2-4, LM1-2) and low-lying upper midland zones (UM2) Altitude: 1–1,800 m a.s.l.	Lower highland zone LH3 Altitude: 1,900–2,100 m a.s.l.
Dendrocalamus hamiltonii	Coastal lowlands (CL2-4), lower midland (LM1-2) and upper midland (UM2) zones with reliable rainfall Altitude: 1–1,800 m a.s.l.	Lower highland zone LH3 Altitude: 1,900–2,100 m a.s.l
Dendrocalamus giganteus	Lower midland (LM1-2) and upper midland (UM1-2) zones with reliable rainfall Altitude: 1,200–2,100 m a.s.l.	Lower highland zone (LH3) Altitude: 1,900–2,100 m a.s.l.
Dendrocalamus brandisii	Low lying humid midland zones LM1-2 and UM1-2 Altitude: 1,200–1,800 m a.s.l.	Lower highland zone LH3 Altitude: 1,900–2,100 m a.s.l.
Dendrocalamus birmanicus	—	Lower highland zone LH3 Altitude: 1,900–2,100 m a.s.l.
Dendrocalamus asper	Humid coastal lowlands (CL2) and humid lower midlands LM1-2 Altitude: 1–1,500 m a.s.l.	Lower highland zone (LH3) Altitude: 1,900–2,100 m a.s.l.
Bambusa vulgaris var. vulgaris	Coastal lowlands (CL2-4), humid lower midlands LM1-2 and low-lying UM1 zones Altitude: 1–1,650 m a.s.l.	Upper midland (UM2) and lower highland (LH1-3) zones Altitude: 1,700–2,100 m a.s.l
Bambusa vulgaris var. vittata	Agroecological zones CL2-4, LM1-5 and UM2 zones. Performance depends on silvicultural management and soil moisture content Altitude: 1–1,800 m a.s.l.	Higher upper midland zones (UM1) and lower highland zones LH1-3 Altitude: 1,900–2,100 m a.s.l. and above
Bambusa tulda	LM1-2 and UM1-2 zones Altitude: 1,200–1,700 m a.s.l.	LH3 zone Altitude: 1,900–2,100 m a.s.l.
Bambusa multiplex	LM1-2 and lower elevation UM1-2 Altitude: 1,200–1,700 m a.s.l.	LH1-3 zones Altitude: 1,900–2,100 m a.s.l.
Bambusa blumeana	CL2-4, LM1-2, and low-lying UM1-2 zones Altitude: 1–1,600 m a.s.l.	LH3 zone Altitude: 1,900–2,100 m a.s.l.
Bambusa bambos	CL2-4 and LM1-2 zones Altitude: 1–1,600 m a.s.l.	Higher UM1-2 and LH3 zones Altitude: 1,900–2,100 m a.s.l.

available at an altitude of 2,300−3,200 m a.s.l. and especially used for ornamental and conservation use. *Phyllostachys aurea* variety of bamboo grows at a height of 1,000–2,100 m a.s.l. and mostly used by local community as a live hedge. They are widely used for fencing purposes by most of the lower income group people and village dwellers. Some of the other varieties of bamboo are used for furniture, roofing of houses, and other miscellaneous purposes.

5. Conclusion

The results on bamboo performance and yield strongly show that Kenya has a great potential for bamboo development. Thus, with focused planting guided by species-site suitability matching, the growth performance and yield are likely to increase significantly. The study found the utilization of bamboo to be still rudimentary in regards to product portfolio. It is an indication that this is an aspect which bamboo sector development needs to prioritize. Some evident facts lie in that in many instances, uses of bamboo remain unexplored. These include scaffolding (which is a major driver of *Eucalyptus* planting in Kenya), roof construction using round poles, and fabrication of basic household furniture including tables, benches, and beds. It is expected that the expansion of bamboo planting coupled with training of contractors and carpenters will promote its widespread use in the construction sector. During heavy infestations of insect pests, there is a need for power equipment when spraying systemic chemicals to control thrips, spider mites, and other sap suckers so that material can reach insect pests under webbing. A spreading surfactant, recommended by some labels (including bifenazate), 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 as well as infections. Spraying the soil with deltamethrin-based chemicals at 240 g/l can be effective in preventing the invasion of bamboo diseases in prone areas. Research trials tended to register a better yield than farmers' plantations. Bamboo culms in some farms were hardly being harvested. In such cases, farmers feared that harvesting would interfere with research data. The situation presented a challenge because it resulted in significantly larger culms and higher yield compared to the case in farmers' plantations [38].

Data Availability

The data used to support the findings of this study are available on request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] Z. Wang, J. Li, X. Yue et al., "A phenomic approach of bamboo species identification using deep learning," *International Center for Bamboo and Rattan, SFA and Beijing Co-built Key Lab for Bamboo and Rattan Science & Technology*, vol. 1, pp. 1–16, 2022.

[2] S. Canavan, D. M. Richardson, V. Visser, J. J. L. Roux, M. S. Vorontsova, and J. R. Wilson, "The global distribution of bamboos: assessing correlates of introduction and invasion," *AoB Plants*, vol. 9, no. 1, Article ID plw078, 2016.

[3] J. Q. Yuen, T. Fung, and A. D. Ziegler, "Carbon stocks in bamboo ecosystems worldwide: estimates and uncertainties," *Forest Ecology and Management*, vol. 393, pp. 113–138, 2017.

[4] S. Kaushal, A. Siwach, and R. Baishya, "Diversity, regeneration, and anthropogenic disturbance in major Indian Central Himalayan forest types: implications for conservation," *Biodiversity & Conservation*, vol. 30, no. 8-9, pp. 2451–2480, 2021.

[5] B. Behari, "Status of Bamboo in India. Compilation of papers for preparation of national status report on forests and forestry in India," *Survey and Utilization Division, Ministry of Environment and Forest*, pp. 109–120, 2006.

[6] L. Yeasmin, M. N. Ali, S. Gantait, and S. Chakraborty, "Bamboo: an overview on its genetic diversity and characterization," *3 Biotech*, vol. 5, pp. 1–11, 2015.

[7] S. Abebe, A. S. Minale, and D. Teketay, "Spatio-temporal bamboo forest dynamics in the lower beles river basin, northwestern Ethiopia," *Remote Sensing Applications: Society and Environment*, vol. 23, Article ID 100538, 2021.

[8] T. Kassahun, "Review of bamboo value chain in Ethiopia," *International Journal of African Society Culture and Traditions*, vol. 2, no. 3, pp. 52–67, 2014.

[9] T. Bahru and Y. Ding, "A review on bamboo resource in the African region: a call for special focus and action," *International Journal of Financial Research*, vol. 2021, Article ID 8835673, 23 pages, 2021.

[10] E. Wagemann and M. H. Ramage, "Briefing: bamboo for construction in Pakistan–a scoping review," *Proceedings of the Institution of Civil Engineers-Construction Materials*, vol. 172, no. 1, pp. 3–9, 2019.

[11] Msme, "Bamboo resource status and business opportunities in Jharkhand, foundation for MSME clusters (FMC)," 2019.

[12] R. L. Banik, "Distribution, diversity and prospects for propagation of industrially suitable bamboo species in India," *Journal of Bamboo and Rattan*, vol. 19, no. 3, pp. 52–69, 2020.

[13] J. C. van Dorsser and T. Faulds, "Propagation system for the production of rooted cuttings from physiologically mature Pinus radiata within 2 years of field collection," *New Zealand Journal of Forestry Science*, vol. 21, no. 2/3, pp. 135–143, 1991.

[14] Y. Mulatu and M. Fetene, "Propagation techniques for highland bamboo (arundinaria alpina) in the choke mountain, northwestern Ethiopia," *Ethiopian Journal of Agricultural Sciences*, vol. 24, no. 2, pp. 23–36, 2014.

[15] S. Dutta, A. Deb, and P. Biswas, "Identification and functional characterization of two bamboo *FD* gene homologs having contrasting effects on shoot growth and flowering," *Scientific Reports*, vol. 11, no. 1, p. 7849, 2021.

[16] M. N. Muchiri and M. O. Muga, "A preliminary yield model for natural Yushania alpina Bamboo in Kenya," *Journal of Natural Sciences Research*, vol. 3, no. 10, pp. 77–84, 2013.

[17] C. Sasahara and S. Shibata, "Indigenous bamboo and resource management in Kenya's aberdare forests and rural communities," *Preprints.org*, vol. 2020, Article ID 2020110415, 2020.

[18] B. Engler, S. Schoenherr, Z. Zhong, and G. Becker, "Suitability of bamboo as an energy resource: analysis of bamboo combustion values dependent on the culm's age," *International Journal of Forest Engineering*, vol. 23, no. 2, pp. 114–121, 2012.

[19] Kefri (Kenya Forestry Research Institute), "Status of bamboo resources development in Kenya," 2008, https://fornis.net/sites/default/files/documents/BambooResources.pdf.

[20] M. C. C. Bawer, "Diversity of bamboo species in lubuagan, kalinga, north luzon, Philippines," *International Journal of Interdisciplinary Research and Innovations*, vol. 3, no. 3, pp. 72–79, 2015.

[21] S. T. Partey, O. B. Frith, M. Y. Kwaku, and D. A. Sarfo, "Comparative life cycle analysis of producing charcoal from bamboo, teak, and acacia species in Ghana," *International Journal of Life Cycle Assessment*, vol. 22, no. 5, pp. 758–766, 2017.

[22] X. Li, T. Shupe, G. Peter, C. Hse, and T. Eberhardt, "Chemical changes with maturation of the bamboo species Phyllostachys pubescens," *Journal of Tropical Forest Science*, vol. 19, pp. 6–12, 2007.

[23] J. R. Okalebo, K. W. Gathua, and P. L. Woomer, *Laboratory Methods for Soil and Plant Analysis: A Working Manual*, TSBF, Nairobi, Kenya, 2002.

[24] B. Singh, Y. Dessalegn, M. W. Wakjira, C. Girma, A. A. Rajhi, and A. A. Duhduh, "Characterization of bamboo culm as potential fibre for composite development," *Materials*, vol. 16, no. 14, p. 5196, 2023.

[25] P. A. Lal, G. S. A. Rawat, and N. S. Bisht, "Nursery techniques of bamboo-standardization of planting method," *Indian Forester*, vol. 124, no. 3, pp. 184–191, 1998.

[26] B. G. Holt, J. P. Lessard, and M. K. Borregaard, "An update of Wallace's zoogeographic regions of the world," *Science*, vol. 339, no. 6115, pp. 74–78, 2013.

[27] R. Li, M. J. A. Werger, H. J. During, and Z. C. Zhong, "Carbon and nutrient dynamics in relation to growth rhythm in the giant bamboo Phyllostachys pubescens," *Plant and Soil*, vol. 201, no. 1, pp. 113–123, 1998.

[28] V. Kumar, "Failures and success in bamboo plantations," *Myforest*, vol. 28, no. 1, pp. 91–98, 1992.

[29] Y. Wang, J. Chen, D. Wang et al., "A systematic review on the composition, storage, processing of bamboo shoots: focusing the nutritional and functional benefits," *Journal of Functional Foods*, vol. 71, Article ID 104015, 2020.

[30] R. Ghimire and P. Bista, "Crop diversification improves pH in acidic soils," *Journal of Crop Improvement*, vol. 30, no. 6, pp. 657–667, 2016.

[31] R. Gentili, R. Ambrosini, C. Montagnani, S. Caronni, and S. Citterio, "Effect of soil pH on the growth, reproductive investment and pollen allergenicity of Ambrosia artemisiifolia L," *Frontiers in Plant Science*, vol. 9, p. 1335, 2018.

[32] L. Qiu, "Research progress on the effects of soil acidity and alkalinity on plant growth," *Open Journal of Applied Sciences*, vol. 12, no. 6, pp. 1045–1053, 2022.

[33] Y. Y. Zhang, W. Wu, and H. Liu, "Factors affecting variations of soil pH in different horizons in hilly regions," *PLoS One*, vol. 14, no. 6, Article ID e0218563, 2019.

[34] R. Kaushal, I. Singh, S. D. Thapliyal, and A. K. Gupta, "Rooting behaviour and soil properties in different bamboo species of Western Himalayan Foothills, India," *Scientific Reports*, vol. 10, no. 1, p. 4966, 2020.

[35] M. A. Arshad, B. Lowery, and B. Grossman, "Physical tests for monitoring soil quality," in *Methods for Assessing Soil Quality*, J. W. Doran and A. J. Jones, Eds., SSSA Special Publications, Madison, WI, pp. 123–141, 1996.

[36] J. Huang and A. E. Hartemink, "Soil and environmental issues in sandy soils," *Earth-Science Reviews*, vol. 208, Article ID 103295, 2020.

[37] R. Terefe, D. Samuel, M. Sanbato, and M. Daba, "Adaptation and growth performance of different lowland bamboo species in Bako, West Shoa, Ethiopia," *Journal of Natural Sciences Research*, vol. 6, no. 9, pp. 61–65, 2016.

[38] Y. Mulatu, B. Kidane, A. Anjulo, and S. Reza, "Species-site suitability matching study of introduced bamboos in Ethiopia," *Journal of Bamboo and Rattan*, vol. 21, no. 3, pp. 103–112, 2023.