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RESEARCH ARTICLE

Species-Site Suitability Matching Study of Introduced Bamboos in Ethiopia

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Abstract: In view of broadening the genetic base of bamboo resources and looking for alternative bamboo species that can grow in mid altitude areas where indigenous species are not growing in Ethiopia, different introduced bamboo species were tested for their adaptability and growth performance in different areas across the country. Data on ecological and climatic conditions of testing sites and corresponding growth in terms of diameter, height and density of the species were assessed; growth in Ethiopia was compared with growth of the species in their place of origin, i.e. South, Southeast and Tropical Asia. Accordingly, *Dendrocalamus asper, Dendrocalamus hamiltonii, Bambusa vulgaris* and *Dendrocalamus giganteus* were found to have similar diameter and height growth while *Dendrocalamus membranaceus* showed lower values in Ethiopia when compared to growth in its origin. The species-site matching effort of the species within Ethiopia in this regard, is conducted based on similarity in altitude and climatic conditions (rainfall, temperature) of experimental sites to other sites across the country. All the species, except *B. bambos,* perform well in Oromia, Amhara, SNNP and Tigray regions. All species, except *D. gigantues. B. balcoa* and *B.bambos* performed well in Benishangul-Gumuz region. Research on adaptability study needs to be extended in other regions of Ethiopia.

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Introduction

Globally, there are more than 1,500 species that are widely distributed in the tropical, subtropical and temperate regions of all continents except Antarctica, in wide agro-ecological conditions starting from sea level to 4,000 m (Nirbhay, 2017). The highest diversity and area coverage of bamboo is recorded from the Asian continent, followed by America and Africa (Ohrnberger, 1999). Africa possesses about 43 species on over 1.5 million ha of land; 40 of these species are primarily distributed in Madagascar while the remaining three species are found in mainland Africa (Ensermu, *et al*., 2000). Ethiopia is one of the countries in Eastern Africa that possess considerable bamboo resources, 1.47 million ha (INBAR, 2018), but comprised of only two species, namely *Oxytenanthera abyssinica* (lowland bamboo) and *Arundinaria alpina* (highland bamboo) which are indigenous to the country.

Lowland bamboo is confined to the western side of the central highlands in Moist and Wet lowland agro-climatic zones at altitudinal range of 500-1800 masl with mean annual temperature between 17 and 35°C and mean annual rainfall of 500-1000 mm but also tolerating erratic mean annual rainfall down to about 600 mm (MEFCC, 2018). A recent research report by Agena *et al*., (2022) has also indicated that lowland bamboo can grow well up to 1900 masl *A. alpina* is found in different places in Ethiopia (Yebeyen *et al*., 2022; Yigardu *et al*, 2016a)) but being restricted to high elevations (2200-3500 masl) with average monthly maximum temperatures 13-32°C, and average monthly

minimum temperature -4°C to 11°C and annual rainfall of 900 - 2,400 mm (Phillips, 1995; MEFCC, 2018).

Thus, in view of broadening the genetic base of bamboo resource and with the objective of evaluating exotic bamboo species that can grow in mid altitude, 1700- 2400 masl, areas where the two indigenous bamboo species are not naturally growing or where they perform marginally, more than 23 bamboo species were introduced in the country since 2007.

The bamboo species introduced in Ethiopia include the more widely evaluated species namely *Dendrocalamus asper, Dendrocalamus hamiltonii, Dendrocalamus giganteus, Dendrocalamus membranaceus, Bambussa vulgaris sub. Var. green, Guadua amplexifolia, Bambussa vulgaris* sub. var. vitata and *Bambusa balcooa* (Asabeneh *et al*., 2015; Yigardu *et al*., 2016b; Yigardu *et al*., 2018). Currently, these species are found maintained on the testing sites being used for training purposes and also as planting material sources for promoting the species. Except *Guadua amplexifolia* which is introduced from South America, the origin of the other introduced bamboo species considered in this study is Asia (South, Southeast and Tropical) and the species were introduced by a project, East African Bamboo Project (2006-2010), which was implemented by Ministry of Agriculture of Ethiopia and UNIDO, supervised by INBAR and sponsored by the Common Fund for Commodities (CFC). The species were evaluated for their adaptability and growth performance in different testing sites across the country by the Forestry Research Directorate of the Ethiopian Institute of Agricultural Research and by the Ethiopian Environment and Forest Research Institute.

Thus, this paper presents ecological conditions and growth characteristics of the introduced bamboo species studied under the respective sites and shows areas suitable for expanding the selected bamboo species, outside the testing sites, across the country. Identifying the potentially suitable areas for the selected bamboo species has paramount importance for the expansion of bamboo plantations in the country.

Materials and Methods

Data collection

Secondary data collection: Published and unpublished materials from different international and national sources were reviewed concerning biology, growth characteristics, utilization, and ecological aspects of the exotic bamboo species. Climatic data such as rainfall and temperature were consulted from secondary sources mainly district and zonal reports of the respective sites and also from published literature. Climatic data ENACT Grid data was browsed from web-based information to extract information on extrapolated rainfall and temperature data of the study sites which is used for developing species suitability maps.

Field data collection: Survey was conducted to five regional states of the country in locations where introduced bamboo species were planted to observe adaptation in Ethiopian agroclimatic and edaphic conditions. Field assessment to these locations was carried out to record ecological conditions of the testing sites and growth performance of the species in Ethiopia.

Accordingly, the planted areas which include Arba Minch Univesity and Chano Mille Nursery (Gamo Zone, Southern Nations, Nationalities, and People's Region); Chagni District (Awi Zone, Amhara Region); Jimma Agricultural Research Centre, Ethiopian Institute of Agricultural Research (EIAR) (Oromia Region); Tepi Agricultural Research Centre, EIAR (South Western Ethiopia Region); and Wondo Genet Agricultural Research Centre, EIAR (Sidama Region) were evaluated for their climate, elevation, some soil physico-chemical characteristics, and growth performance of the species planted in each area.

Growth data: DBH (diameter at breast height) and height of culms by age class (<1 year, 1-3 and >3 years) from sample clumps and selected plots; number of culms per clump; and internode length at DBH were recorded. Diameter tape, caliper, hypsometer and measuring tape were used while collecting data.

Geographic information and soil data: latitude, longitude, slope, and altitude were recorded; composite soil samples (0-30 cm) were taken from three dug pits five meters away from each other per plot and used to determine selected soil physico-chemical properties. Soil physico-chemical properties were analysed at EEFRI Environmental laboratory.

Data analysis

Qualitative information such as origin of the species introduced to Ethiopia were tabulated and described

in detail. Quantitative information such as growth characteristics in six tested sites and in their respective origin were presented for comparison. Ecological data of the introduced sites such as altitude, the mean annual rainfall, temperature maximum and minimum along with soil texture, organic carbon and pH, were summarized and presented in descriptive form. Based on the elevation and climatic conditions of sites where each introduced bamboos species well performed were taken as criteria to compare with other potential areas in the country to produce species-suitability maps for Ethiopia.

Result and Discussion

Origin of introduced species found adaptable under Ethiopian condition

The places of origin where the six bamboo species were introduced were South, Southeast and Tropical Asia (Table 1). Online sources (KCF, 2022; Steven and David, 2022**;** Dando, 1998) indicate that South Asia has three somewhat distinct seasons: (1) hot and dry: from March to May/June; (2) rainy: from June/July to November; and (3) cool and dry: from December to February. April is the hottest month, with mid-day temperatures of 33°C on most days. During the rainy season, short downpours can happen every afternoon, and occasionally streets can flood. Temperatures range from stifling hot before a rainstorm to pleasantly cool afterwards.

Southeast Asia comprises four main climate regions: alpine or mountain, subtropical, tropical, desert and savanna. Alpine climate of this region is found on the northern most part of India meeting the Himalayan Mountains. The higher mountains hence the cooler humid-tropical climate gives rise to deciduous and coniferous temperate forest at elevations of between about 1,300 and 3,000 m in the alpine region. The subtropical climate region covers most of the northern part of India. Tropical, desert and savanna are also found in this region. Much of Southeast Asia, the mainland historically known as Indochina, is within the tropical climatic zone with temperatures above 25°C throughout the year. The region is strongly influenced by the Asian monsoons, which bring significant amount of rainfall (Steven and David, 2022; Falinia, 2017 and Yen *et al*., 2015). Distribution of these bamboo species is also documented by Canavan *et al*., 2017; Nirbhay, 2017; Lobovikov *et al*., 2007; Wang *et al*., 2006 and Ohrnberger, 1999.

Ecological conditions and growth performance of introduced bamboos at testing sites in Ethiopia

Altitude of the adaptation and demonstration sites for introduced bamboos ranged from 1188 to 1920 masl (Table 2). The two lowest elevations (1188, 1197 and 1200 masl) were recorded from Chano Mile and Arbaminch University Nurseries and Tepi.

Jimma and Chagni are having relatively higher altitude as compared to the aforementioned three sites but still with similar precipitation. The Chano Mile and Arbaminch University Nurseries experience highest maximum temperature (36^{o}C each) followed by Tepi (30^{o}C) and Chagni (28.6^{o}C). The highest altitude

Table 1. Origin of introduced bamboo species considered for the study

No.	Species	Origin of species
1	*Dendrocalamus hamiltonii*	South Asian: India, Sri Lanka, Bhutan, Nepal, Pakistan, and far eastern China
2	*Dendrocalamus membranaceus*	Southeast Asia: Cambodia, Laos, Myanmar, Peninsular Malaysia, Thailand, and Vietnam)
3	*Dendrocalamus asper*	Southeast Asia: China
4	*Dendrocalamus giganteus*	Southeast Asian: India, Myanmar, Thailand and China's Yunnan province.
5	*Bambusa vulgaris*	Tropical Asia
6	*Bambusa bambos*	Southern Asia: India, Bangladesh, Sri Lanka, Vietnam, Cambodia, and Laos
7	*Guadua amplexifolia*	South America: Colombia, Ecuador and Venezuela

Source: Plant Resources of South-East Asia (PROSEA), accessed date 01/01/2022; https://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:1074014-2,accessed date 01/01/2022;

recorded was 1920 masl at Wondo Genet site which on the other hand receives the second lowest precipitation (1372 mm) as compared to all other sites.

The soil conditions in which the introduced bamboo species were tested are presented on Table 2. pH varied from 5 to 7.1, organic carbon from 2.1% to 4.4%; bulk density from 0.83 to 1.31 g/cm^3 and textural class from sandy clay, sandy loam, sandy clay loam to loam.

Growth characteristics of introduced bamboo species in testing sites in Ethiopia and aboveground growth characteristics of introduced bamboo species under their place of origin are presented on Tables 2 and 3.

Matching introduced bamboo species in to suitable sites in Ethiopia

Criteria used to develop bamboo species-site matching maps

Climate data of the selected sites collected during the field assessment and climate data extracted from *ENACT Grid* were used to produce suitability maps of introduced bamboo species. Due to inconsistencies of climate data collected from unpublished reports from study areas, climate data, i.e. minimum and maximum limits of sites (Table 4) where good performance of introduced bamboo species was set to be criteria for classifying sites for further expansion of selected introduced bamboo species elsewhere in Ethiopia. A total of four criteria (i.e., temperature, rainfall, slope, and elevation) were used in this study to identify the potential sites suitable for introduced bamboo plantations of introduced species in the country. Soil properties greatly vary in different spatial areas, even within a farmland scale, due to the combined effects of biological, physical, and chemical processes happening over time and associated with variation in land use type and management practices. Thus, in this paper, soil properties are only indicated at research sites level together with associated growth characteristics as indicated on Table 2 above.

Accordingly, suitability maps are presented on Figs 1-6. All the criteria used were given equal weight and thus the contribution of all the factors are the same in the final suitability map.

Suitability maps

Based on the values of altitude and climatic factors determined from testing sites, as described on section 3.4.1, suitability maps were produced for each introduced bamboo species at national level**.**

Bambusa balcoa

This species performed well with average DBH of 7.8 cm, height 20 m and number of culms per clump of 62 in a site of altitude 1920 masl, annual rainfall of 1372 mm, Max. Temp, 26.2 and Min. Temp. of 11.5 (°C) Table 3. Accordingly, the suitable areas of *B. balcoa* in the different regions of Ethiopia is mapped to be as follows (Fig. 1). The result indicateindicates that *Bambusa balcoa* can be promoted in different areas of Oromia, SNNP, Amhara, Tigray regions.

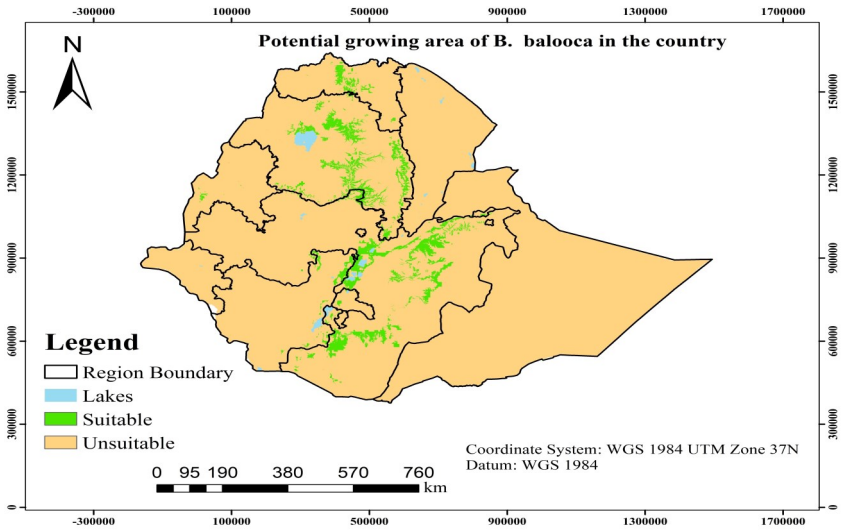

Fig 1. Suitable areas of *B. balcoa* in *Oromia, SNNP, Amhara, Tigray regions* of Ethiopia

Table 2. Location and ecological conditions of testing sites and growth performance of introduced bamboo species in Ethiopia

No.	Name of site	Alt. (m)	Climate, Average values			Soil properties, average values				Introduced species/ growth characteristics													
										B.bamboos		*B.balooca*		*B.vulgaris var. green*		*D.asper*		*D.giganteus*		*D.hamiltonii*		D. *membranaceous*	
			RF (mm)	Max. Temp. (°C)	Min. Temp. (°C)	Soil PH	OC (%)	BD (g/ cm^3)	Soil texture	DBH (cm)	Ht (m)	DBH (cm)	Ht (m)	DBH (cm)	Ht (m)	DBH (cm)	Ht (m)	DBH (cm)	Ht (m)	DBH (cm)	Ht (m)	DBH (cm)	Ht (m)
1	Arba minch University	1197	1725	36	23	7.1	3.5	1.12	Sandy clay	-	-	-	-	-	-	-	-	15.1	22	-	-	-	-
2	Chagnii	1700	1725	28.6	13.2	7.0	2.0	1.31	Sandy loam	-	-	-	-	2.6	10	7.1	20	-	-	4.7	11	3.2	13
3	Chano mille Nursery	1188	1725	36	23	7.1	2.1	1.24	Sandy clay	-	-	-	-	-	-	-	-	17.9	24	-	-	-	-
4	Jimma	1753	1530	26.2	11.3	5.0	2.5	1.20	Sandy clay loam	-	-	-	-	-	-	-	-	-	-	7.5	16	5.9	12
5	Tepi	1200	1678	30	15	5.8	4.4	0.83	Loam	8	16	-	-	8.2	15	-	-	-	-	8.4	20	7.3	16
6	Wondo Genet	1920	1372	26.2	11.5	5.6	3.5	1.12	Sandy clay	-	-	7.8	20	-	-	12	21	-	-	-	-	-	

Table 3. Aboveground growth characteristics of introduced bamboo species under their place of origin

No.	Species	DBH (cm) at the origin			Height (m) at the origin		
		average	min	max	average	min	max
1	*Dendrocalamus hamiltonii*	10	2.5	20	16.5	15.0	25
2	*Dendrocalamus membranaceus*	17.5	15.0	20.0	12.5	10.0	15.0
3	*Dendrocalamus asper*	14.0	8.0	20.0	16.0	12.0	20/30
4	*Dendrocalamus giganteus*	35.0	30.0	40.0	22.5	10.0	35.0
5	*Bambussa vulgarius green*	7.0	4.0	10.0	15.0	10.0	20.0
6	*Bambussa bamboos*	22.5	15.0	30.0	27.5	20.0	35.0
7	*Bambusa balcoa*	-	2.5	15.0	20.0		25
8	*Guadua amplexifolia*	6	2.5	10.0	-	5.0	17.5

Source: Plant Resources of South-East Asia (PROSEA), accessed date 01/01/2022; Yigardu *et al.* 2016b

Table 4. Factors and ranges of altitudinal and climatic parameters used for producing suitability maps for introduced bamboo species

Factor	Altitude (m)	Annual Rain Fall (mm)	Max. Temp. (°C)	Min. Temp. (°C)
Dendrocalamus hamiltoni	1200-1750	1350-1725	26.2-35	11.3-21
Dendrocalamus membranaceous	1200-1753	1350-1725	26.2-35	11.3-21
Dendrocalamus asper	1500-1900	1350-1725	26.2 -35	11.5 - 21
Dendrocalamus gigantues	1188-1900	1000-1725	28.3-36	8.9-23
Bambusa vulgaris	1200-1500	1350-1678	30-35	15-21
Bambusa balcoa	1920	1372	26.2	11.5

Note: Climatic data ENACT Grid data was browsed from web based information.
Max. Temp. - Maximum Temperature; Min. Temp. = Minimum Temperature

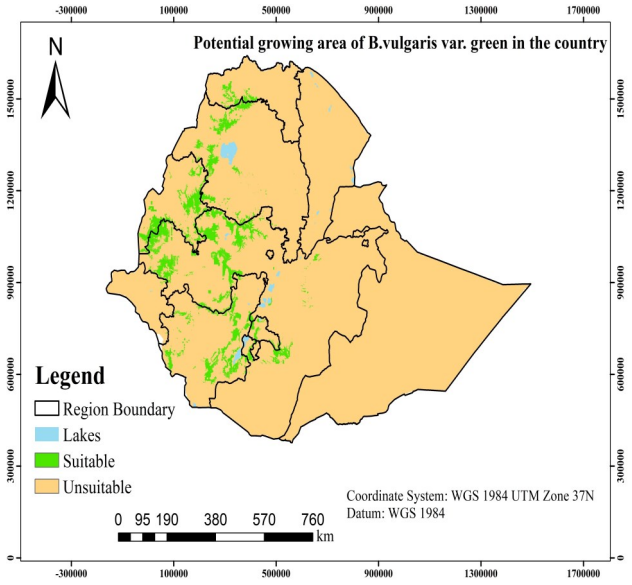

Fig 2. Suitable areas of *B. vulgaris* Var. green in Oromia, SNNP, Amhara, Tigray, Benishangul-Gumuz regions of Ethipia

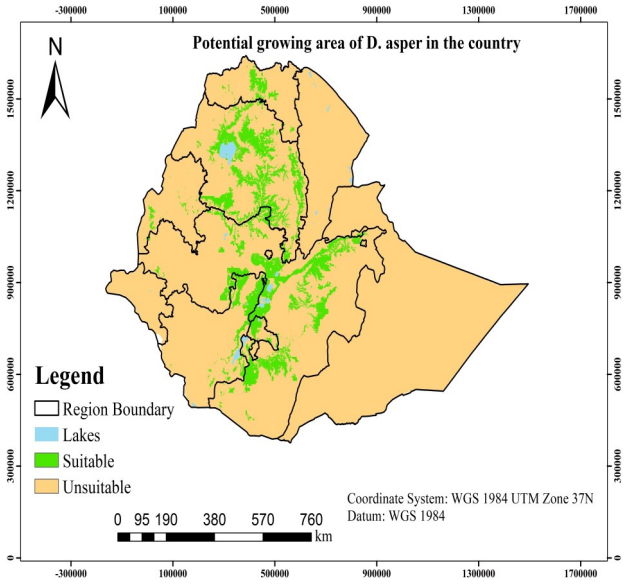

Fig 3: Suitable areas of *D. asper* in different areas of Oromia Amhara, Oromia, SNNP, Tigray, Benishangul-Gumuz regions in Ethiopia

Bambusa vulgaris

The DBH, height and number of culms per clump of *B. vulgaris* (2.6 - 8.2 cm, 10-15 m and 171-422, respectively) were recorded in areas of altitude 1200-1500 masl, annual rain fall of 1350-1678 mm, Max.Temp. of 30-35°C and Min. Temp, of 1 5-21°C. Accordingly, the suitable areas of *B. vulgaris* in different regions of Ethiopia is mapped to be as shown in Fig. 2. Performance of *B, vulgaris* in Ethiopia can be considered comparable to the growth of the species at its origin, Tropical Asia (DBH 7 cm and height 15 m) (Table 3),

Dendrocalamus asper

This species had superior performance at two sites with DBH 7-12 cm and height of 20-21 m of altitude 1500-1900 masl, which receive annual rain fall 1350 -1725 mm, Max. Temp. 26.2 -35°C and Min. Temp. 11.5 - 21°C. Accordingly, the suitable areas of *D. asper* in the different areas of Ethiopia is mapped to be as shown in Fig. 3 below. *D. Asper* showed generally similar DBH and height growth compared to growth in its origin, Southeast Asia (DBH 14 cm and height 16 m) (Table 4).

Dendrocalamus giganteus

This species performed well with DBH 15 to 18 cm and height of 22-24 m in sites which have altitude if 1188-1900 ASL with annual rainfall of 1000 - 1725 mm, Max. Temp. 28.3-36°C and Min temp. of 8.9-23°C. Accordingly, the suitable areas of *D. giganteus* in Oromia, Amhara, Tigray, SNNP regions of Ethiopia is mapped to be as follows (Fig. 4). Diameter growth of *D. giganteus* was lower in Ethiopia as compared to its growth in its origin (35 cm), Southeast Asian, but similar height growth was recorded (Tables 3 and 4).

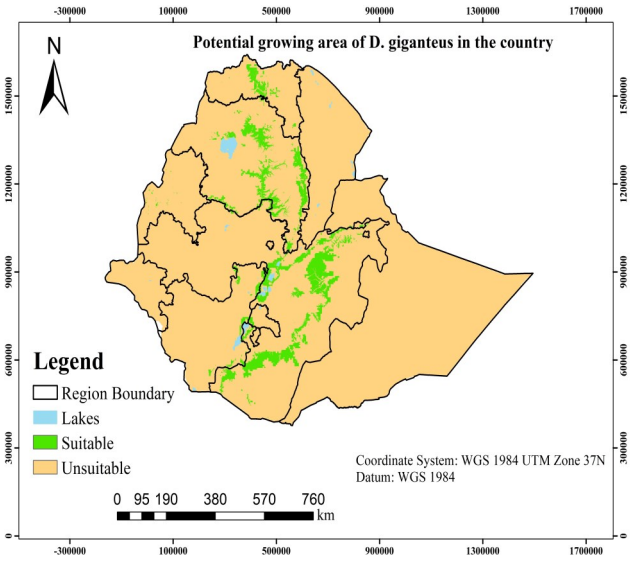

Fig 4. Suitable areas of *D. giganteus* in in different areas of Oromia, Amhara, SNNP and Tigray regions in Ethiopia

Dendrocalamus hamiltonii

This species performed well with DBH and height 7.2 - 8.4 cm and 16 - 20 m, respectively, across sites having altitude of 1200-1750 masl, annual rain fall 1350-1725 mm, max, temperature of 26.2-35 °C and min temp, of 11.3-21°C. Accordingly, the suitable areas of *D. hamiltonii* in Oromia, Amhara, SNNP, Benishangul-Gumuz, Tigray regions of Ethiopia is mapped to be as shown in Fig. 5, *D. hamiltonii* showed generally similar DBH and height growth compared to its growth in its origin (Table 4).

Dendrocalamus membranaceus

D. membranaceous performed well with DBH and height of 3.2 - 7.3 cm and 12-16 m, respectively, across sites at 1200-1753 masl, annual rainfall 1350-1725 mm, max temperature of 26.2-35 °C and min temperature of 11.3-21°C. Accordingly, the suitable areas for *D. membranaceous* in Oromia, Amhara, Benishangul-Gumuz, SNNP, Tigray regions of Ethiopia is mapped to be as shown in (Fig. 6).

Bambusa bambos

B. bambos performed well with DBH 7.98 cm and height 16 m and culms and number of culms per clump of 170 in one site (Table 2), but from our observations at Chagni and Pawe conditions its performance was poor and even not considered in the evaluation in this assessment.

Conclusion and recommendations

Seven bamboo species of origin Asia (South, South-east and Tropical) were introduced and tested across different sites for their adaptability in Ethiopia for the last 15 years. Based on the study, the seven bamboo species, *Dendrocalamus asper, Dendrocalamus hamiltonii, Bambusa vulgaris var, green, and Dendrocalamus giganteus* had similar growth characteristics (DBH and height) and showed generally similar DBH and height growth as compared to their growth in their origin, South Asia and Southeast Asia, while *Dendrocalamus membranaceus* showed lower values in Ethiopia. *Bambusa bambos* generally performed poorly under the testing site conditions. The suitable areas of introduced bamboo species in the different regions of Ethiopia is mapped to be as follows;

- *Bambusa balcoa:* different areas in Oromia, SNNP, Amhara, Tigray
- *Bambusa vulgaris* Var. green: different areas in Oromia, SNNP, Amhara, Tigray, Benishangul-Gumuz regions,
- *Dendrocalamus asper*: different areas in Amhara, Oromia, SNNP, Tigray, Benishangul-Gumuz regions;
- *Dendrocalamus gigantues*: different areas in Oromia, Amhara, Tigray, SNNP regions;
- *Dendrocalamus hamiltoni*: different areas in Oromia, Amhara, SNNP, Benishangul-Gumuz, Tigray regions;

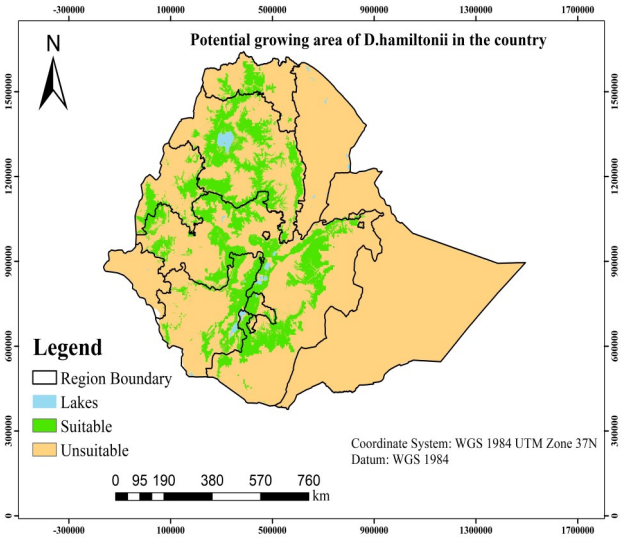

Fig 5. Suitable areas of *D. hamitonii* in in different areas of Oromia, Amhara, SNNP, Benishangul-Gumuz and Tigray regions in Ethiopia.

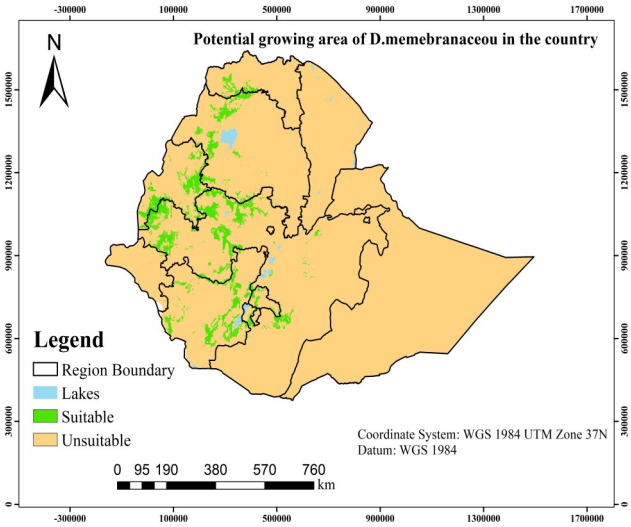

Fig 6. Suitable areas of *D. membranaceous* in different areas of Oromia, Amhara, Benishangul-Gumuz, SNNP, Tigray regions in Ethiopia

- *Dendrocalamus membranaceous*: *different areas in* Oromia, Amhara, Benishangul-Gumuz, SNNP, Tigray regions.

It indicated that all the species, except *B. bambos,* perform well in Oromia, Amhara, SNNP and Tigray regions. All species, except *D. gigantues, B. balcoa* and *B. bambos* were found performing well in Benishangul-Gumuz region.

This result indicates that introduced species have a wider suitable area in Ethiopia to be expanded. Moreover, with further adaptation studies, more suitable sites of the different introduced bamboo species might be mapped. Expansion of these species could be aligned with directions given in the Ethiopia National Bamboo strategy and actions (2019-2030), EFCCC and INBAR (2019)

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