DEVELOPMENT OF SUITABLE PLANTING MECHANISM FOR THE ELEPHANT FORAGES IN SRI LANKA

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Thesis submitted in partial fulfillment of the requirements for the degree Master of Science in Civil Engineering

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DECLARATION

I declare that this is my own work and this thesis does not incorporate without acknowledgement any material previously submitted for a degree or Diploma in any other University or institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

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Name of the Supervisor: Prof. R. U. Halwatura

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Abstract

The elephants are considered the largest terrestrial mammalian in the world, requiring a larger amount of plant material for survival. The degradation and shrinking of forest of the island resulted due to anthropological activities. The ultimate result of the depletion and loss of habitats and niches is the elephant migration to explore new habitats and food sources. Food plays an important role in the elephant movement and is considered to be one of the factors leading to Human-Elephant Conflict (HEC). The within-range enhancements of the elephant forage availability led to within-range confine the elephant and reducing the gravity of the HEC.

A study was conducted aiming to increase elephant forage availability in inaccessible rangeland by establishing elephant forage plants. The study proposed a mechanism for establishing forage plants through a device made up of bamboo cells. Information on the elephant forage plants was gathered through the field and literature survey. The information was placed in a database and used to prepare a Plant matrix. A questionnaire survey was conducted on the palatability of the elephant forage plants, and based on the responses, an index, the Forage Selection Index was developed. Bamboo was chosen as a construction material since the Biological, mechanical and physical properties of the material are well suited for the purpose.

A device was designed from bamboo cells with varying diameters and cutting angles and optimum penetration depths. The optimized device was subjected to a field trial with eight elephant forage plants. The best geometric shape, diameter, and the cutting angle for the device for the optimum substrate penetration depth were shaped with double cutting, 7.5 cm and 45^{o}, respectively.

The grasses *Pennisetum purpureum* (Ali maana), *Sacciolepis interrupta* (Beru), *Panicum maximum* (Gini thana), and *Echinochloa glabrescens* (Bajiri) demonstrated better performance in the proposed device for the purpose of establishing elephant forage plants in inaccessible elephant rangelands. Further, studies are needed to improve the device performance for free falls from higher elevations and an array of elephant forage plants to generalize the findings.

Keywords: Elephants forage availability, Device for establishing forage plants, bamboo cell mediate device, Forage plant growth performance in bamboo mediated device.

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Abbreviations	Description
ANOVA	Analysis of Variance
CA	Cluster Analysis
DWC	Department of Wildlife Conservation
Df	degrees of freedom
EHC	Elephant Human Conflict
FSI	Forage Selection Index
LSD	Least Significant Difference
IUCN	International Union for Conservation of Nature
PCA	Principal Component Analysis
RCBD	Randomized Complete Block Design
RTI	Right to Information
Std.	Standard

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CHAPTER 1: INTRODUCTION

1.1 Background

The tropical island of Sri Lanka, given its small size with an area of approximately 65,610 km^2 and located at the southeast of the southernmost tip of the Indian subcontinent, lies between 5°55’ and 9°51’ northern latitudes, is one of the world’s most densely populated countries (21.5 million), located at the southeast of the southernmost tip of the Indian subcontinent [1]–[3].

Sri Lanka is one of Asia's most prosperous and diverse countries with the richest biodiversity, abundant rainfall and drainage, and the natural climax vegetation, which has 10% of the Asiatic elephant population in 2% of the country’s land area [4]. The Asian elephant (*Elephas maximus*), widely distributed in the South Asian and Southeast Asian countries of the world, is one of the last surviving terrestrial mega-herbivores around the globe. They are referred to as ecological ‘keystone species’ that can modify the ecosystem and many other species that share this ecological benefit from these changes by contributing to sustainable coexistence [4]. However, they also cause economic losses in terms of crops and infrastructure damages when roaming outside the protected areas and the Asiatic elephants have been classified as an endangered species on the IUCN Red List from 1986 until today [4]–[6].

Without an overview of an island-wide assessment and studies, it would be difficult to make objective decisions about elephant management and conservation in Sri Lanka; people and elephants cannot live together where agriculture is a dominant form of land use. Before the advent of plantation agriculture, Sri Lanka had extensive forests covered across much of the island, and the average rate of deforestation had been around 42,000 ha per year during the last few decades [4], [7]. According to the literature on forest cover and forest cover changes, a drastic decrease has been evidenced.

As far as the island's human population is concerned, there was a substantial growth during the past ten years, and this significant increase in the population created unexpected pressure on the natural forests on the island. Therefore, the existing forest cover does not support feeding and providing habitats for the elephant population in the country.

1.2 Significance of the study

A more substantial number of remedial measures have been implemented to avoid HEC. However, there was a growing tendency in reports on HEC that included economic losses due to crop-raiding, property damages and even loss of human lives due to the elephant roaming for palatable forage species [8]. Therefore, the present study was conducted to evaluate the most palatable fodder species and to develop a suitable planting mechanism which is a part of ongoing research to increase Asian elephants' forage availability based on the behavior of wild elephants in elephant-ranging forest ecosystems. Identifying elephant forage plants with their palatability and transplanting such forage species in areas of limited accessibility would increase the availability of higher palatable forage species and minimize the food roaming movement of the wild elephants in such areas.

Hence, the study findings would provide at least baseline information for policy making and implementing mitigatory measures for ever-growing HEC towards an in-situ conservation approach. Additionally, the result directly or indirectly contributes to reducing economic losses. It reduces the death of elephants, which leads to Human-Elephant Conflict-related impacts on the elephant population in the country.

1.3 Scope and limitations of the research

The study focuses on the elephant forage plants in Sri Lanka and the introduction of a growing mechanism as a novel application for forage plantation in order to increase the availability of edible plant species in inaccessible areas where elephant density is higher as a remedial measure to restrict elephant movement to their habitat to minimize the loss of humans lives as well as elephants, economic losses including crops and infrastructure.

The identification of forage plant species and their perceived palatability assessment was ascertained through the responses of the wildlife experts to the questionnaire, field visits and face-to-face interviews. However, it is not certain whether responders had provided honest and reliable responses. The determination of elephants' forage preferences needs studies on chemical and physical characteristics, analysis of elephant dropping and field observations to have a clear picture. The plant selection matrix prepared on the elephant forage plants was used in identifying, and the process can be justified since extensive literature was sought for the deployment of the plant database.

A device was designed and optimized to use the free-fall mechanism to establish forage plants in inaccessible elephant habitats. Though The optimization of the device was performed with the diameter and the cutting angle, variation of free fall height and the device's behavior should also be ascertained before implanting the device in the field. Further, the designed device needs further testing since free fall penetration is very complex when soil substrate is involved. Because of the limitation mentioned above, care should be exercised during the interpretation and generalization of the finding of the results.

1.4 Aim and objectives of the research

The overall aim of the present study was to evaluate the palatability levels of selected forage plant species and increase the abundance of such species in inaccessible areas where elephant population densities are higher in Sri Lanka.

The main objectives of the research are;

i. Identification of the short – term elephant forage plant types growing in the natural environment.

ii. Collection of data for external environmental factors and plant growth factors for selected elephant forage plants.

iii. Developing a planting mechanism by designing and optimizing the Bamboo shell mediated device and evaluating plant growth performances incorporated with the developed device targeting the short term to medium term.

The following specific objectives were formulated, and attempts were made to achieve them.

i. Creating a plant database including data on factors affecting the plant growth through comprehensive literature review to identify the elephant's preferred grazing forages.
ii. Conducting an E-based questionnaire survey to evaluate perceived palatability levels of selected elephant forage plants.
iii. Developing scores for evaluating perceived palatability, estimation of yield and identification of propagation methods to create a forage selection matrix through a qualitative approach and to develop an index through a quantitative approach.

1.5 Methodology

The methodology included the following five steps.

i. Developing a forage plant database.
ii. Assessment of forage plant palatability based on the questionnaire survey.
iii. Construction of forage plant selection matrix.
iv. Developing a forage plant selection index.
v. Designing and optimization of a Bamboo mediated planting device.
vi. Evaluation of the device’s performance in cooperation with the chosen forage plant growth performances.

An extensive literature survey was carried out on the elephant forage plants available in Sri Lanka, and field observations were made to collect information on elephant forages in wild elephant-ranging forests in the country. The observations and the information gathered from the literature were used to develop a questionnaire to assess the palatability of forage plants. The E-based survey method was used to collect the information, and the developed questionnaire was administered to wildlife experts in eight provinces of the country in order to assess the palatability of forage plants preferred by elephants using human perception. A forage plant database and a plant selection matrix were constructed to select the elephant forge plants. Scores for the yield, perceived palatability and propagation were developed to create a forage selection index and to discriminate the plant species by their performance. A device was designed, constructed and optimized for transplanting the fodder plant of higher perceived palatability using a freefall mechanism. A field experiment was conducted using Randomized Complete Block Design (RCBD) with eight plants using previously optimized devices. The responses obtained from the palatability survey data were converted to a score and statistically analyzed using descriptive and inferential statistical procedures. All the calculations and analyses were carried out through SPSS software (PC Ver. 26/IBM, 2019).

The data recorded during the optimization and field experiments were presented by graphs and analyzed using multiple means comparison with the least significant difference. In the case of field experiment data, a three-way analysis of variance and multiple means of comparisons was made after checking the interactions.

1.6 Main findings

The major findings of the study are summarized as follows:

i. A plant selection matrix was developed for the purpose of selecting the elephant forage plants.
ii. Perceived palatability levels for the forages were identified out of the total of 22 forage plants using the palatability survey.
iii. Based on the responses received for the questionnaire and metadata gathered from the literature, an index was developed to select elephant forage plants.
iv. Of the designed and optimized devices, the device (Shape 2) with a diameter range of 6.5 -7.5 cm and an angle of 45° performed better during optimization, indicating higher penetration depth.
v. In the field experiments, the selected Bamboo device (Shape 2) performed better than the standard devices (Black polybags).

1.7 The arrangement of the thesis

Chapter 1 delivers the introduction to the research topic, and the first section of the chapter describes the background of the research, followed by significance of the study, scope and limitations, aim and objectives, summary of methodology, main findings and the arrangement of the report.

Chapter 2 is dedicated to the literature review of the study. Several dimensions related to the Elephant-Human conflict are examined in the context of anthropogenic activities that impact elephant behavior. The elephant's foraging behavior, focusing on forage palatability, is also reviewed. The existing alleviation measures to manage the Elephant-human conflict were examined in the policy-making and implementation of such policies.

Chapter 3 demonstrates the detailed methodology used in the research study. The chapter detailed the methods used to achieve the aims and objectives of the study. Methodology elaborated the targeted sample population and sample, sampling method, and data collection tools. The construction of the plant selection matrix and forage selection index is described in detail. The design and optimization process of the proposed device is clearly shown. Methodology for evaluating the plant growth performances incorporated with the proposed device in field establishment is also presented. Assumptions made in the survey and field experiments are well explained. The statistical procedures used in analyzing data gathered through the different processes are also presented in this chapter.

Chapter 4 presents the results obtained from the analysis thematically under the descriptive and inferential statistics. This section reports the findings of the study based on the results of the data analysis.

Chapter 5 discusses the results and findings along with the objectives of the study. Major findings are discussed along with the research objectives while evaluating how the results and findings are consistent with the same in the literature.

Chapter 6 illustrates the conclusion, recommendations, limitations, and suggestions for further research to improve the understanding of the alleviation measure proposed by the study. It includes the future work that can be done on the basis of this research.

CHAPTER 2: LITERATURE REVIEW

2.1 General

This chapter outlines the literature review related to elephant populations including classification of African and Asian elephants, elephants' behavior, and the contributing factors. Further, current status of elephants, consequences of HEC and current mitigatory methods in general are also presented. Sri Lankan state and public perspectives towards HEC and importance of approaching to novel remedial methods, value of increasing grass availability and existing agricultural techniques for plant establishment are also described.

2.2 Trends in forest cover change and Human Elephant Conflict in Sri Lanka

Even though Sri Lanka is a small country, an island with a high population density, it is enriched with natural resources with high biological diversity [9]. Since the origin of humans, the competition for natural resources has been inherited and, as a consequence, humans interact positively or negatively with the environment.

In 1881, about 84 % of the land was surrounded by closed-canopy forests, and by 1900, the forest cover had declined to about 70 %. In 1950, Sri Lanka had more than 50 % of the total forest area and the total population was only 8 million, but it was raised to 15 million in 1980 and over 18 million in 2000 [10]. By 1983, only 27 % of the land was under dense natural forest [11]. The extent of the closed canopy natural forest cover had further declined to 23.9 % in 1993 and it was reported that natural forest cover of the island was 34.2 % in 2020 [7]. A recent study carried out on HEC and the land-use patterns of the island has demonstrated that the prevailing land use pattern aggravated the HEC in Sri Lanka [8].

Hence, the over-exploitation of the natural resources by humans, specially the fragmentation of forests, has led to the human wildlife conflict [12]. Being the largest terrestrial herbivore, the elephant interacts with humans for natural resources, which has become prominent in the other wildlife-human conflicts [13].

2.3 Elephants in the world

There are two main species of elephants as the African (*Loxodonta africana* and *Loxodonta cyclotis*) and the Asian (*Elephas maximus*). The members of the genus *Elephas,* housed within the family Elephantidae, are widely distributed in the African and Asian countries of the world [14]. Further, the Asian elephants have been classified into subspecies as the Sri Lankan (*Elephas maximus maximus*), the Indian (*Elephas maximus indicus*), the Sumatran, (*Elephas maximus sumatranus*), and the Bornean pygmy (*Elephas maximus hirsutus*). Among the African Elephants, two subspecies were recognized as the South African bush (*Loxodonta africana knochenhauer*) and the East African bush (*Loxodonta africana oxyotis*) elephants. However, the subspecies classification of the Asian Species (*E. maximus*) has been a controversial issue [15]. The recognition of elephant subspecies is of importance for the proper conservation of elephants in different [16]. Wild elephants are present in 50 countries worldwide; out of them, 13 are in Asia, whereas 37 are in Africa [17]. In the contemporary context, the total elephant populations of Africa and Asia were 550,000 to 700,000 and 41,410 to 52,345 respectively while the number in captivity is around 16000 due to a range of anthropogenic factors related to the human population growth, loss and degradation of forest habitat, fragmentation of breeding population and increasing Human-Elephant Conflict [18], [19].

According to the latest estimations in 2020, the number of wild Asian elephants (*Elephas maximus*) is between 48,323 to 51,680 consistent with possible estimates for Asian countries and as a crude guess, the relative abundance of elephants is not more than about 40000-50000 with the perpetual global population [20].

2.4 Asian elephants

Asian elephants are distributed in the South and Southeast Asian countries and the populations in each country have been assigned subspecies. However, evidence from molecular analyses, especially (DNA), implies that the subspecies level classifications need to be revisited [21], [22]. Asian Elephants previously ranged from eastwards into South-east Asia, including Sumatra, West Asia along the Iranian coast into the Indian subcontinent, Borneo, Java, and into China, which covered 9 million km^2, whereas now Asian Elephants are inexistent in West Asia, Java, and most of China [20], [23]

The Asian Elephant is categorized as Endangered (EN), based on a reduction in its area of occupancy and the quality of its habitat on account of a population size decrease over the last three generations, concluded to be at least 50% [20]. According to the IUCN Red List of threatened species the number of elephants in the Indian subcontinent, Indo-Malayan, and Total Indochina + China was 36846, 11173, and 1304 respectively[20]. Comparatively, the number of elephants in the Indian subcontinent is higher than in the other regions (Table 2-1).

Table 2-1: Estimated number of Asian elephants in the wild by country and regions within country.

Country	**Number of elephants**
India	29964
Nepal	109
Bhutan	605
Bangladesh	289
Sri Lanka	5879
Totals Indian Subcontinent	**36846**
Myanmar	2000
Thailand	3126
Malaysia (Peninsular + Sabah)	3263
Borneo (Indonesia and Malaysia)	1,000
Indonesia	1784
Total Indo-Malayan	**11173**
Laos DPR	500
Cambodia	400
Vietnam	104
China	300
Total Indochina + China	**1304**
Total	**98646**

Source: The IUCN Red List of Threatened Species: *Elephas maximus* [19], [20].

The Asian elephant density distribution across the countries and the regions are depicted in Figure 2-1 and Figure 2-2.The comparison of region-wise elephant density clearly shows that the Indian subcontinents have the highest elephant density and the Indo-China region has the lowest density and comparison of elephant density across the countries in the Indian subcontinent shows that the density is highest in Sri Lanka.

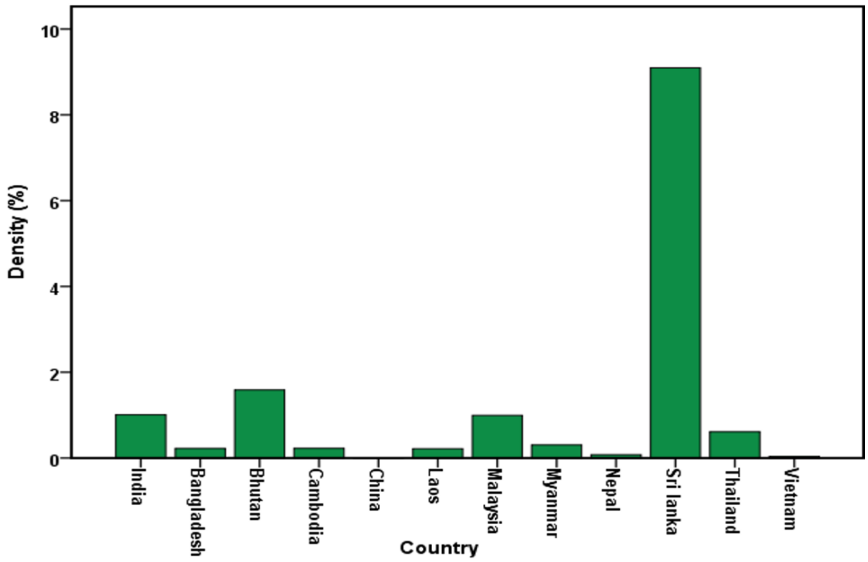


Figure 2-1: Population density of Asian elephants by countries.
Source: The IUCN Red List of Threatened: Species: *Elephas maximus*.

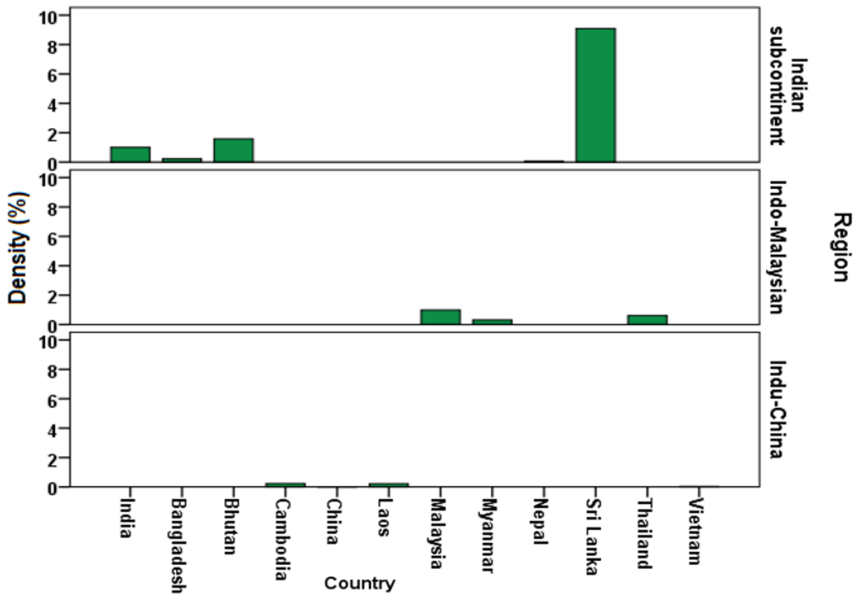


Figure 2-2: Population density of Asian elephants in different countries by regions.
Source: The IUCN Red List of Threatened: Species: *Elephas maximus* [19], [20].

2.5 Asian elephants in Sri Lanka

Sri Lankan elephants belong to the category of Asian elephants (*Elephas maximus*) and Sri Lankan history runs a long time back to the relationship between man and elephant. Sri Lanka provides homage to at least 5879 elephants, in approximate estimation, which represents 10% of the global total of the Asian elephants in the wild [4], [18].

Figure 2-3: Asian elephant herd in Sri lanka.

According to the DWC report (2013), most of the elephant populations are spatially concentrated in the Mahaweli and Eastern regions [4], [24], [25]. However, it has been reported that the elephant population was subjected to fluctuations through 1951, when there was an increase (1500 elephants in 1951). Since then, the elephant population has continuously increased to 1600-2200 in 1969, 2000- 4000 in 1978, 5879 in 2011 and the estimated elephant population in Sri Lanka as of 2017 was *ca.* 6000 [26], [27].

Conforming to the available data, the space obtained by the forest area is 20% of the total land area of 65000 km^2 and of this, 14% is designated as protected areas [10]. In a study of male and female groups, it was estimated that the sizes of home ranges have been estimated to be between 34 and 400 km^2 and moreover, it is reported that the estimated home range sizes lie between 217 and 326 km^2 for the two female groups in Sri Lanka [28], [29].

However, Sri Lanka has 10% of the wild Asian elephant population. Nevertheless, 2% is only available for elephants in that area. As far as the human population of the island is concerned, there has been a substantial growth during the past ten years and it created unexpected pressure on the natural forests on the island. Growth of the human population and agricultural area expansion at the expense of forests, has caused continuous reduction of elephant habitat. As a consequence, about 70% of the elephant's range lies outside the system of national parks and nature reserves, according to the department of wildlife conservation. Therefore, the existing forest cover is insuffcient for feeding and providing habitats for the elephant population in the country [4], [24].

2.6 Major aspects of habitats and ecology

The behavior of animals consists of five major ethological aspects, such as social, feeding, ranging, homing, and habituation. That holds true for the elephants also. There is a common ground in management of conflict resulting from wild animals as well as wild elephants. However, being the largest terrestrial mammalian member, reaching around 1000kg, elephants' behavior is of the utmost importance in conflict management [23].

Being a mega-herbivore, food and water are basic energy requirements of the Asian elephant where feeding depends on the habitat, season and its digestive system, which is not efficient due to hind gut fermentation. In general, they move around to a great extent to find their food, and consume up to approximately 150kg of wet weight per day and drink 200-250 L per day. Therefore, they feed on over 150 species of plant matter, preferring grass, herbs, thorny plants, crops etc. as-generalists and may spend around 14-19 hours per day feeding [30].

It is a well-known fact that the elephant is an edge species, preferring disturbed habitats like grassland or scrublands, semi-evergreen forest, moist deciduous forest, semi-evergreen forest, dry thorn forest, dry deciduous forests, cultivated and secondary forests rather than tropical evergreen forests population [20].

Elephants are social animals, living as groups in which 80% of elephants are males [23]. In particular, males tend to increase their range during the musth period and are mostly vulnerable due to HEC [31]. Females live in herds with baby elephants where the leader of a group is a female [32]. Adult males are either solitary or temporary bull groups associated with the herd for mating, where males take greater risk than females for Human Elephant Conflict [33].

Home range is an area that an animal uses to meet its requirements such as food, water, breeding sites [28] and the size of the home range depends on how these resources are distributed in time and space. The extent of the home range of an elephant depends on the size of the elephant, habitat quality, single or multiple patches, whereas the homing behaviors of elephants returning to the previously known place is also an important aspect which determines the success of the elephant translocation [34]. The wild elephant also demonstrates habituation behavior in which loss of response to a stimulus after repeated exposure is observed. The repeated stimuli will lead to learning and has become an important behavioral aspect in HEC management practices [35].

Due to the similarity between human and elephant ecological requirements, conflicts arise and it is inevitable when both species inhabit the same area. For these reasons, elephants have become a threat to the lives of people due to the damage that they cause to loss of crops, property and mainly to their loss of lives, and also, people may harm elephants by wounding or killing elephants as a counter attack.

2.7 Human-Wildlife conflict (HWC)

Conflict between humans and wildlife is one of the critical issues facing conservation biologists today. This conflict is a complex interaction between humans and wildlife and presents detrimental impacts on both parties. The main reason for this human wildlife conflict is the fact that the wildlife and humans lack resources. When wildlife and humans in a particular area share the same resources as food, shelter and water, they have to compete with each other for their survival [36]. In terms of HWC, it can cause potential harm to all who are involved in this, and leads to negative attitudes towards people and it can also lead to less appreciation towards wildlife and potentially cause severe detrimental effects on conservation. The main reasons for this, due to property losses, economic losses of agriculture, for instance, the loss of cattle through predation and destruction of crops by species, including primates, rodents, leopards and wild boars, etc. are responsible for the destruction can be taken into consideration [37]. In addition, HWC occurs when people establish their power upon the habitat of animals by clearing forests, crop establishment and building villages and roads. Livestock also perpetrates the significant damage to human wildlife coexistence, but there are locally accepted measures of restitution [37], [38].

Conflicts can occur anywhere. However, if those are frequently concentrated appropriately at the fringes of reserves where wildlife enjoys protection, the land is also fertile and it leads to a wealth of agriculture. Socio-economic costs associated with human-wildlife conflicts can outweigh the direct costs of agricultural damage and it may be a major cause of the conflict as perceived by the local people. Human death is a perfect example of this, and it also includes restrictions on mobility, competition for natural resources, the need to protect property, lack of school attendance, lack of employment opportunities, and exposure to disease and stress [37]–[39].

2.8 Human-Elephant conflict (HEC)

Human-elephant conflict (HEC) is one of the most controversial topics that receive a wide range of attention due to the increased rate of threats to both humans and wildlife species today, and conservation biologists receive more attention. Conflict starts from a series of both direct and indirect negative interactions between humans and animals.

Figure 2-4: Consequences of Human elephant in Sri Lanka.

HEC is a well-known major challenge to enhance the chances of the existence of elephants within their ranges, since these are places where many development projects are implemented for human well-being.

Thus, human and elephant communities have to share the space for the fulfillment of their requirements. In Sri Lanka, the intensity of HEC in many rural areas adjacent to elephants' habitats has been increasing fast whereas in the dry zone, this problem prominently occurs over access to water and the competition for resources.

A previous study provided evidence-based on three districts of the northern western wildlife region of Sri Lanka, reported that a land area of 11000 km^2 comprising around 1200 villages showed that there were over 1000 elephants in the area. During this period, it resulted in 24 human deaths and 66 elephants, while there were 452 incidents of crop damage and 119 incidents of damage caused to property in this area. A major consequence of HEC was significant degradation in the quality of life of rural people [40]. As reported by countries such as India, ca. 400 human deaths 400 and 100 elephants annually due to the HEC [41]. In Sri Lanka, it has been reported that there are 70 human and 200 elephant mortalities annually from the HEC [27].

It is a renowned fact that a majority of low-income subsistence farming communities often reside close by the forests and protected areas due to limited availability of the arable lands, inaccessible irrigation access, and cultural affinities in the protected areas [42]. A greater number of farming and pastoral areas are changing ecological dynamics and habitat patterns through agricultural production and management of important natural resources [43], [44]. The land clearance for agricultural extension and enhancing forage land for new vegetative growth for farming animals led to the move of elephants into refugees [45], [46].

Meanwhile, based on the data recently available for 2021 at the Wildlife Department of Sri Lanka, the elephant deaths of the period of 2010– 2021 indicated a considerable increasing trend, with a total of *ca*. 3338 whereas human deaths accounted for 1061. Hence, elephant deaths seem to have increased steadily, and allocated compensation also ascended drastically for the period from 2010 to 2021 (Figure 2-5).

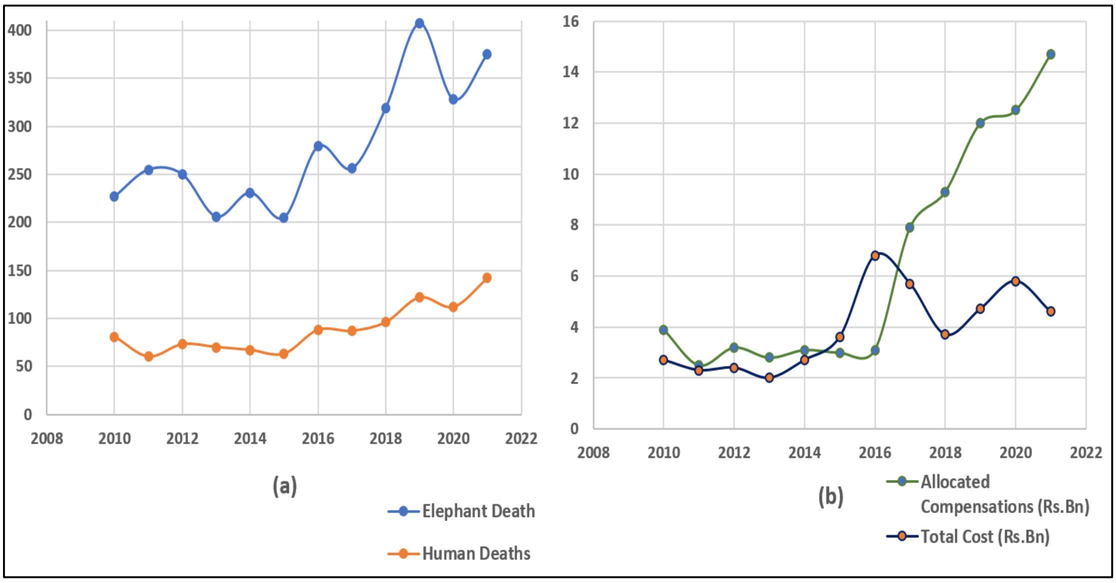


Figure 2-5: (a) Human and elephant deaths by the year and (b) Government raised budget for EHC damages from 2008 to 2022.
Source: DWC Reports (2008 to 2021).

Human activities significantly impact the nearby forestland and their activities restrict the elephants' home range and their population density by direct and indirect competition of natural resources such as water, food, and space [47]–[49]. The results of research conducted in Zimbabwe have reported that the human-elephant coexisting has a minimum threshold of ca.15–20 people/km^2 of human population density. At this threshold level, the loss of habitats and fragmentation is expected to be in the range of a 40–50 % conversion of the forestland for human purposes, which in turn creates an uninhabitable area for elephants [50].

Further, elephant migration routes have changed due to the establishment of planted fields adjacent to water sources and even digging wells to obtain groundwater in such plantations. Thus, habitat destruction enhances the HEC possibilities, For instance, roads and farmland in the vicinity of fragmented feeding grounds provide higher opportunities for conflicts [51]. The most frequent form of HEC is the crop-raiding by elephants in agricultural fields for their food requirements [52]–[57].

Moreover, the intensity of HEC in many rural areas adjacent to elephant habitats has been increasing fast whereas elephants are also killed in various ways and most of them are killed using gunshots, electrocution and poisoning, "Hakka patas"**,** landmines, engulfing polythene, accidental falling into agricultural waterways, drowning, road accidents, and abandoned gem pits and collision with the trains [4].

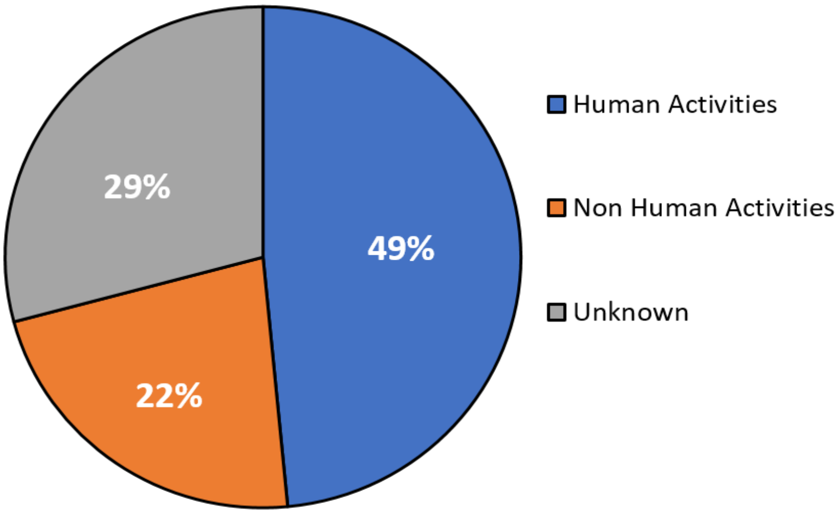


Figure 2-6: Causes of Elephant Death in 2021.
Source: DWC Report - 2021

A recent study has provided evidence-based on the year 2021 of the DWC reports of Sri Lanka: elephant deaths are commonly attributed to human activities, non-human activities and unknown reasons (Figure 2-6.).The majority of elephant deaths (49%) in 2021, were related to human activities. Meanwhile, unknown reasons contributing to the death of the elephants are difficult to determine, since most incidents, like dead bodies, are recovered after decomposing or putrefying and postmortem examinations are difficult. Natural deaths and deaths due to worm infestation and septicemia-like factors have been categorized into non-human activities [18], [26], [27].

Thus, declining forest cover associated with anthropogenic activities is also one of the major contributing factors associated with the increase in elephant deaths and has led to perpetual HEC. The transformation of forest lands into human well-being leads to narrowing the gap between the elephant and human populations where they have to live in nearby proximity and, it also is obvious that the possibilities are often lethal results [58], [59], [60]. Therefore, up-to-date literature on the measures taken for mitigation of HEC is summarized in section (2.9) onwards.

2.9 Measures and strategies of Human-Elephant conflict (HEC) mitigation

There are several methods in practice for mitigating HEC, ranging from conventional to novel methods. However, those methods need assessment for effectiveness concerning the HEC mitigation.

2.9.1 The measures taken for mitigation of HEC

People use various methods in order to overcome this problem. Mainly, these mitigation methods are categorized into three: physical, vigilance, and deterrent to mitigate HEC.

I. Physical barriers

Fences, non-electric fences, live fences, and trenches are some of the physical barriers that man uses to overcome this problem. However, there are advantages as well as disadvantages regarding its effectiveness. The main purpose of these physical barriers is to prevent elephants from entering community areas and agricultural lands [61].

i. Trenches and electric fences

Methods such as electric fencings and ditching trenches have been used to discourage elephants from entering farmland and human settlements. These methods demand a considerable construction and maintenance cost, labor and may preclude larger-scale establishments [62],[63].

In the long run, the efficiency of these methods reduced reports on the breaking of fences by elephants and other fence-breaking animals [64]. Some studies conducted on African elephants have demonstrated that elephants are sufficiently intelligent enough to learn that tasks do not conduct electricity and could be used to break an enclosing electric fence [65].

In addition, these types affect long-term survival by isolating elephant populations already being fragmented by restricting movement for food and water resources and at last the gene flow [66]. Thus, fencing effectiveness remains largely unexplored in Asia.

ii. Modern communication tools

The advancement in communication facilities, quick location and attention of elephants are made possible using mobile phones among farmers and local wildlife personnel, to facilitate cooperation in chasing away troublesome elephants [67]. These applications of this method suffer from many difficulties from the lack of internet connectivity or network coverage to communicate the alarms to farmers in remote areas [68].

II. Vigilance Method

The vigilance method is used to inform farmers about the approaching elephants and to increase the chance of driving them away. Buffer zones, watch-towers, string fences, and detection and alarm systems using tripwire fences, optical, laser or infrasound technologies are some of the vigilance methods that people use to eradicate this problem [62].

i. Use of protected Elephants' corridors –

Even though the protected areas are established as a measure of conservation by wildlife conservationists, the process is, in brief, a physical separation of human and wildlife communities [69], [70]. The elephants' corridors connect fragmented habitats together and separate the protected areas, facilitating connectivity between elephant herds, offering higher rescue effects, and an increase in gene flow [71]. Thus, it is believed that corridors contribute to the ecological requirements and behavioral features of humans and elephants, minimizing human elephant confrontations. Further, corridors provide alternative routes for elephant migration and ranging behavior for food and water [72].

However, elephant corridors have become less effective with the pressure of development of expanding infrastructure within the vicinity of elephant ranges with little concern for environmental impact [73]. Therefore, for a meaningful establishment of elephant corridors, it is necessary to have a solid knowledge of man-made land-use change and concern for its impacts on elephant habitat, habitat connectivity, and elephants' migratory patterns.

III. Deterrent method

Deterrent methods are used to discourage the passage of elephants into the fields or villages. Buffer zones are used as a deterrent method to chase away elephants from unpalatable crops such as chili, sesame, and tea. Making sounds using metal objects, recorded sounds, firecrackers are ways of chasing away elephants [74].

i. Acoustic deterrents

It has long been known that farmers protect their crops by scaring raiding elephants by shouting, using firecrackers, making noise by hitting metal objects together, etc.,[51], [75]. These methods are effective to a certain extent in chasing elephants from crops [76]. The audio playbacks of threatening sounds have recently been tested as short-term and short-distance elephant repellents [63].

However, studies have shown that elephants are rapidly conditioned to resist sounds and continue raiding crops [77]. Furthermore, establishing and maintenance of these systems posed problems with accessing remote areas. Though these methods are reported to be effective by 65–100%, the potentially negative interference audio playbacks on other wildlife species need to be addressed before wider use for elephant crop raiding [78], [74]. The studies carried out in Africa have recently demonstrated that the use of beehive fences deters elephants effectively [79].

ii. Light as deterrents

It has been reported that sources of light such as bonfires and flashlights repel the elephants from the ripening crops [51]. Similar to that of the acoustic methods, light-based deterrents are temporary solutions and long-term use of such measures has become ineffective because elephants rapidly adapt to the deterrents [80].

iii. Agricultural repellants

The most predominantly agricultural repellant methods include the use of less attractive, less palatable crops in between the frequently raided crops [27], [81]. Furthermore, repellant plants such as mustard, sesame, and chili have long been used to repel elephant raiding during Chena cultivation [82].

The crops not only repel the elephant but also benefit the farmers by providing additional income.

2.9.2 Remedial measures of HEC Mitigation

As a remedial measure of HEC incidents, several methods have been used in practice to elephant conservation while mitigating future incidents. These methods include domestication, culling, and translocating certain troublesome individuals or herds of elephants to new locations [80].

i. Domestication -

Domestication of wild elephants has long been practiced since prehistoric in Asian countries for several purposes. Even today, wild elephants are domesticated on a small scale. In this practice, both the elephant and human elephant-human behavioral harmony enhanced and shared the benefits. The disappearance of this practice has led to the loss of these positive human-elephant connections in local communities and wild elephant populations, possibly contributing to human-elephant conflict. However, domestication indicates certain negative impacts on captive as well as wild elephant well-being [83].

ii. Culling

The culling is a selective slaughtering of problematic and history with constant problematic elephants such as man killers, which are often culled to prevent future confrontations with humans. Though up-to-date statistics of annually slaughtered elephants are unavailable, discriminatory culling of elephants is practiced time-to-time in certain elephant range countries. The effectiveness and necessity of culling are controversial issue questions because male elephants are subjected to culling due to their wider niches that encompassed the human settling areas. However, this method is not practiced in Sri Lanka [80].

iii. Translocation

Translocation is a process in which the problematic elephants are captured, transported and resettled to protected areas far away from human settlement or farmland [84]. However, effectiveness of elephant translocation have not been subjected to in-depth investigations, while results of preliminary studies imply that translocated elephants frequently return back to their original range and during their retunin they create conflict in the release areas [84]. Furthermore, there are a number of reports on the elephants death due to capturing and transportation during translocation [85].

In summary, though there are a number of methods used in the alleviation of HEC, there is a growing tendency in the reports of HEC incidents elsewhere in Asian countries providing evidence that neither method is effectively minimizing the HEC.

However, the combination of above-mentioned methods would provide an effective method in mitigation of the gravity of the HEC. This idea is well represented by litereature suggesting the model approach i.e., human–elephant coexistence model to minimize the HEC and conservation of elephants [24].

2.10 Sri Lankan state and public perspectives of HEC

The animal attack is one of the major disasters in Sri Lanka though it is not included in the Sri Lanka Disaster Management Act, No. 13 of 2005 [86]. However, an animal attack can be considered a disaster by the nature of the disaster. Human wildlife conflict incidents involve interaction between humans and animals even leading to the death of humans and elephants [12]. This adverse interaction results, from a humans' point of view, in the loss of crops, human deaths and infrastructure in turn economic losses.

On the contrary, the elephants' deaths have also increased drastically leading to the considerable depletion of the elephant population in the country. Various alleviation strategies have been advised and are practiced to mitigate HEC at different scales. Even though most present conflict prevention techniques are driven by site-specific circumstances and only provide short-term solutions, HEC persists, and mitigation strategies transfer conflict risk from one location to another. Furthermore, the significance of a multidisciplinary conceptual method for managing long-term species coexistence was demonstrated [19].

At the state level, the majority of authorization is assigned to the Department of Wildlife conservation and a part is allocated to the Forest Conservation Department in terms of responsible agencies in Sri Lanka to mitigate HEC. Further, elephants are conserved under the Fauna and Flora Protection Ordinance in Sri Lanka [87].

Further, in the context of the National Policy on Conservation and Management of Wild elephants in Sri Lanka, Policy of 2009 and Fauna and Flora Protection (Amendment) Act, No.22 of 2009, it has been restricted to introduce any plants without granting permission from the relevant authorities [88],[87]. Nevertheless, the replacement of annual crops with perennial grasses has the ability to provide wildlife with stable cover and food resources, according to the international context, and is a successful coexistence approach [89], [90].

Therefore, the use of *in-situ* conservation strategies for HEC mitigation in Sri Lanka is limited, owing to a lack of specific information. HEC incidents involve crop-raiding animals that consume or destroy food crops and injure or kill those people trying to protect their fields [25].

This can lead to the failure of elephant and biodiversity conservation measures that rely on the support of local people. Enrichment of forest cover, educating people, policy planning, using modern technology, in-situ and ex-situ conservation of elephants, introducing physical barriers such as an electric fence, biological fence, etc. can be used to achieve resilience.

In accordance with the recent data available with WDC, the land area of Sri Lanka has been divided into 6 regions as (Figure 2-7) Mahaweli (Polonnaruwa, Trincomalee, part of Badulla, Matale), North western (Kurunegala, Anuradhapura, Puttalam,), Southern (Colombo, Gampaha, Kalutara, Kegalle, Matara, Hambantota, Rathnapura, Monaragala), Eastern (part of Badulla, Ampara, Batticaloa), Northern (Jaffna, Kilinochchi, Mullaitivu, Mannar, Vavuniya), and Central (Kandy, Nuwara Eliya, and Badulla) [4].

Further, the land area of the country was divided into such areas by the DWC, to facilitate the work of wildlife officers and based on regional availability. By considering the increase in the population and the number of cases regarding EHC, after the year of September, 2012, based on unpublished information from the DWC, wildlife regions have been re-divided into 12 regions to develop the efficiency of the officers and to maximize the security of the zones as shown in Table 2-2.

Therefore, this study focused on filling the gap by investigating a suitable planting mechanism for elephant forage with a multidisciplinary conceptual approach using an innovative transplanting method (Bamboo method) to increase the elephants forage availability in order to the mitigation of HEC over the long-term species coexistence.

Table 2-2: Wildlife Regions in Sri Lanka

Wildlife Region	**District**
Puttalam	Puttalam
Kilinochchi	Kilinochchi, Mullaitivu, Jaffna
North Western	Kurunegala, Palagala and Kekirewa areas of Anuradhapura
Polonnaruwa	Polonnaruwa, Matale
Anuradhapura	Anuradhapura
Central	Kandy, Nuwara Eliya, Mahiyanganaya, parts of Haldummulla areas of Badulla
Trincomalee	Trincomalee
Vavuniya	Mannar, Vavuniya, Padaviya area of Anuradhapura
Western	Colombo, Gampaha, Kalutara, Kegalle
Southern	Matara, Hambantota, Rathnapura
Eastern	Batticaloa, Ampara, part of Dimbulagala area of Polonnaruwa
Uva	Badulla, Monaragala

Source: DWC Reports (2011 to 2021)

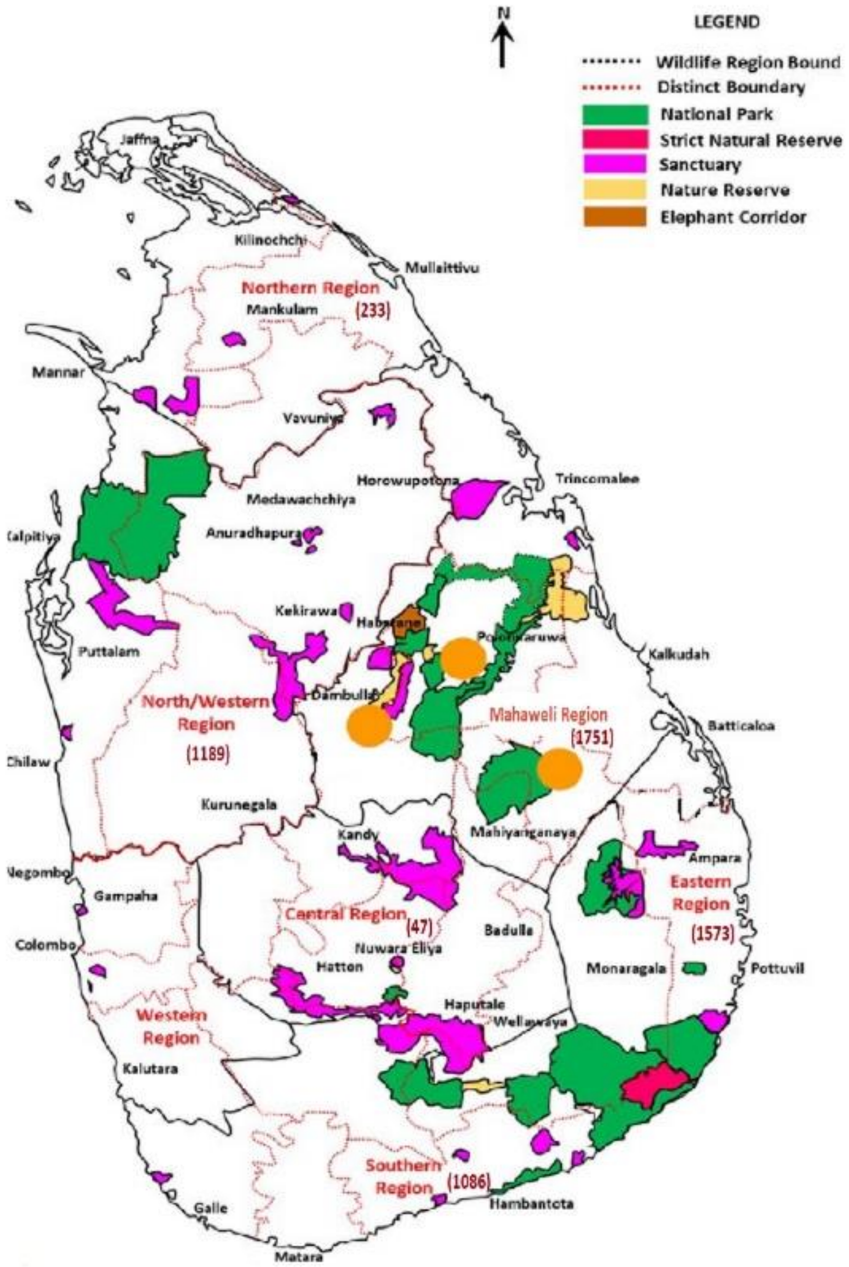


Figure 2-7: Distribution of elephants by Wildlife regions in Sri Lanka. (Modified after Rajapakse et al., 2019).

Source: DWC Report -2021.

2.11 Elephant forage plants and Availability of grazing forages in Sri Lanka

There are several migratory measures in practice, including the introduction of electric fences as well as trenching to restrict the movement of elephants. However, HEC remains persistent as most existing prevention strategies driven by site-specific factors only offer short-term solutions, while mitigation strategies transfer conflict risk from one place to another [19]. For a sustainable solution for the HEC, a holistic approach to the problem is essential and the factors of basic needs such as water, food, and breeding sites are of importance in such endeavors [91].

As far as feeding behavior such as fodder palatability, availability, and nutrient requirement is concerned, it provides indispensable factual evidence for finding migratory measures for the HEC [92]. Therefore, it is necessary to focus on the increase in the availability of grass fodder. It is a well-known fact that forage palatability is associated with physical characteristics such as fiber content, level of maturity, toughness, succulence, and leafiness, which are determined through the observation of forage intake of elephants.

Further, forage grass palatability, availability, and the physiology of an animal were the major factors influencing the relative preference made [93],[94]. Therefore, identifying the palatability levels and preferences for each plant species is of importance in enhancing the habitat enrichment endeavors to mitigate human-elephant conflict (HEC) by avoiding the implementation of fences, including biological and electric, with unsustainable pressure on elephant behavior [95],[96]. There are a considerable number of studies carried out in Sri Lanka on the number of elephant behavioral aspects. The work carried out on the elephant forage, in general, indicated that most of the Sri Lankan elephants preferred grasses over the other plants, the preferences vary with seasonal availability of forage plants during dry/wet seasons [97], [98]. The forage grass availability is lower during the dry season.

Thus, the majority of elephants feed on the grassland established in reservoir beds as well as drained natural water bodies on the island [52], [89], [99]. One of the major concerns over the availability of elephant forage grasses which has been addressed by wildlife authorities is that illegal grazing by cattle and buffaloes during the dry season and encroachment of the grassland by invasive plant species such as *Lantana camara* [97], [98][100].

Therefore, an increase in forage availability would lead to minimizing the HEC, and in this regard, it is worthwhile attempting to identify the plants that could be introduced into the inaccessible elephant ranges. The grasses possess higher adaptability and regenerative capacity and thrive well in varying climatic conditions. Therefore, it is appropriate to increase the abundance of grazing forage availability to minimize the elephant movement from the protected areas, which in turn reduces the chances of human-elephant confrontations. As far as feeding behavior is concerned, fodder palatability, availability, and nutrient requirement play a crucial role in planning mitigatory measures for the HEC [92]. It is a well-known fact that forage palatability is associated with physical characteristics such as fiber content, level of maturity, toughness, succulence, and leafiness, which can be determined through the observation of the forage intake of elephants. Further, forage palatability, availability of grass species, and the physiology of an animal were major factors influencing the relative preference made [5]. Asian elephants consume a wide variety of vegetation, as many as 165 species of plants belonging to 56 families [101].

Hence, identifying the palatability levels and preferences for each plant species is of importance in enhancing the habitat enrichment endeavors to mitigate HEC avoiding the implementation of fences, including biological and electric, with unsustainable pressure on elephant behavior [96]. A comprehensive literature survey on the relative palatability level of wild range elephants for each grazing forage in Sri Lanka revealed that there was a scarcity of in-depth studies available on the feeding behavior and diets of Asian elephants grazing on rangelands and secondary forests [5],[102]. However, mitigation of EHC through wild elephant management and enhancing habitat enrichment techniques requires a crucial understanding of feeding behavior and ecology [96]. For the survival of wild-range Asian elephants in fragmented landscapes through a habitat enrichment approach and co-existence strategy, in-depth researches are required to fill the gaps of knowledge about the relative preference of fodder plants of the Asian elephants in the ranging forests in Sri Lanka [3].

2.12 Section of Plant Transplantation method

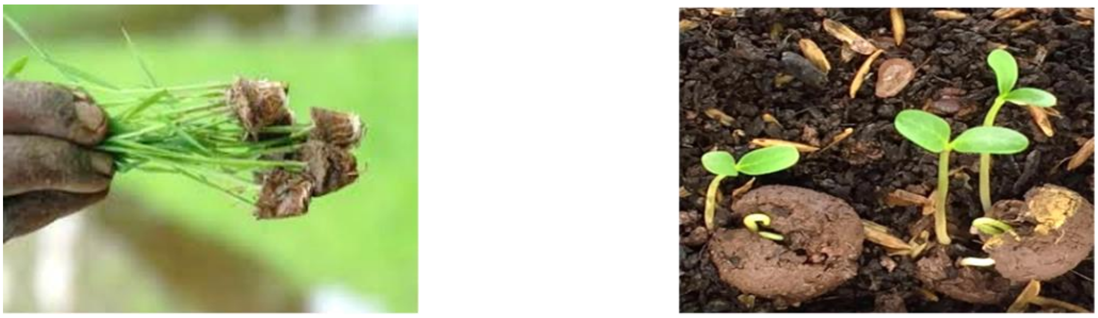
Transplantation in agriculture is a process in which a plant or seedling is removed from one location such as a nursery and resettled in the soil at another location. The term plant transplantation is defined as the establishment of plants other than sowing seeds [103].

However, before transplantation, seedlings are grown in nurseries. Based on the crop requirements, an array of transplanting methods is in practice elsewhere in the world. In rice cultivation, most often transplanting the seedlings in rice manually in Asia, however, with the advancement of technology, transplanting of rice plants is being achieved through planting machines. In ecological restoration of vegetation, the methods already applied in agriculture are modified to suit the requirements [104]. Plant establishment methods included direct seedling, transplanting by parachute method, broadcasting and speedball method, etc. [104]. The throwing methods such as seed ball and parachute methods are already practiced elsewhere in the world for transplantation of rice [103].

In addition, the seed ball (Clay Dumplings) method is an ancient technique for propagating plants using the distribution of seeds by encasing them in a mixture of clay coat which protects the seeds by preventing them from sun drying, being eaten by animals and blown away until rainy season. It is an efficient method which is used without opening up soil with cultivation tools [103]. The seed ball method of plant transplantation has been suggested for forest regeneration whereas it provides a feasible method for seed dissemination, though the seed in the ball may be vulnerable to pests such as insects, rodents, wild boars, birds like wild animals [105] .

Further, Parachute plant transplanting is being practiced as a random transplanting method in Agriculture, as an alternative plant establishment method which is important because of reducing labor count, shorter time and achieving optimum plant population. China is credited with the invention of the parachute method, which involves tossing seedlings to establish rice fields. The parachute method will avoid the transplanting shock, which provides considerable results in cultivation practices [106], [107], [108].

Therefore, a novel method of transplantation was developed, based on the parachute method and seed ball method for the proposed plant growth mechanism for the elephant grazing foraging plants in inaccessible ranging forest areas and marshlands.



(a) (b)

Figure 2-8: Plant establishment methods; (a) Parachute method and (b) Seed ball method.
Source: Department of Agriculture, Sri Lanka (1) [328] and Seed-balls.com (2) [329].

2.13 Suitability of Bamboo material as a device

Bamboos are grasses that botanically belong to a sub-family of Bambusoidea of the family, Poaceae. The subfamily consists of about 100 genera and 1400 species distributed in tropical and subtropical countries of the world [109]. However, a majority of species are confined to East and Southeast Asia and in the islands of the Indian and Pacific oceans. Technically, the Bambosidea is further divided into the tribes and the genus *Bambusa* is housed within the tribe Bambuseae which includes ca. 49 genera distributed in tropical and warm temperate regions world [109]. In Sri Lanka, there are six genera and 12 species, and the genus *Bambusa* represents four species. Among these species, *Bambusa vulgaris,* commonly known as “Una” (Sinhala) is growing all over the island except at higher altitudes. The culms of *Bambusa vulgaris* are smooth and reach 15-20 m in height and 4-10 cm in diameter [110]. Bamboo culms consist of nodes and an internode is placed between two nodes. The cavity is not continuous along the culm and is separated into chambers by the septum which lies at nodes. The culm can be cut and separated into the internodes by the septum and remaining node with one end opening at the other end [110] (Figure 2-9).

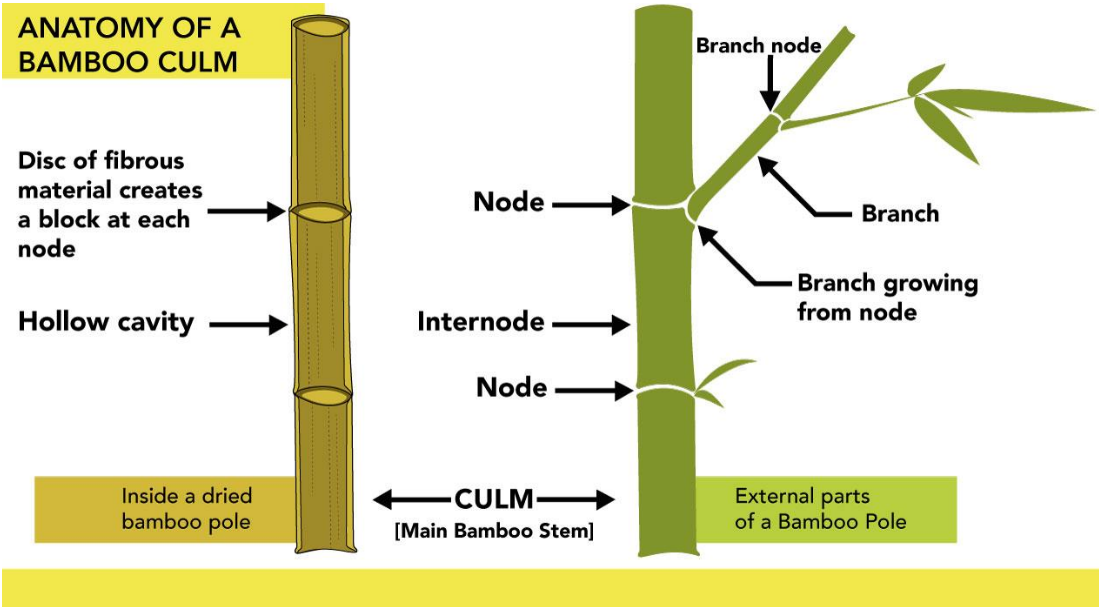


Figure 2-9: Anatomy of a Bamboo culm with a longitudinal section.
Source: www.ukbamboo.com [330].

The culm anatomical characteristics of *B. vulgaris* in physical and mechanical characters have been studied and demonstrated that the morphology of fibers and arrangement, distribution of vascular bundle vascular, bundle length, fiber length, fiber diameter, lumen diameter, and fiber wall thickness contribute considerably to the strength of the bamboo. In addition, the inner layer of bamboo consists of a thicker layer of parenchymatous tissues which retain the highest moisture content than that of the middle and the outer layers. The physical properties such as basic density, and moisture content differ significantly at the outer, middle and inner layers of the culm vary [111], [112].

The shrinkage is a more pronounced radial facet, however, higher at the tangential facet. The mechanical properties such as the Tensile Modulus of rupture and elasticity of bamboo are considerably higher [113]. Since the higher tensile strength, the culms of the *Bambusa vulgaris* have long been used in a variety of non-structural and structural works [113]–[115]. Thus, mature bamboo culms are of valuable candidature for non-structural and structural constructions.

2.14 Summary

The behavior of wild elephants caused several issues centering around human death and injuries, property losses, crop losses, and social losses. In addition, a considerable number of incidents have been reported of human-induced damage to elephants, even leading to deaths. This situation is at present referred to as the HEC. A noticeable fluctuation is in the elephant population of Sri Lanka. A gradual increase from 1500 elephants in 1951 to 1600-2200 in 1969, 2000- 4000 in 1978, and 5879 in 2011.

The unpublished elephant population data available for 2021 at the Wildlife Department, the elephant deaths of the period of 2010 – 2021 indicated a substantial increasing trend with a total of 3181 human deaths and 685 elephant deaths.

The mitigatory methods practiced at present for reduction of EHC were discussed, their benefits and drawbacks. The availability and limitation of elephant forage grasses were disused to a certain extent. The palatability of wild range elephants grazing forage in Sri Lanka revealed that in-depth studies were scarce.

Highlighted the importance of identification of palatability and preferences in relation to the elephants' forage. The increase in forage availability would lead to minimizing the HEC, and in this regard, it is worthwhile attempting to identify the plants that could be introduced into the inaccessible lands. The grasses possess higher adaptability and regenerative capacity and thrive well in varying climatic conditions. Therefore, it is appropriate to increase the abundance of grazing grass availability.

Available transplanting methods were discussed and special attention was paid to the seed ball and parachute techniques. Biological, anatomical , physical, chemical, and mechanical properties of Bamboo (*B. vulgaris*) were elaborated.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 General

This chapter outlines the research methodology used in the study in detail. The study envisages exploring the different aspects of the problem from field observations, preparation of an elephant-forage database, an E–based questionnaire survey, designing and optimization of a planting device for a suitable plant growth mechanism, and assessment of the devices' appropriateness through growing selected forage plant in the device. Therefore, the methodology employed in the study is presented under the sub-heading of each aspect of the research.

3.2 Development of a database for Elephant-forage plants

An extensive literature survey on the elephant forage plants was conducted and simultaneously, observations were made during the field visit to the elephant-affected areas on the island (Figure 3-1). In field visits, structured interviews were conducted with the wildlife experts as well as the villages. The field visits were made from June to August 2021 to Wilpattu, Ampara, Weli Oya, Mullaitivu, and Puttalam areas, etc., for preliminary observations regarding the HEC. Based on the information collected from these sources, a database of Elephant- forage plants was developed. The developed plant database consists of a total of 22 fodder plant species (Appendix B).

Figure 3-1: Field observations at Human - Elephant conflicted areas in Sri Lanka.

3.3 E-base survey on the perceived palatability of Elephant forage plants

A survey was conducted in the provinces where the elephant population is higher, except for the Western Province of the island. The responders were chosen at random based on knowledge and experiences of rangeland and interest in wild animals.

The study employed the survey method in collecting information regarding the perceived palatability levels of elephants (Appendix: C). A questionnaire was prepared and validated by subject experts, piloted, and then validated through a reliability test of Cronbach α (≥ 0.92) (Appendix: D). The validated questionnaire was converted into Google form and an E-Based survey tool since the prevailing pandemic condition of the country precludes the field surveys (Appendix C). The Google form was disseminated through emails and social media and followed up by telephone communication from October-December, 2021. The questionnaire included 22 items on a 6-point Likert scale, as shown in Table 3-1 [116].

Table 3-1: Likert scale with palatability levels.

Response	**Scale**
Intensely palatable	5
Strongly palatable	4
Moderately palatable	3
Mild palatable	2
Weekly palatable	1
Unknown/ Not in this region	0

An additional survey was also conducted from July 2021 to August 2021 to assess errors and avoid confusion among respondents, since rangers of the Wild Life Conservation Department and ecologists were interviewed from different regions of the country to make a list of preferred herbaceous plant species by wild elephants [99], [102], [5]. The data gathered through the survey was explored for errors and was subjected to descriptive and inferential statistical analysis.

The responses to the items, except for zero values, were transformed into scores according to Equation (1) [117], and these scores were further converted into percentile values [118].

$$Weighted\ Sum = \sum_{i}^{n}(xi * wi) \quad (1)$$

Where,

wi = Weight assigned to the indicator (Scale of Palatability Level)

xi = Number of responses for each indicator (Field experts) [117].

3.3.1 Forage plant Selection Matrix and Index

A list of the most important plant growth factors that was obtained from the prepared database for the Elephant forage plants with the aid of literature, was taken to construct a key referred as a "Plant Selection Matrix" in terms of qualitative approach. Subsequently, the extracted plant characteristics by means of forage plant database and "Forage Selection Matrix" were used to develop a "Forage Selection Index" (FSI) to select most suitable elephant forage plants for a detailed quantitative approach. Here, palatability, propagation and yield were taken into account using weighted mean formula, Likert scale and Z-score values of each plant character Table 3-1 and

Table 3-2 [119]. In order to get a measurable value for the selection of suitable Elephant forage out of selected forage species, FSI was developed using the propagation score, yield score and the perceived palatability of forage plants, with regards to the standard E-based questionnaire which consisted a set of statement rated on six point Likert scale ranging from Intensively palatable to unknown or not in the region,

Table 3-2: Likert scale with propagation.

Indicator	Scale
Readily by vegetative propagation with seed propagation	3
Rarely by vegetative propagation	2
Only by vegetative propagation	1

3.4 Field Experiment 1: Designing and optimization of Planting Device

A conceptual designing of a device to establish forage plants in inaccessible elephant ranges through aircrafts such as helicopters and drones, has been proposed as shown in Figure 3-2.

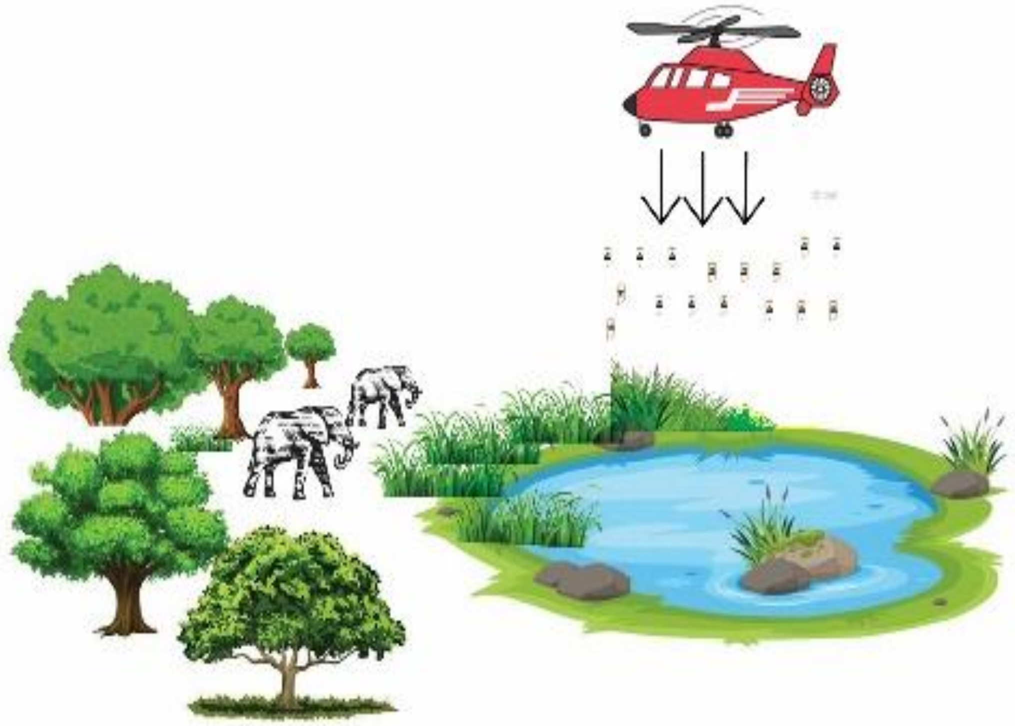


Figure 3-2: Theoretical concept of using aircraft for the establishment of elephant forage plants in elephant ranges.

Bamboo (*Bambusa vulgaris*) was chosen as the material for developing a proposed planting device. The present concept was developed by combining the agricultural techniques that are used in transplantation and plant establishments, i.e., parachute and seed ball methods reported in the literature [103], [105].

Mainly, there were two devices proposed as planting devices in this study. Two shapes for the cutting end of each device were designed using bamboo sections to select the most suitable device after the device optimization process to develop a suitable planting device, whereas the proposed devices were named as Shape 1 and Shape 2 (Figure 3-3).

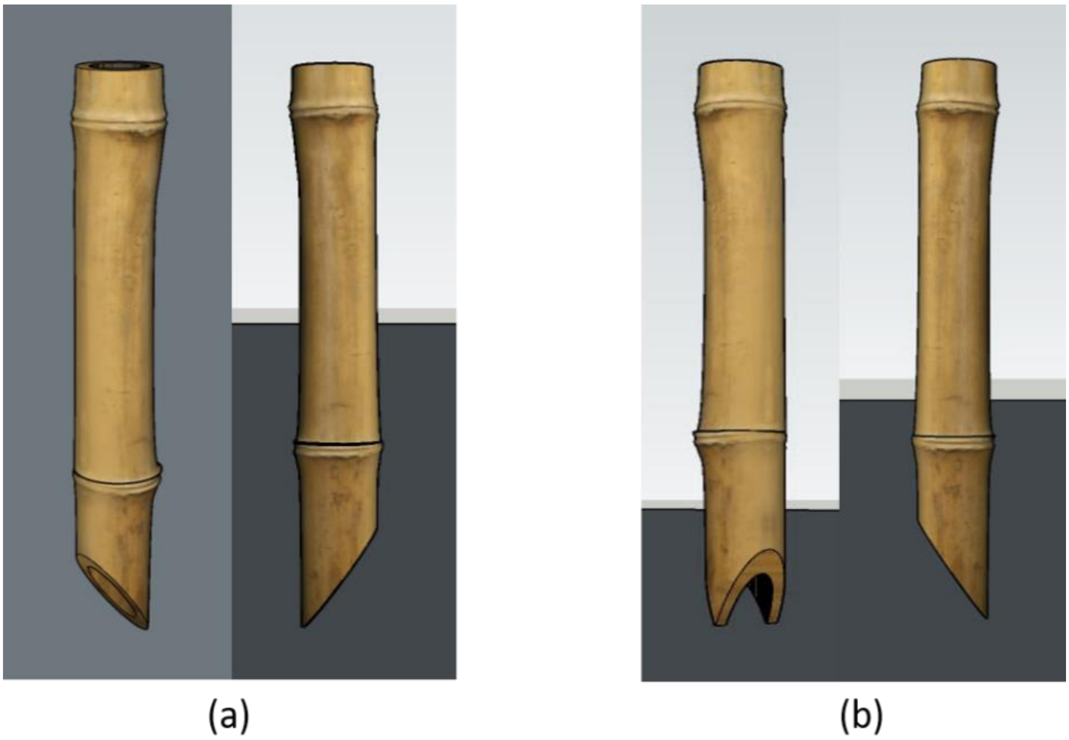


Figure 3-3: Designed Bamboo devices for the Experiment 1; (a) Shape 1, (b) Shape 2.

Subsequently, mature bamboo stems were collected and were used to prepare experimental samples for the proposed device with (proposed height) 550 mm in length and diameter ranging from 550 mm to 800 mm (Figure 3-4, Figure 3-5 and Figure 3-6).

Often two internodes of the bamboo stem were severed. During the cutting of the Bamboo section, care was exercised to retain the septum (cavity layer) at the bottom of each bamboo section and to remove the septum at the middle part of the bamboo stem to retain the substrate or potting medium and the plant. An angular power saw was used to cut with the cutting angles ranging from 15º, 30º, 45º, 60º, 75º since the angles were ranged from 0 º to 75º in the machine.

Figure 3-4:Preparation of Bamboo structures using Circular power saw.

Figure 3-5: Some prepared Bamboo structures for the Experiment 1.

Figure 3-6: Metal pills.

Later, measurements of length, diameter (including internal and external), and initial weight, was recorded for each bamboo stem cutting and was brought to the weight of 2 kg by adding metal balls to maintain a constant weight, since there was a variation in the weight of the bamboo i.e., even though they are in the same length, the weights were less than 2 kg approximately.

Further, an artificial marshland was constructed with a barrel (empty containers of isopropyl alcohol) with a diameter of 600 mm and a height of 760 mm and filled with paddy soils up to 30 mm below the brim, and maintained a water level in the rest of the space in order to keep the water saturation of paddy soils at maximum level. Subsequently, prior to each bamboo cell trial, excess water from the barrel was drained and the soil was stirred well with a wooden rod to maintain a homogeneous soil substrate as shown in Figure 3-7. Paddy soil was chosen as a homogenous soft soil substrate in this experiment for maintenance of even soil properties and to measure the high experimental range of penetration depths for the device optimization process minimizing the residual (experimental) errors. Further, it was assumed that the device performed better in soft soils, and the properties of the device would behave a similar way in any soils elsewhere.

(a) (b)

Figure 3-7: Artificial marshland used for the optimization process; (a) soil saturation by excess water level and (b) saturated soil barrel.

The artificial wetland built in a barrel was placed below the balcony on the two-story building with a dropping height of 5 m (L).

(a) (b)

Figure 3-8: (a) Free-fall experiment conducted for the device optimization process; Artificial marshland with penetrated device and (b) Free-falling of device from two story building.

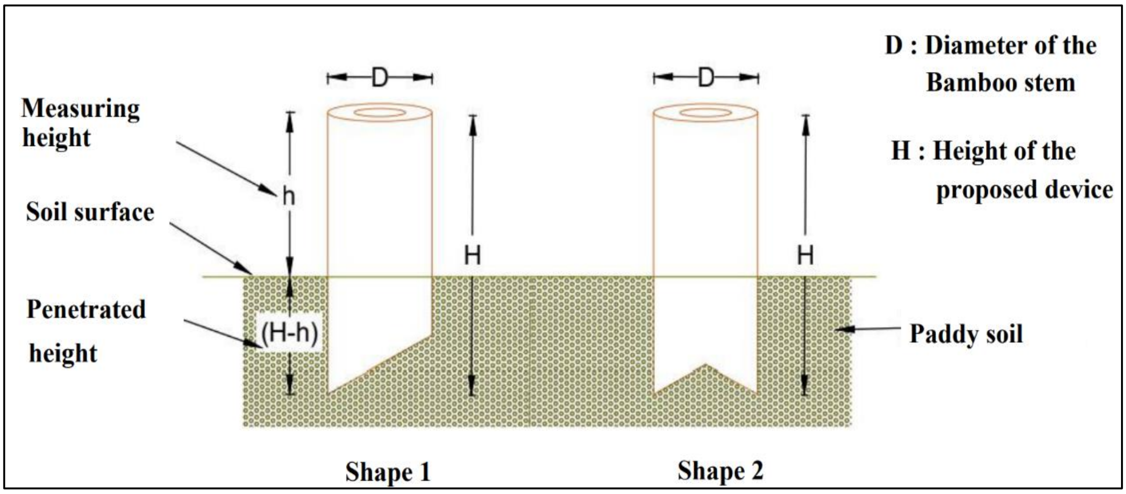


Figure 3-9: Sketch diagram for the Measuring of penetration in the marshland using proposed devices (Shape1 and Shape 2).

As shown in the Figure 3-8 and Figure 3-9, experiment one was conducted for the optimization of the Bamboo device. Experimental Bamboo structures were free-fallen to the artificially prepared marshland and the penetration depth of each sample was measured by using a ruler. Three replicates were prepared from each sample, whereas those are labeled with diameter, shape, and weight, and three trials were carried out from each sample to minimize residual errors and human errors.

During these field tests, the environmental conditions and the structural conditions of Bamboo structures are assumed to be constant except for diameter, the cutting angle, and the geometric shape of the device. Therefore, the collected data were recorded using a pre-prepared data entry sheet (Appendix: E).

Further, the behavior of each sample during the free-fall experiment was visually observed and reported.

Figure 3-10 : Behaviour of the devices during the freefall experiment.

3.5 Field experiment 2: Evaluation of the device for growth performance of forage plants

The proposed Bamboo device was tested by incorporating the growth performances of selected eight forage plants through a plant database, plant selection matrix, and plant performance index. Implementation of field experiments with selected elephant fodder plants was made in the real environment. The appropriateness of the bamboo shell-mediated transplanting method was analyzed for plant growth performance.

3.5.1 Experimental site

The field experiment was conducted in the Rathupaswala area, Gampaha District in Sri Lanka. The site lies in the low country Wet zone (WL3) at an elevation of 30 m above mean sea level where the predominant soil type of Red Clay loam subsoil is moderately well-drained [120]. The climatic conditions of the study site are shown in Table 3-3.

Table 3-3 Climatic parameters of the experimental area.

Climatic parameter	Measurement
Mean rainfall	85.5 mm
Humidity	80 %
Soil temperature	28.5 °C
Average day temperature	32.5 °C
Night temperature	23.5 °C

3.5.2 Experimental Design

The treatments were arranged in a Randomized Complete block design (RCBD) with four replicates. There were five treatments and eight plant species with four replicates for each plant (Table 3-4). The five treatments included plants grown in the ground (control) –T1, Bamboo shell (55cm) placed on the surface – T2, Bamboo shell (55 cm) submerged in the soil - T3, Standard (Std.) size polybag (25 cm in height)– T4 [121], Polybag with 55 cm height –T5.

One hundred and twenty-eight plant containers were prepared to provide drainage holes at the bottom part of each device and 32 other plants were grown directly in the soil. In terms of the material selection, the plant types to be studied in the field experiment were selected from the same field for the same species with approximately the same size, height, and a same number of leaves at their seedling stage and they were vigorous and healthy and had exposure to the sunlight with homogeneous intensity.

Table 3-4: Details of the treatments used in the experiment.

Treatment	**Description**
T1	Control
T2	Bamboo device on the soil surface
T3	Bamboo device submerged in the soil
T4	Standard (Std.) polybag (250 mm)
T5	Height of 550 mm polybag

3.5.3 Layout of the experiment

Five plots were prepared to size 8 x 4 m with a plant spacing of 500 mm [122]. Sunken beds were used in the experiment as depicted in Figure 3-11 and Figure 3-12. The density of 32 plants per plot (bed) was chosen to be planted [123].

H_1: 550 mm

K_1: 500 mm

H_2: 250 mm

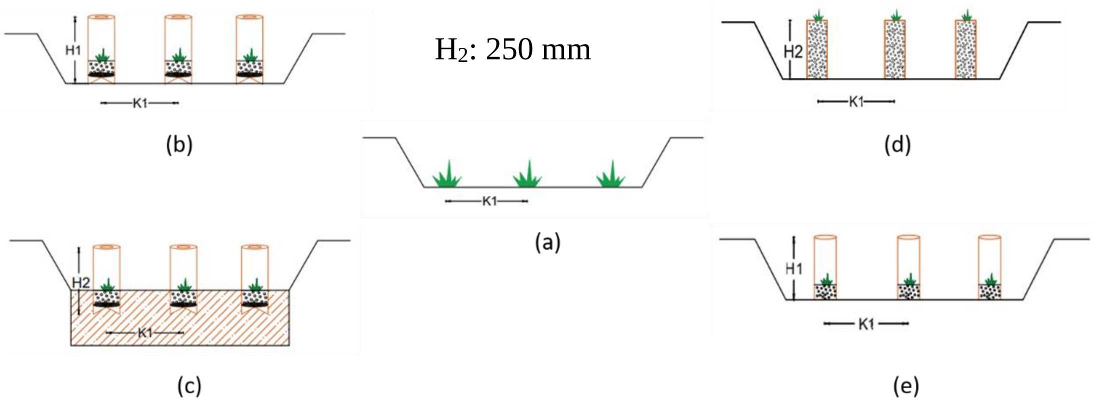


Figure 3-11: Side view of sunken beds prepared for the field experiment 2 **:** (a) control, Bamboo devices (550 mm); (b) on-surface & (c) submerged, polybags; (d) Std. size (250 mm) & (e) height of 550 mm.

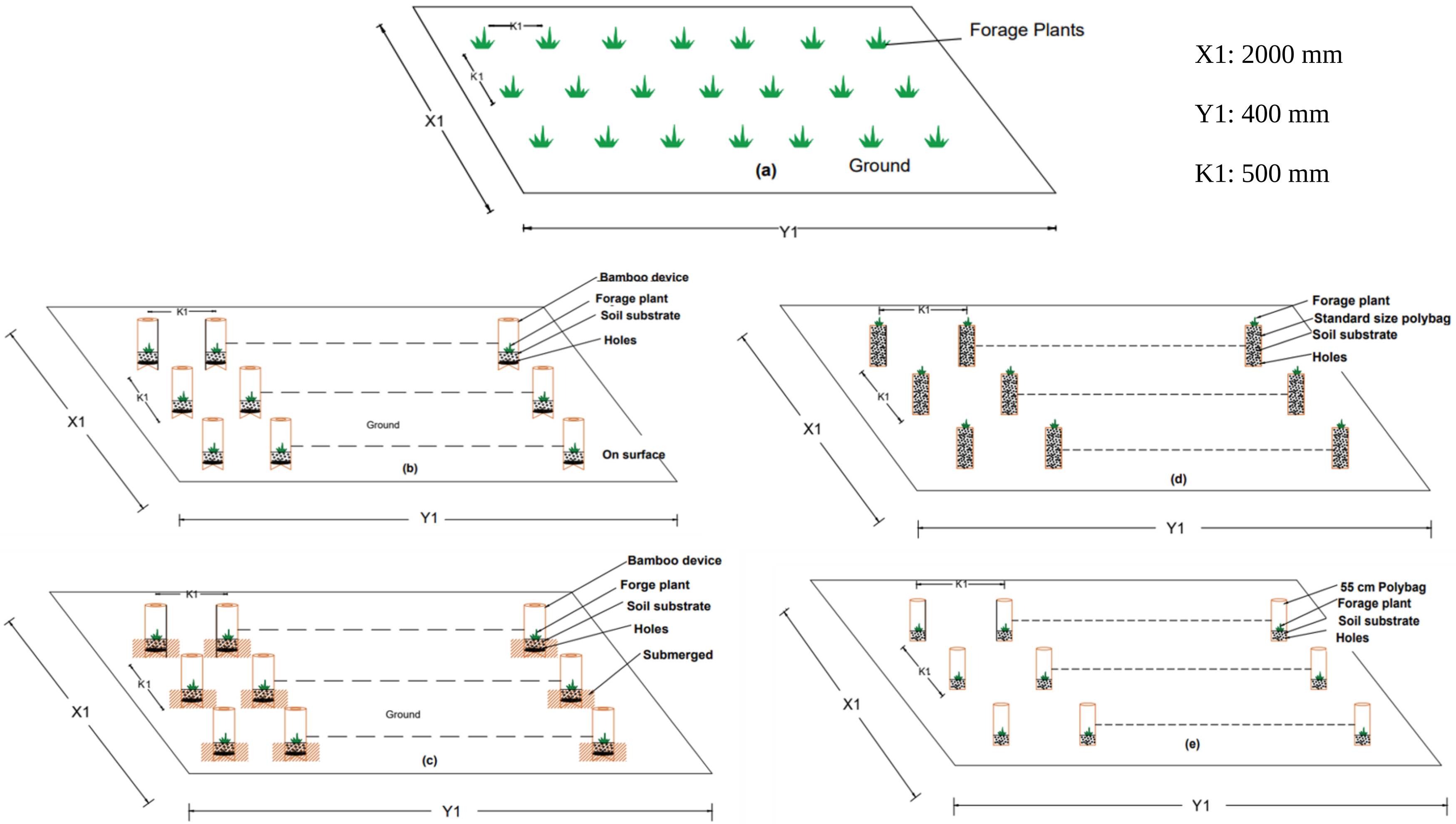


Figure 3-12: Field layout; (a) Control, Bamboo devices (550 mm); (b) on surface & (c) submerged , Poly bags; (d) Std. size (250 mm) & (e) height of 550 mm.

3.5.4 Bed preparation and Transplantation

Sunken beds were prepared and zero tillage practices were applied. Each device and each polybag was filled to a soil depth of 23 cm and surface soil collected from the vicinity was served as potting medium [121]. The soil was washed off from the roots of the tillers and one plant was inserted directly into each perforated device or polybag [123]. None of the fertilizers were applied during the experiment. The weeding, watering and the other cultural practices were done twice a week.

Figure 3-13: Primary land preparation and culturing practices.

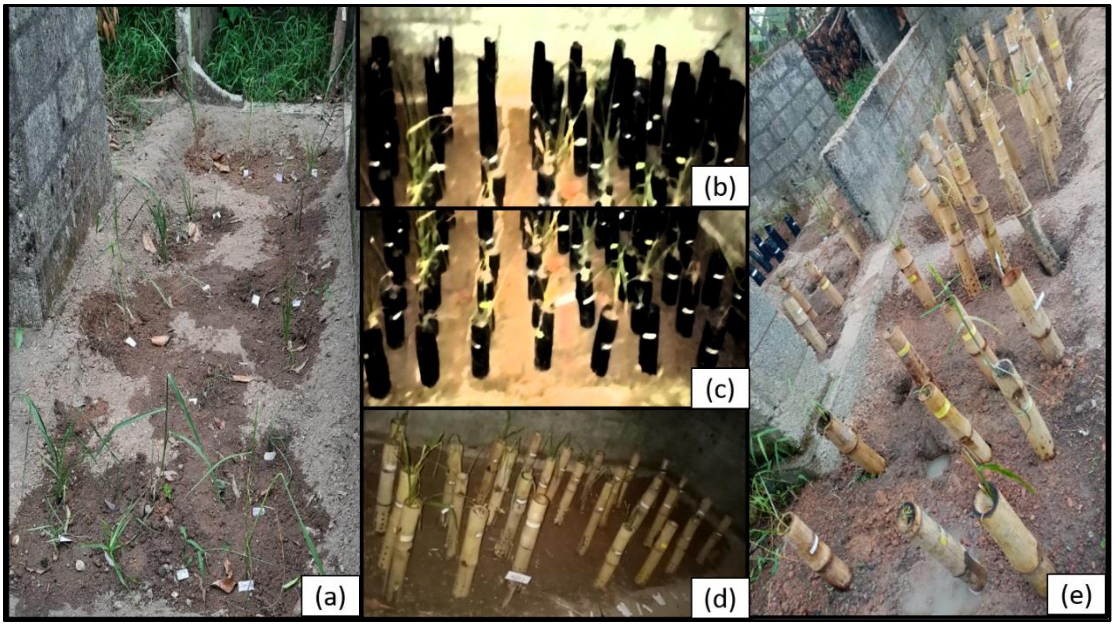


Figure 3-14: Initial stage of the plants transplanted in the beds treated by (a) Control, (b) Poly bags; height of 55cm , (c) Std. size & Bamboo devices (55cm); (d) on surface & (e) submerged .

3.5.5 Data Recording

Data were collected from each plant treated by each device for vegetative parameters and reproductive parameters. The measurements of the height of the plants, the number of leaves per pot, and number of tillers per pot were observed once a week throughout the period of three months. Plant height was measured from the base of the plant to the distal end of the longest leaf. Number of leaves were determined by counting all unfolded leaves without yellowish and dead leaves. The number of days taken for reaching the flowering stage was counted by visual observations.

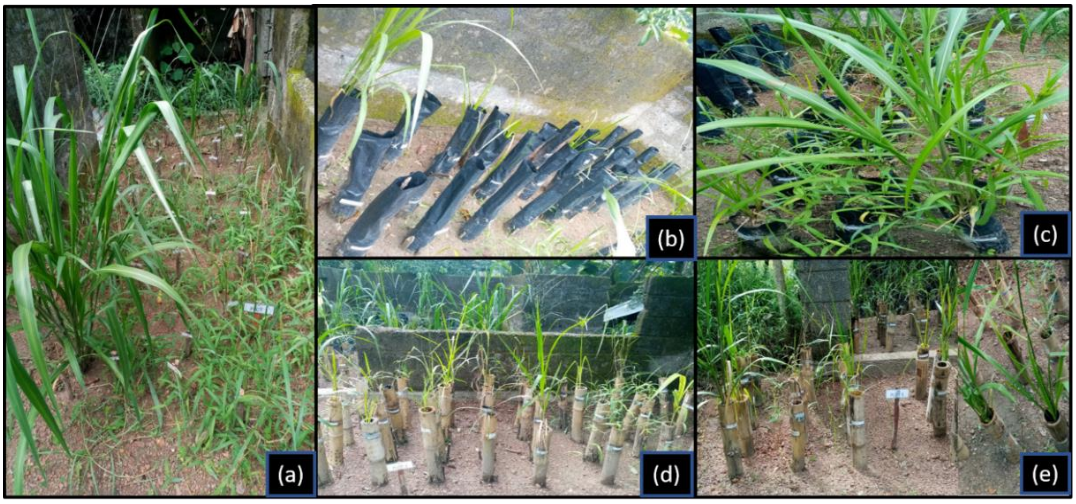


Figure 3-15: Vegetative stages of forage plants in each beds: (a) Control, (b) Poly bags; height of 55cm, (c) Std. size & (d) Bamboo devices (55cm); on surface & (e) submerged.

Figure 3-16: Flowering stages of forage plants in Bamboo devices.

3.6 Data Analysis

The analysis of data was performed according to the data types and different statistical procedures were separately taken for the qualitative data and the quantitative data. The responses to the questionnaire were analyzed using frequency distribution and cross-tabulations and cluster analysis. The perceived palatability score, the height of the plant, number of leaves /pot, number of tillers/pot and, the number of days taken to initiate the flowering were analyzed using One-Way-ANOVA, and the mean separation test using LSD was employed when more than two treatments are involved. Further, Three-Way ANOVA was carried out where more than three analysis of variance was carried out to ascertain the interactions among the treatment by using one-way analysis of variance (ANOVA) to compare the means.

In addition, cluster analysis (CA) and principal component analysis (PCA) were used to observe the patterns reflected in the data collected from the questionnaire survey and plant database. The scores derived from the PCA were used to develop an index to measure the elephants' forage selection. The data generated from the experiment were statistically analyzed using SPSS software (PC Ver. 26/IBM, 2019) and SAS statistical package (Version 9.2).

3.7 Summary

A plant database was prepared from the information gathered through field visits and the comprehensive literature survey on the elephant forage plants. The information collected was used to construct a Plant Matrix towards a qualitative approach. The plant matrix was used to select the fodder plant to continue the study.

The responses collected from the questionnaire were used to calculate the perceived palatability score, which was later converted to the percentile scores. The information on yield and method of propagation collected from secondary sources was used to construct an index referred to as the Forage Selection Index (FSI) to identify the suitable fodder plants. The Index was used to confirm the plant chosen from the plant matrix and the prepared plant database through a quantitative approach.

A Bamboo device was designed with varying cutting shapes, diameters, and cutting angles. The proposed device was optimized using artificial marshland prepared from the paddy soil in a barrel. The device was freely fallen from the two-story building onto the soil surface of the barrel with a dropping height of 5 m. The depth of soil penetration of each device was measured and analyzed to assess the penetration depth performance of the constructed device. The optimized bamboo device was further tested for its suitability for planting with chosen plants from the FSI.

The plant growth performance of the proposed device was evaluated by comparing with the control (directly grown in the soil bed), and two types of poly bags (Std. size and 550 mm). Further, the effect of the devices' position (on surface soil and submerged in the soil) was also compared and assessed by measuring the plant growth performance of each device. The RCBD was employed with eight forage plant species selected by using the FSI values in the experiment-2 carried out in the field. The data gathered from the survey and field experiments were analyzed using appropriate statistical procedures.

CHAPTER 4: RESULTS AND DISCUSSION

4.1 General

Several approaches were made to achieve the objectives of the study, *viz.*, developing a plant database, evaluation of palatability of forage plants, designing, optimization of a plant device and field trials with optimized design with selected forage plant species. The result of the study is presented according to the order of the methodology conducted and thematically arranged under the subtopics from 4.2 to 4.7. Further, this chapter is dedicated to the discussion of the research carried out and owed to conclude the results and findings obtained from the study.

4.2 Plant Database

The outcomes of field visits and the literature survey conducted on the common potential elephant forage plants growing in Sri Lanka, were used to prepare an Elephants' Forage Plant Database as demonstrated in Appendix B and all the sources of information gathered were also referred and included. The details of the characteristics of the selected plants are tabulated separately. Essential forage plant growth external and internal characters as Habitats of the plants, propagation methods, Rate of growth per seed and seed nature, Optimal growth of the plant, Tolerance / resistance ability, Flowering and pollination, Plant nature and description, Life cycle, grown areas, rainfall, adapted geological condition, soil requirement, suitable pH level, palatability, yield and maturity height are basically taken into the consideration and summarized in the plant database.

The summary prepared from the extraction of information from the plant database is shown in Table 4-1 for the basic identification purposes. The list included a total of 22 forage plant species with five sedges, three herbaceous, and 14 types of grasses commonly occurring in the island belonging to five plant families. The data gathered from the plant database mainly, yield, propagation method like characteristics were important to prepare forage selection matrix and index.

Table 4-1: List of selected Elephants' forage plants in Sri Lanka.

Scientific Name	**Family**	**Vernacular name (§-Sinhala)**	**Plant Type**
Achyranthes aspera L.	Amaranthaceae	Gas Karalheba	Herb
Schoenoplectus grossus (L.f.) Palla	Cyperaceae	Thunhiriya	Sedge
Cyperus haspan L.		Halpan	Sedge
Cyperus iria L.		Thunessa	Sedge
Cyperus rotundus L.		Kalanduru	Sedge
Fimbristylis miliacea (L.) Vahl		Mudu halpan	Sedge
Alysicarpus vaginalis (L.) DC	Fabaceae	Asvenna	Herb
Echinochloa colona (L.) Link	Poaceae	Gira thana	Grass
Echinochloa crusgalli (L.) Beauv		Wel maruk	Grass
Eleusine indica (L.) Gaertn.		Bela thana	Grass
Imperata cylindrica (L.) Beauv		Illuk	Grass
Isachne globosa (Thunb.) Kuntze		Batadella	Grass
Ischaemum timorense Kunth		Rila thana	Grass
Leersia hexandra SW		Levu	Grass
Panicum maximum Jacq.		Gini thana	Grass
Panicum repens L.		Etora (Atawara)	Grass
Echinochloa glabrescens Kossenko		Bajiri	Grass
Ischaemum rugosum Salisb.		Gojarawalu	Grass
Pennisetum purpureum K. Schumach.		Ali maana	Grass
Sacciolepis interrupta (Wild.) Stapf		Beru	Grass
Dactyloctenium aegyptium (L.) Wild.		Putu thana	Grass
Bacopa monnieri (L.) Pennel	Scrophulariaceae	Lunuwila	Herb

4.3 Evaluation of the perceived palatability of forages

The results of the questionnaire survey data analysis on the perceived palatability of elephant forages were presented under subheading 4.3.1 and 4.3.2.

4.3.1 Questionnaire survey

The validation of the questionnaire through a piloting sample was achieved by calculating Cronbach's α and the value obtained was 0.92. Thus, the questionnaire is reliable and consistent (Appendix D).

The targeted population included 80 responders, whereas the sample consisted of 15 females and 65 males. The distribution of responders across the provinces is shown in Table 4-2. The highest number of responders included in the sample were from the

Northcentral province (23 %) and the provinces of Northwestern, Central, Southern, and Eastern were presented by 20.0 %, 18.8 %, 16.3 %, and 12.5 % of responders respectively. The provinces such as Northern, Uva, and Sabaragamuwa were represented by 3.8 %, 2.5 % and 2.5 % in the sample respectively.

Table 4-2: Distribution of responders across the provinces.

Province	Frequency	Percent
Central	15	18.8
Eastern	10	12.5
North Central	19	23.8
Northwestern	16	20.0
Northern	3	3.8
Sabaragamuwa	2	2.5
Southern	13	16.3
Uva	2	2.5
Total	80	100.0

The gender distribution in the sample by gender is presented in Table 4-3. Female distribution in females by comparatively very low numbers. The highest number of females included in the sample were from the North Central provinces and the lowest number of females were from the Northern and Sabaragamuwa provinces. There was not any female responder from the Eastern and Uva provinces. The number of male responders was higher in the Northcentral province (15), followed by Northwestern (13), Central and Southern with equal numbers (11), Eastern (10), Northern and Uva with equal numbers (02) and Sabaragamuwa with one respondent.

Table 4-3: Gender distribution in sample by the provinces.

Province	Gender		Total
	Female	Male	
Central	4	11	15
Eastern	0	10	10
North Central	4	15	19
Northwestern	3	13	16
Northern	1	2	3
Sabaragamuwa	1	1	2
Southern	2	11	13
Uva	0	2	2
Total	15	65	80

The distribution of gender in the total sample and distribution of respondents by provinces are shown in Figure 4-1. Gender distribution within the total sample indicated that there was low female participation in the questionnaire survey (18.75 %), whereas the majority of respondents were male (81.25 %).

The spatial distribution of responders indicated that the majority of responders were reported from the Northwestern province (28.75 %). The rest of the provinces represented, i.e., North Central province (21.25%), Central province (16.25 %), Uva province (12.50 %), a considerable number of responders. However, Southern, Sabaragamuwa, and Northern have reported a moderate percentage of responders (6 % to 8 %) while the minimum percentage of responders were reported for the Eastern province responders (1.25 %).

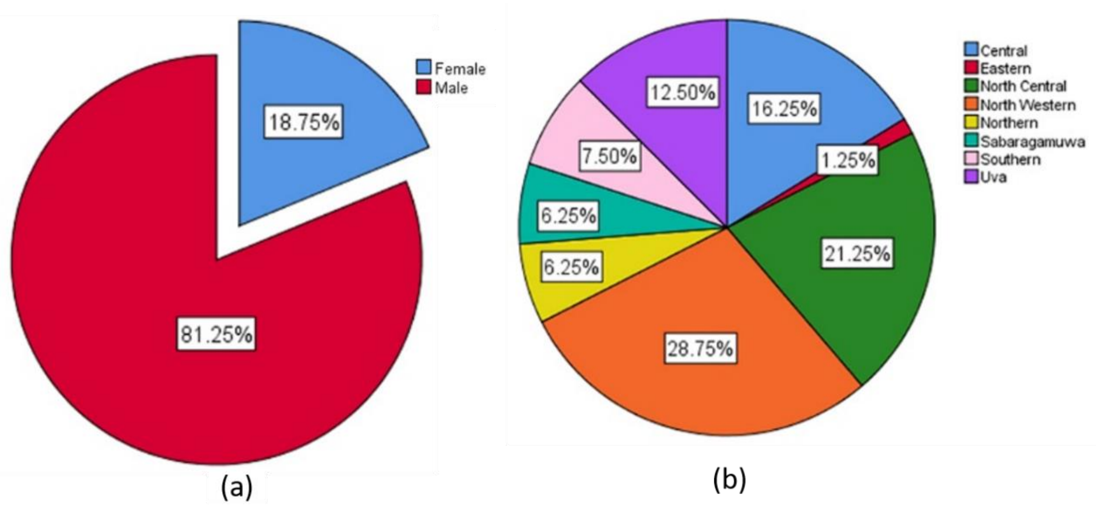


Figure 4-1: (a) Responders' gender distribution and (b) province within the sample.

In addition, the responses to the items in the questionnaire were used to calculate the palatability scores. And the descriptive statistics of the weighted mean scores of Elephant forage plant species are presented in Table 4-4.

The distribution of the mean palatability scores (expressed as %) among the selected Elephant forage plant species, is shown in Table 4-4. The mean palatability scores of Ali maana (*Pennisetum purpureum*), Beru (*Sacciolepis interrupta*,) and Gini thana (*Panicum maximum*) were 8.22 %, 7.53 %, and 7.00 % respectively.

Table 4-4: The averaged percentage palatability score among the elephant forage plants collected in the study.

Plant name	Mean (%)	Palatability Levels	Std. Error
Pennisetum purpureum (Ali maana)	8.22	High (8.22 - < 6.58)	1.44
Sacciolepis interrupta (Beru)	7.53		1.94
Panicum maximum (Gini thana)	7.00		1.3
Echinochloa glabrescens (Bajiri)	6.66		1.12
Isachne globosa (Batadella)	6.34	Medium (≥6.58 -<4.94)	1.35
Echinochloa crusgalli (Wel marukku)	6.25		1.08
Imperata cylindrica (Illuk)	5.78		0.98
Schoenoplectus grossus (Thunhiriya)	5.72		1.21
Panicum repens (Etora)	5.63		0.83
Cyperus iria (Thunessa)	5.56		0.94
Eleusine indica (Bela thana)	5.41		0.9
Ischaemum timorense (Rila thana)	5.41		0.98
Echinochloa colona (Gira thana)	5.34		0.76
Ischaemum rugosum (Gojarawalu)	5.09		1.02
Dactyloctenium aegyptium (Putu thana)	5.03		0.88
Cyperus rotundus (Kalanduru)	4.56	Low (≥4.94 -<3.31)	0.88
Fimbristylis miliacea (Mudu halpan)	4.47		1.24
Cyperus haspan (Halpan)	4.41		0.95
Alysicarpus vaginalis (Asvenna)	3.84		0.88
Achyranthes aspera (Gas Karalheba)	3.78		0.62
Leersia hexandra (Lavu)	3.31		0.53
Bacopa monnieri (Lunuwila)	3.31		0.88

The mean palatability of a subset of plants, which included Bajiri (*Echinochloa glabrescens*), Batadella (*Isachne globosa*), and Wel maruk (*Echinochloa crusgalli*) fell within the mean palatability range of 6.66 % - 6.25 %, and the mean palatability of Illuk, (*Imperator cylindrical*) and Thunhiriya (*Schoenoplectus grossus*) ranged from 5.78 % to 5.72%.

The rest of the fodder plants indicated low palatability percentages (4.56 % -3.31 %). The plant palatability scores were divided into classes based on the magnitude of the score, *viz*., Low (< 4), Medium (≥ 4 and < 7), and High (≥ 7) as shown in Table 4-4 and Table 4-5. According to the palatability class, the forage species such as Ali maana, Beru, and Gini thana fell within the "High" palatability group. The rest of the forage species form two groups based on their palatability levels. The fodder species of Bajiri, Batadella, Bela thana, Etora, Gira thana, Gojarawalu, Illuk, Putu thana, Rila thana, Thunessa, Thunhiriya, and Wel maruk were clustered under Medium palatability group. The low palatability group of forage species included Asvenna, Gas Karalheba, Halpan, Kalanduru, Levu, Lunuwila, and Mudu halpan.

Table 4-5: Distribution of palatability classes by plant species.

Plant species	**Palatability class**			**Total**
	Low	**Medium**	**High**	
Pennisetum puerperium (Ali maana)	0	0	1	1
Sacciolepis interrupta (Beru)	0	0	1	1
Panicum maximum (Gini thana)	0	0	1	1
Echinochloa glabrescens (Bajiri)	0	1	0	1
Isachne globose (Batadella)	0	1	0	1
Eleusine indica (Bela thana)	0	1	0	1
Panicum repens (Etora)	0	1	0	1
Echinochloa colona (Gira thana)	0	1	0	1
Iachaemum rugosum (Gojarawalu)	0	1	0	1
Imperata cylindrica (Illuk)	0	1	0	1
Dactyloctenium aegyptium (Putu thana)	0	1	0	1
Ischaemum timorense (Rila thana)	0	1	0	1
Cyperus iria (Thunessa)	0	1	0	1
Schoenoplectus grossus (Thunhiriya)	0	1	0	1
Echinochloa crusgalli (Wel maruk)	0	1	0	1
Alysicarpus vaginalis (Asvenna)	1	0	0	1
Achyranthes aspera (Gas Karalheba)	1	0	0	1
Cyperus haspan (Hal pan)	1	0	0	1
Cyperus rotundus (Kalanduru)	1	0	0	1
Leersia hexandra (Levu)	1	0	0	1
Bacopa monnieri (Lunuwila)	1	0	0	1
Fimbristylis miliacea (Mudu halpan)	1	0	0	1

The distribution of the type of plants in the sample is shown in Figure 4-2. The majority of elephant forage plants were belonged to grasses (63.64 %) and a portion of 22.73 % represents the sedges, and the fraction of 13.62 % falls within the herbs

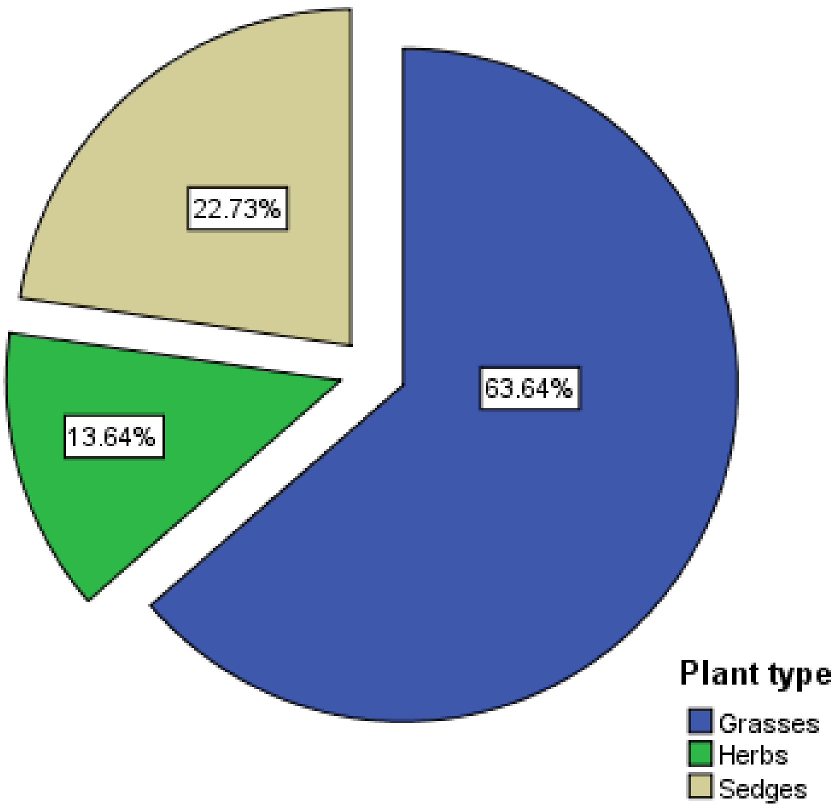


Figure 4-2: Distribution of plant types within the sample.

Further, the breakdown of the plant types along with their palatability levels is indicated in Figure 4-2 as A, B, and C. Among the grasses, the majority of grasses (63.64 %) were low in palatability, meanwhile 21.43 % of grass species and 7.14 % fell within the medium and high palatability classes (Figure 4-3 A).

However, almost all herbs were low in palatability class as shown in Figure 4-3 B. Among the sedges, the majority of plants were low in palatability (60.00 %) and 40.00 % of plants indicated a medium level of palatability (Figure 4-3 C).

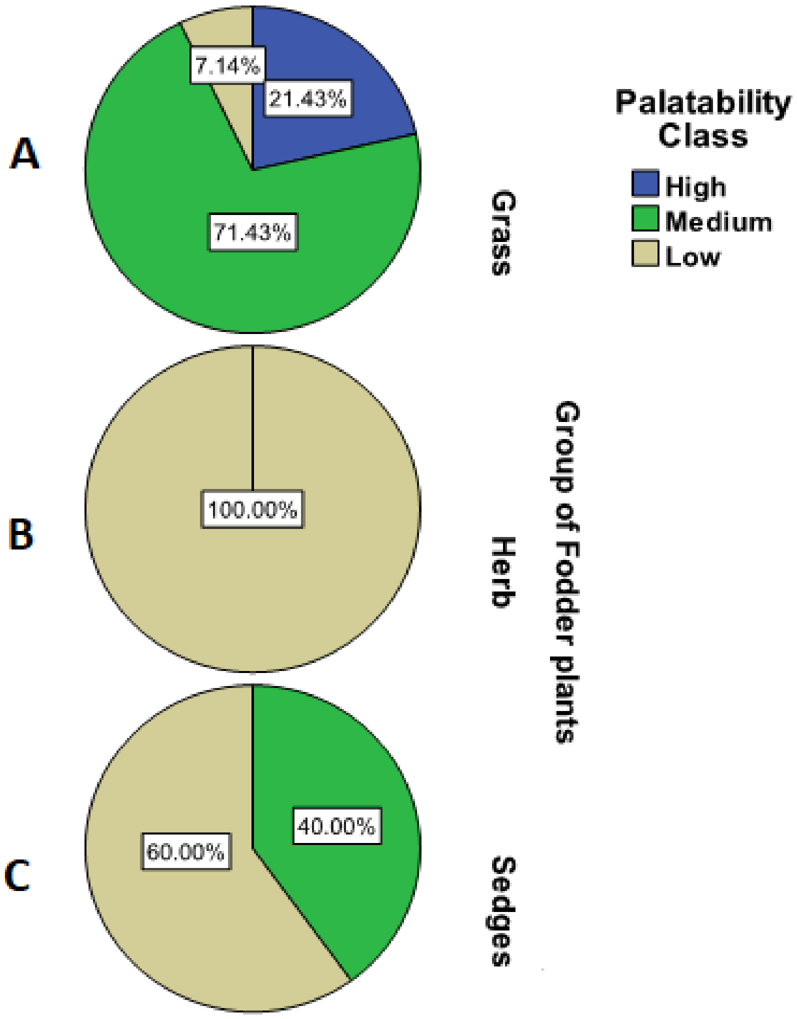


Figure 4-3: The variation of the palatability within the plant types included in the study.

4.3.2 One-way Analysis of Variance (ANOVA) of perceived palatability

The results of ANOVA obtained by analyzing between and within the perceived palatability variation in the scores of the plants and the provinces are summarized in Table 4-6.The summary of the ANOVA of between provinces variation of perceived palatability indicated that there were significant differences in palatability scores (expressed as %), with the F-value associated with higher statistical significance ($F = 51.445$, $p < 0.05$). However, the variation in perceived palatability between the plants was not statistically insignificant ($F= 1.452$, $p > 0.05$).

Table 4-6: Summary of the Analysis of Variance (ANOVA) performed on the palatability levels across the provinces and plant species.

	Sum of Squares	**df**	**Mean Square**	**F ratio**	**Sig.**
			Province		
Between Province	1158.57	7	165.50	51.45	0.00
Within Province	540.50	168	3.23		
Total	1699.10	175			
			Plants		
Between plants	280.87	21	13.40	1.45	0.10
Within plants	1418.20	154	9.21		
Total	1699.10	175			

4.3.2.1 Variation of perceived palatability

The distribution of forage plants across different provinces and their perceived palatability scores are shown in Figure 4-4. According to the figure, there were certain plant species, such as Beru (*Sacciolepis interrupta*) which were highly preferred by wild elephants in the provinces such as Eastern and North Central Provinces, meanwhile Ali maana (*Pennisetum purpureum*) and Gini thana (*Panicum maximum*) indicated higher perceived palatability score from the responders of the North Central province and more or less similar values were reported for the provinces of Northwestern, Eastern, and Uva.

Further, the variation in the plant palatability scores in the Southern and Sabaragamuwa Provinces are considerably lower than that of the rest of the provinces. Meanwhile, discernible within-province variation in the palatability level of the plant was also observed in the plants included in the study.

Thus, plant palatability levels indicated a noticeable spatial variation across the provinces in the country.

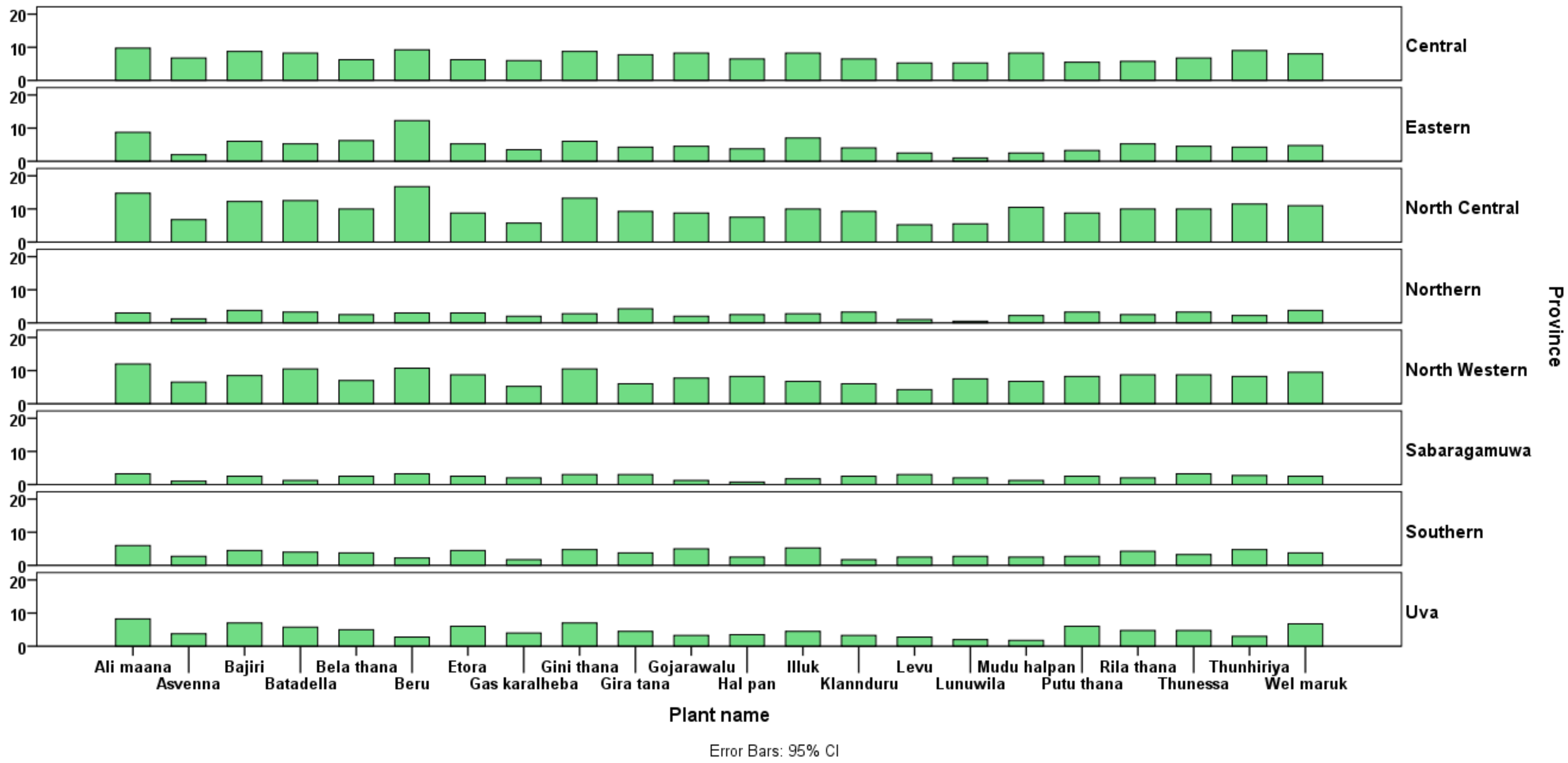


Figure 4-4: Distribution pattern of palatability level (Mean Score percent) of plants by provinces.

4.4 Elephant Forage plant Selection Matrix

The developed database was used to construct a matrix as a tool for the selection of elephant forage plants Table 4-7. The questions and their answers are presented in a Dichotomous key. The key provided a rapid method to identify the elephant forage plants using characteristics of their life cycles and ecological provenance.

Table 4-7: Elephant-forage plant selection matrix.

Question No.	Question	Response	Instructions
1	Is the plant palatable to elephants?	Yes	Go to Question 2
		No	Unsuitable
2	Is the plant type a grass / sedge or herbaceous?	Yes	Go to Question 3
		No	Unsuitable
3	Is the plant type suitable for the tropical region?	Yes	Go to Question 4
		No	Unsuitable
4	Is the plant available in the natural ecosystem?	Yes	Go to Question 5
		No	Unsuitable
5	Does the plant possess considerable ecological tolerance characteristics for survival in natural environment?	Yes	Go to Question 6
		No	Unsuitable
6	Does the plant have considerable yield?	Yes	Go to Question 7
		No	Go to Question 7
7	Does the plant have a rapid propagation method?	Yes	Go to Question 8
		No	Go to Question 8
8	Does the plant have considerable growth rate?	Yes	Go to Question 9
		No	Unsuitable
	What is the life-cycle of the plant?	Perennial	Highly suitable
		Biennial	Suitable
		Annual	Slightly suitable

4.5 Development of Forage Selection Index (FSI)

The plant propagation score, yield score, and perceived palatability level were explored in order to obtain a measurable indicator for selecting suitable forage plants out of selected plant species.

4.5.1 Method of plant propagation

The comparison of the method of propagation among the forage plant species included in the duty is tabulated in Table 4-8.

Table 4-8: Cross tabulation of plant species by their method of propagation.

Plant	Vegetative Propagation			Total
	Rarely	Only	Readily with seed	
Alysicarpus vaginalis (Asvenna)	0	0	1	1
Echinochloa glabrescens (Bajiri)	0	0	1	1
Isachne globosa (Batadella)	0	0	1	1
Sacciolepis interrupta (Beru)	0	0	1	1
Echinochloa colona (Gira thana)	0	0	1	1
Ischaemum rugosum (Gojarawalu)	0	0	1	1
Panicum maximum (Gini thana)	0	0	1	1
Imperata cylindrica (Illuk)	0	0	1	1
Cyperus rotundus (Kalanduru)	0	0	1	1
Cyperus iria (Thunessa)	0	0	1	1
Schoenoplectus grossus (Thunhiriya)	0	0	1	1
Pennisetum purpureum (Ali maana)	0	1	0	1
Panicum repens (Etora)	0	1	0	1
Leersia hexandra (Levu)	0	1	0	1
Eleusine indica (Bela thana)	1	0	0	1
Achyranthes aspera (Gas Karalheba)	1	0	0	1
Cyperus haspan (Halpan)	1	0	0	1
Bacopa monnieri (Lunuwila)	1	0	0	1
Fimbristylis miliacea (Mudu halpan)	1	0	0	1
Dactyloctenium aegyptium (Putu thana)	1	0	0	1
Ischaemum timorense (Rila thana)	1	0	0	1
Echinochloa crusgalli (Wel maruk)	1	0	0	1
Total	**8**	**3**	**11**	**22**

The plants such as Bela thana, Gas Karalheba, Halpan, Lunuwila, Mudu halpan, Putu thana, and Rila thana have formed a group, propagated rarely by vegetative propagation. Meanwhile, Ali maana, Etora and Kalanduru fell into a group that consisted of plants propagated through vegetative propagation only. Further, plant species Asvenna, Batadella, Bajiri, Gira thana, Gojarawalu, and Illuk, Kalanduru, Gini thana are propagated readily by both vegetative and seed propagation methods. Thus, based on the method of propagation, the selected plants could be placed in three distinct groups *viz*., Group 1; "Rarely by Vegetative propagation", Group 2; "Only by vegetative propagation", and Group 3; "Readily by both vegetative and seed propagation".

4.5.2 Yield score of Elephant forage plants

The dry yield values (ton /ha/ Year) extracted from the forage database were summarized in Table 4-9.

Table 4-9: Annual dry yield values of forage plants.

Plant name	Annual Yield (ton/ha)
Pennisetum purpureum (Ali maana)	80
Sacciolepis interrupta (Beru)	18
Panicum maximum (Gini thana)	35
Echinochloa glabrescens (Bajiri)	5
Isachne globosa (Batadella)	2
Echinochloa crusgalli (Wel maruk)	17
Imperata cylindrica (Illuk)	20
Schoenoplectus grossus (Thunhiriya)	29
Panicum repens (Etora)	22
Cyperus iria (Thunessa)	1
Eleusine indica (Bela thana)	4
Ischaemum timorense (Rila thana)	8
Echinochloa colona (Gira thana)	3
Ischaemum rugosum (Gojarawalu)	7
Dactyloctenium aegyptium (Putu thana)	6
Cyperus rotundus (Kalanduru)	30
Fimbristylis miliacea (Mudu halpan)	1
Cyperus haspan (Halpan)	3
Alysicarpus vaginalis (Asvenna)	6
Achyranthes aspera (Gas Karalheba)	4
Leersia hexandra (Levu)	4
Bacopa monnieri (Lunuwila)	6

The distribution of plant yield class by the forage plants is shown in Table 4-10.

Table 4-10: Cross tabulation of plant species and their yield sortation.
$(\text{Low} \leq 11, 11 \leq \text{Medium} \leq 21, \text{High} \geq 21) - (\text{tons /ha / Year})$.

	Yield class			**Total**
	Low	**Medium**	**High**	
Pennisetum purpureum (Ali maana)	0	0	1	1
Panicum repens (Etora)	0	0	1	1
Panicum maximum (Gini thana)	0	0	1	1
Imperata cylindrica (Illuk)	0	0	1	1
Cyperus rotundus (Kalanduru)	0	0	1	1
Schoenoplectus grossus (Thunhiriya)	0	0	1	1
Sacciolepis interrupta (Beru)	0	1	0	1
Echinochloa crusgalli (Wel maruk)	0	1	0	1
Alysicarpus vaginalis (Asvenna)	1	0	0	1
Echinochloa glabrescens (Bajiri)	1	0	0	1
Isachne globosa (Batadella)	1	0	0	1
Eleusine indica (Bela thana)	1	0	0	1
Achyranthes aspera (Gas Karalheba)	1	0	0	1
Echinochloa colona (Gira thana)	1	0	0	1
Ischaemum rugosum (Gojarawalu)	1	0	0	1
Cyperus haspan (Halpan)	1	0	0	1
Leersia hexandra (Levu)	1	0	0	1
Bacopa monnieri (Lunuwila)	1	0	0	1
Fimbristylis miliacea (Mudu halpan)	1	0	0	1
Dactyloctenium aegyptium (Putu thana)	1	0	0	1
Ischaemum timorense (Rila thana)	1	0	0	1
Cyperus iria (Thunessa)	1	0	0	1
Total	**14**	**2**	**6**	**22**

According to the table (Table 4-10), on the basis of plant yield, it can be categorized as the yield of forage plants into three categories, i.e., “Low”, “Medium”, and “High”. The patterns reflected from the cross-tabulation of forage plants against forage yield classes clearly indicated that Ali maana, Gini thana, Kalanduru, and Thunhiriya fall into the high yield category (27 %). Meanwhile, the plants like Beru and Wel maruk fall within the medium group of yield (9 %). Further, most forage plants lie within the low yield group, representing 64 % of the total.

4.5.3 Comparison of scores of palatability, yield and propagation by forage plants

The percentage scores of palatability, yield, and method propagation are presented in Table 4-11.

Table 4-11: Summary of the palatability score, yield score, and method of propagation percentage by forage plants.

Plant name	Palatability Score (%)	Yield Score (%)	Propagation Score (%)
Pennisetum purpureum (Ali maana)	8.22	25.72	33.33
Sacciolepis interrupta (Beru)	7.53	5.79	50.00
Panicum maximum (Gini thana)	7.00	11.25	50.00
Echinochloa glabrescens (Bajiri)	6.66	1.61	50.00
Isachne globosa (Batadella)	6.34	0.64	50.00
Echinochloa crusgalli (Wel maruk)	6.25	5.47	16.67
Imperata cylindrica (Illuk)	5.78	6.43	50.00
Schoenoplectus grossus (Thunhiriya)	5.72	9.32	50.00
Panicum repens (Etora)	5.63	7.07	33.33
Cyperus iria (Thunessa)	5.56	0.32	50.00
Eleusine indica (Bela thana)	5.41	1.29	16.67
Ischaemum timorense (Rila thana)	5.41	2.57	16.67
Echinochloa colona (Gira thana)	5.34	0.96	50.00
Iachaemum rugosum (Gojarawalu)	5.09	2.25	50.00
Dactyloctenium aegyptium (Putu thana)	5.03	1.93	16.67
Cyperus rotundus (Kalanduru)	4.56	9.65	50.00
Fimbristylis miliacea (Mudu halpan)	4.47	0.32	16.67
Cyperus haspan (Halpan)	4.41	0.96	16.67
Alysicarpus vaginalis (Asvenna)	3.84	1.93	50.00
Achyranthes aspera (Gas Karalheba)	3.78	1.29	16.67
Leersia hexandra (Lavu)	3.31	1.29	33.33
Bacopa monnieri (Lunuwila)	3.31	1.93	16.67

The forage plants such as Ali maana, Beru, Gini thana, Bajiri, Batadella, Wel maruk, Illuk, and Thunhiriya indicated a comparatively higher palatability score ($\geq$ 5.72 %), meanwhile the rest of the forage plants were lower ($\leq$ 5.63 %). Similarly, the yield scores of the forage plants Ali maana, Gini thana, Illuk, Thunhiriya, and Etora were higher ($\geq$ 7.07 %).

The propagation scores of most of the species are higher (~50), and the combination of Palatability and the yield score would produce a group of forage plants that includes Ali maana, Gini thana, Illuk, Thunhiriya as suitable elephant forage plants. In the same manner, the combination of three variables (palatability, yield, and propagation) would produce another set of forage plants, which consist of Gini thana, Illuk, Thunhiriya, which could be considered as the best elephant forage plants in the elephant ranges of the country.

4.5.4 Grouping trends in forage plants - Cluster analysis

The cluster analysis of the three variables, plant perceived palatability, yield, and method of propagation produced a dendrogram which is depicted in Figure 4-5.

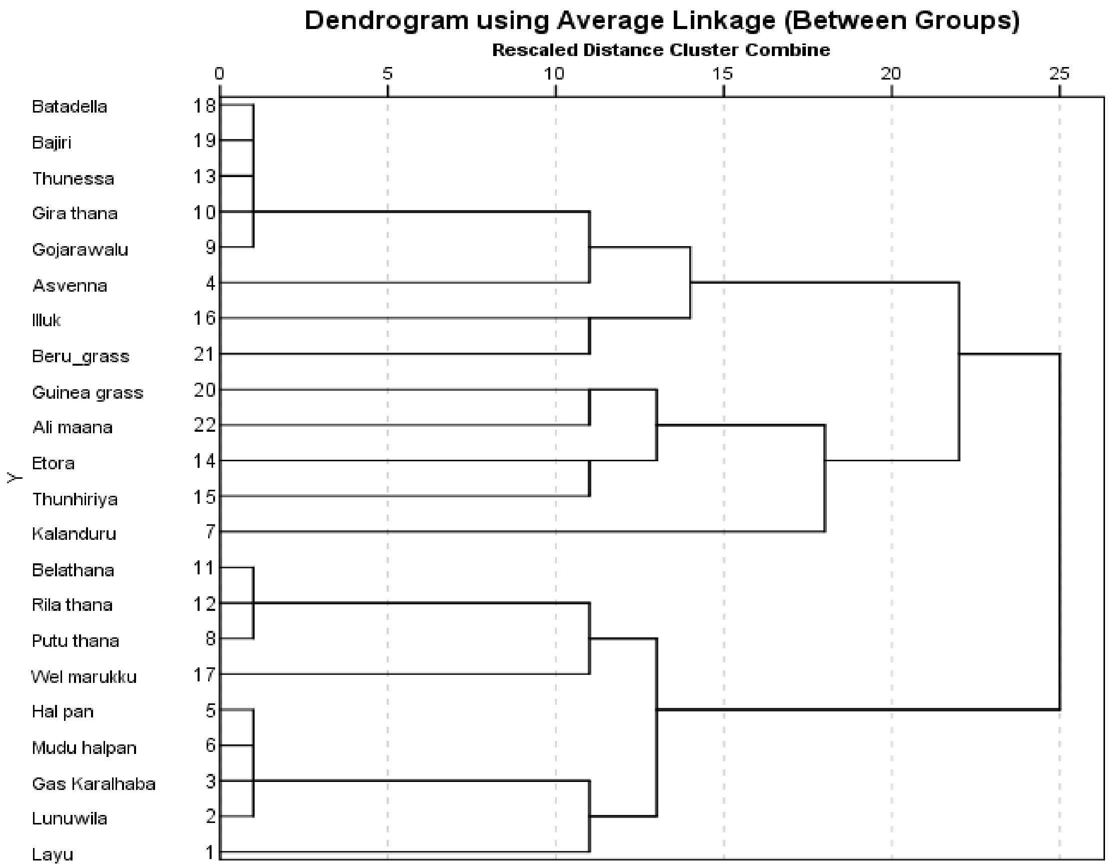


Figure 4-5: A dendrogram showing the relationships between the elephant fodder plants.

According to the figure, three groups of plants were observed. The first group included the forage plants such as Batadella, Bajiri, Thunessa, Gira thana, Gojarawalu, Asvenna, Illuk, and Beru grass. The second group formed from the plant species such as Gini thana, Ali maana, Etora, Thunhiriya and Kalanduru. The third group included Bela thana, Rila thana, Putu thana, Wel maruk, Halpan, Mudu halpan, Gas karalheba, Lunuwila and levu.

4.5.5 Forage Selection Index (FSI)

The result of the principal component analysis (PCA) is summarized as shown in Table 4-12. The analysis yielded a single component with a higher loading from the perceived palatability class (0.80), yield class (0.78), and propagation (0.70). The total variance explained by the PCA was 58.024 % i.e., a satisfactory fraction of the total variance in the original dataset.

Table 4-12: Summary of the principal components analysis.

Description	**Component**
	PCA1
Eigen value	1.74
% of variance explained	58.02
% of cumulative variance explained	58.02
Palatability class (P)	0.80
Yield class (Q)	0.78
Propagation (R)	0.70

Based on the principal component analysis an equation was developed to measure the Forage Selection Index (FSI). Resulting principal component axis was considered as the FSI indicator as expressed in the FSI equation (Equation 2).

$$FSI = \frac{(0.80(P) + 0.78\ (Q) + 0.70\ (R)}{1.74} \tag{1}$$

Where;

P = Z-score of the original variable of palatability;

Q = Z-score of the original variable of yield;

R = Z-score of the original variable of method of propagation;

0.8, 0.78, 0.70 and 1.74 are loadings.

The graphical presentation of the FSI values calculated for each forage plant is illustrated in Figure 4-6.

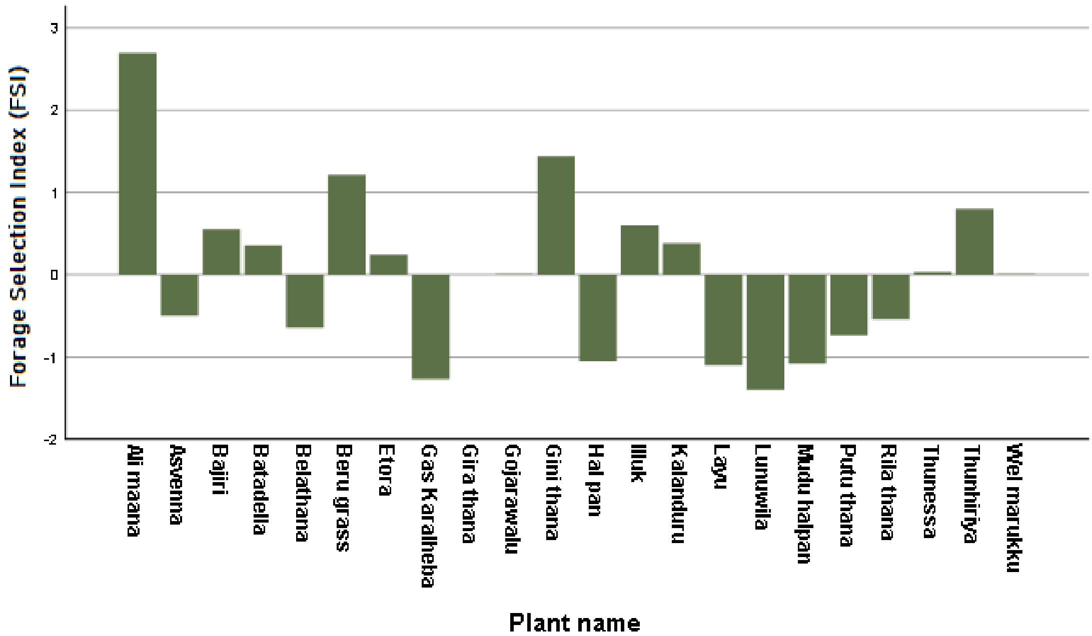


Figure 4-6: Graphical presentation of Forage Slection Index.

The careful observation of Figure 4-6 reveals that the FSI values vary from negative values to positive values. On this basis, certain forage plants are indicated by negative values whereas others are with positive values i.e., forage plants are grouped into appropriate and inappropriate forage plants for elephants.

Therefore, FSI values reflect the capability in distinguishing the appropriateness of elephant forage plants. The comparison of the FSI values further reveals that the plants such as Guinea grass, Ali maana, Beru grass, Thunhiriya emerged as dominant forage plants for the wild elephants in Sri Lanka. Meanwhile, the plants such as Etora, Illuk, and Kalanduru stand out as the second dominant forge plants.

4.6 Field Experiment 1: Optimization of Bamboo device for the planting mechanism

The results obtained from the field Experiment-1, carried out on the optimization of the planting device are described under the following subheadings: 4.6.1, 4.6.2 and 4.6.3. The results of the descriptive and inferential statistical analyses of the experiment data are presented, highlighting the findings.

4.6.1 Relationship between cutting angle Vs. penetration depth

The relationship between the cutting angle and the depth of penetration is indicated in Figure 4-7. According to the figure, the both shapes indicated a similar behavior in which maximum depth of penetration at 45°. Comparatively, the maximum depth of penetration is observed for Shape 2 at the angle of 45°. Even though the depth of penetration was maximum (43 cm) for the Shape 2 with 550 mm diameter, the structure was cracked during the experiment.

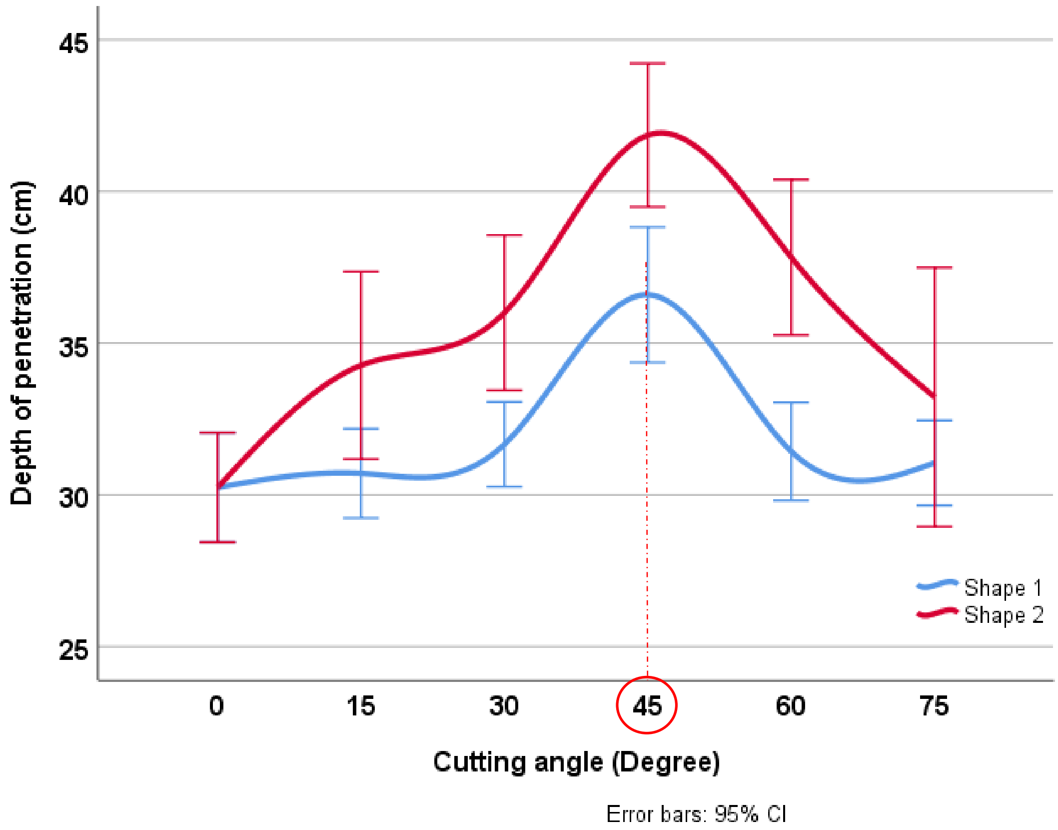


Figure 4-7: Relationship between the cutting angle and the depth of penetration of the two shapes of bamboo mediated devices.

4.6.2 Relationship between diameter Vs. penetration depth

The relationship between the diameter and the depth of penetration is indicated in Figure 4-8. There was a gradual increase in the depth penetration within the range of diameter values from 650 mm to 750 mm. The approximately maximum depth of penetration was observed at a diameter of 750 mm. However, the depth was gradually decreased from 750 mm to a diameter of 800 mm in both shapes.

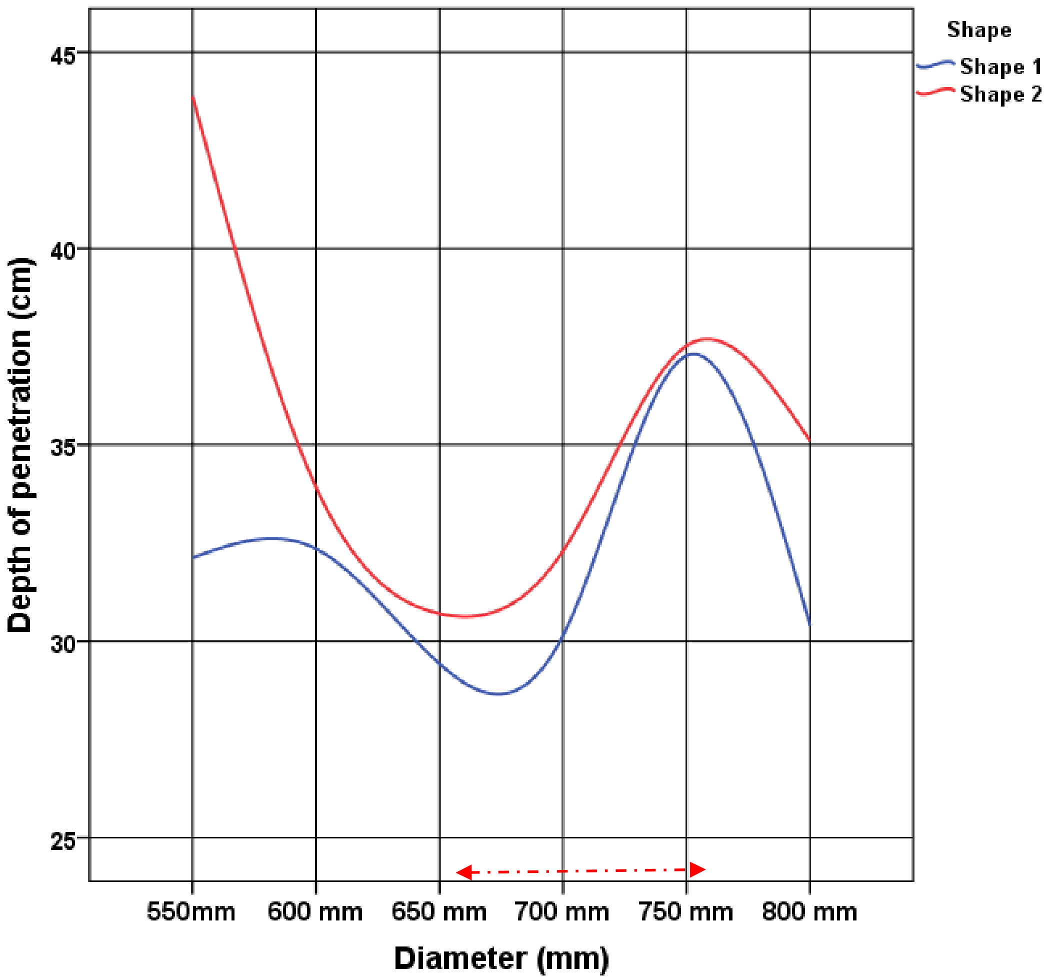


Figure 4-8: Relationship between the diameter and the depth of penetration of the two shapes of bamboo mediated structures.

4.6.3 Variation of the penetration depth by cutting angle, shape and by diameter

Variation of the depth of penetration by cutting angle, shape, and by diameter of the two Bamboo devices is shown in Figure 4-9. Careful observation of Figure 4-9 revealed that there is a considerable variation in penetration depth in both shapes in relation to the diameter and the cutting angle. A higher penetration depth frequently occurred in both Bamboo devices at the cutting angle of 45°. The distribution of mean penetration depths in two Bamboo devices at the cutting angle of 45° revealed that the values of mean penetration depth were comparatively higher in the Shape 2 Bamboo device. In relation to the diameter of the devices, the diameter of 550 mm produced higher penetration depth in both devices, however, is prominent in Shape 2.

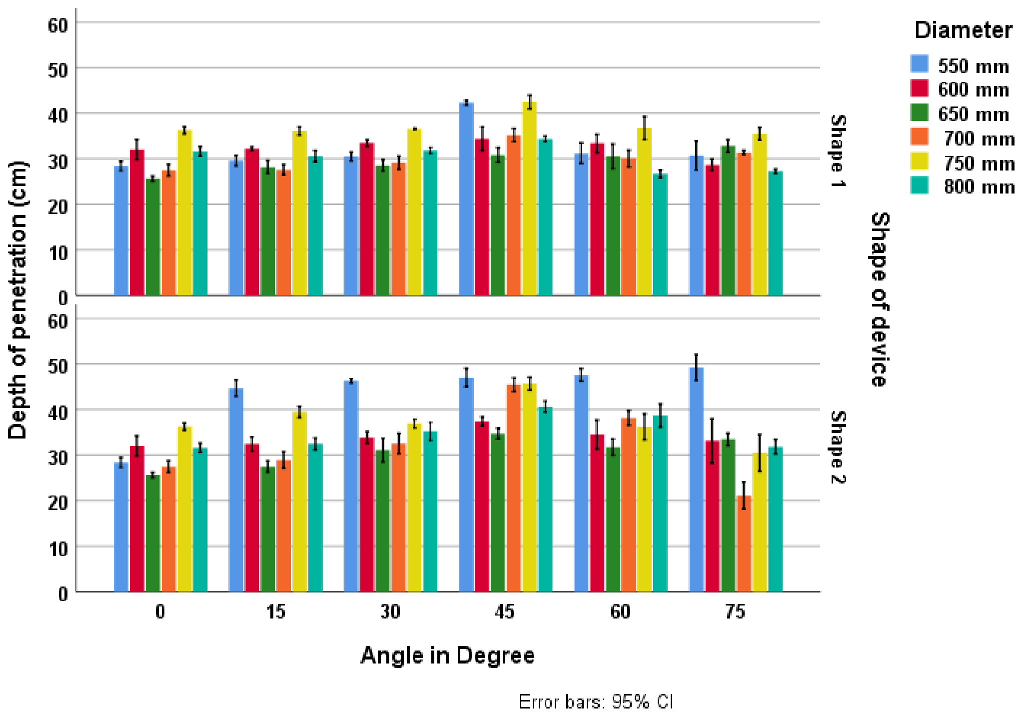


Figure 4-9: Variation of mean penetration depth (cm) by shape, diameter (mm), and angle of the device.

The results obtained from the Field Experiment-1 on the optimization of bamboo mediate devices and their associated penetration depths are presented under each device. Meanwhile, comparison of depth of penetration associated with the two designed devices is summarized in a separate table with results of the mean comparison (LSD). The mean penetration depths of Shape-1 and Shape-2 are shown in Table 4-13.

According to the table, the mean penetration depth of Shape-1 was 31.95 ± 3.93 cm, and the same for Shape-2 was 35.57 ± 6.74 cm whereas the difference between the values was (3.62), which was statistically significant at $p \leq 0.05$.

Table 4-13: Comparison of penetration depth of different shapes of the devices.

Shape	Mean	Std. Deviation
Shape 1	31.95a	3.93a
Shape 2	35.57b	6.74b

(The different letters along the column indicate the significant difference at $p \leq 0.05$).

df = 1

Critical t value = 2.79

Least significant difference =1.48

The mean penetration depths across the different diameters for Shape 2 were shown in Table 4-14 which indicates that the penetration depths vary from 29.42 ±2.42 (diameter 650 mm) to 37.27 ±2.49 (diameter 750 mm). The mean value follows the standard deviation within parenthesis. The comparison of the mean penetration value in Table 4-14 shows that the highest penetration depths occur at the diameter class 750 mm. The diameter class 550 mm and diameter class 600 mm consisted of more or less similar values of penetration depths. Out of the diameter classes, the 550 mm diameter class was prone to be cracked during the free – falling experiment.

Thus, the results in the table suggested that diameter class 750 mm was the best proposed device for the continuation with planting mechanism.

Table 4-14: Means of penetration depth with the diameter classes of the device of Shape 2.

Diameter (mm)	**Mean penetration depth (cm)**	**Std. Deviation**	**N**
550	32.12 (4.81) cb	4.81	18
600	32.35(1.98) b	1.98	18
650	29.42 (2.42) d	2.42	18
700	30.15 (2.73) cd	2.73	18
750	37.27 (2.49) a	2.49	18
800	30.39 (2.77) cbd	2.77	18

(The different letters along the column indicate the significant difference at $p \leq 0.05$).

df = 5

Critical value = 1.98

Least Significant Difference = 1.99

The penetration depth variation along the different cutting angles was tabulated in Table 4-15 showed that the mean penetration depth has fallen within the range of 30.24 (3.63) cm - 36.59 (4.48) cm.

Table 4-15: Means of penetration depth with the cutting angle of the device Shape 2.

Cutting Angle	Mean penetration depth (cm)	N	Std. Deviation
0	30.24 b	18	3.63
15	30.71 b	18	2.96
30	31.67 b	18	2.81
45	36.59 a	18	4.48
60	31.43 b	18	3.25
75	31.06 b	18	2.81

(The different letters along the column indicate the significant difference at $p \leq 0.05$).

df = 5

Critical t value = 1.98

Least Significant Difference = 2.23

The maximum penetration depth occurred at 45° and was significantly different from the rest of the values of the cutting angles ($p \leq 0.05$). Thus, the cutting angle of 45° degrees associated with the highest penetration depth could be considered the suitable cutting angle for the bamboo mediated device.

The results of the one-way analysis of variance carried out on the penetration depth, diameter class, cutting angle of the bamboo shell mediated structure of the Shape 2 is summarized in tables (Table 4-16, Table 4-17 and Table 4-18). The variation of penetration depth and diameter class of Shape 2 shown in Table 4-16**.** According to the table, the penetration depth ranges from 30.70 (3.33) cm to 43.88 (7.28) cm representing the diameter class 650 mm and the diameter class 550 mm respectively (Table 4-16). Out of all the diameter classes, the penetration depth of the 550 mm diameter class was 43.88 cm and stood out from the rest of the values. However, the design with the diameter class indicated a higher potential of cracking during the free fall experiment. On the basis of penetration depth and the diameter classes, except for 550 mm diameter class, the second higher penetration was observed for 750 mm diameter class which was the optimum diameter for the maximum penetration depth.

Table 4-16: Mean comparison of penetration depth with the diameter classes of the device of Shape 2.

Diameter (mm)	Mean penetration depth (cm)	N	Std. Deviation
550	43.88 a	18	7.28
600	33.92 cd	18	2.05
650	30.70 d	18	3.33
700	32.30 cd	18	8.08
750	37.52 b	18	4.74
800	35.09 cb	18	3.65
Total	35.57	108	6.74

(The different letters along the column indicate the significant difference at $p \leq 0.05$).

df = 5

Critical value =1.98

Least significant different =3.83

The variation of penetration depth with the cutting angle of the Shape 2 is shown in Table 4-17. The comparison of the mean values of penetration depth across the cutting angles revealed that the values had fallen within the range of 30.24 (3.63) cm – 41.85 (4.76) cm. Further, the depth values were differing from each significantly ($p \leq 0.05$). As far as the optimum angle for the optimum penetration depth is concerned, the cutting angle of 45° fulfilled the requirement of the study.

Table 4-17: Mean comparison of penetration depth with the angle classes of the bamboo mediated Structure 2.

Angle (degree)	Mean penetration depth (cm)	N	Std. Deviation
0	30.24 d	18	3.63
15	34.27cb	18	6.21
30	36.01cb	18	5.14
45	41.85 a	18	4.76
60	37.83 b	18	5.15
75	33.22 cd	18	8.59
Total	35.57	108	6.74

(The different letters along the column indicate the significant difference at $p \leq 0.05$).

df = 5

Critical t value = 1.98

Least Significant Difference = 3.83

The results of the 3-Way Analysis of Variance of penetration depth by shape, cutting angle and diameter are tabulated in Table 4-18. The close observation of the table indicated that there is a significant effect of the shape, angle and diameter on the depth of penetration ($p \leq 0.05$). Moreover, the interactions of Shape x Angle, Shape x Diameter, Angle x Diameter and Shape x Angle x Diameter were also statistically significant, and imply that there is a combined effect of the parameters of the device's performance on the depth of penetration (≤ 0.05).

Table 4-18: Summary of 3-way ANOVA of penetration depth by shape of device. angle and diameter.

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Shape	707.06	1	707.06	1379.38	*
Angle	1699.29	5	339.86	663.02	*
Diameter	1897.75	5	379.55	740.45	*
Shape x Angle	234.99	5	47.00	91.69	*
Shape x Diameter	814.62	5	162.92	317.84	*
Angle x Diameter	964.18	25	38.57	75.24	*
Shape x Angle x Diameter	829.14	25	33.17	64.70	*

(* Denotes that the mean difference is significant at $p \leq 0.05$ level).

The one-Way Analysis of Variance (one-Way ANOVA) of the penetration depth by the shape of the device was shown in Table 4-19. According to the table, it is evidence from the results that there was a statistically significant difference in penetration depth performance between two Shapes ($p \leq 0.05$).

Table 4-19: Summary of the results obtained from one-way analysis of variation of depth by Devices.

	Sum of Squares	df	Mean Square	F	Sig.
Between Devices	248.59	1	248.59	11.64	*
Within Device	726.33	34	21.36		
Total	974.92	35			

(* Denotes that the mean difference is significant at $p \leq 0.05$ level).

The multiple comparison of diameter and degree in association depth difference of the Bamboo devices is shown in Table 4-20. The significant levels of mean value differences are significant at $p \leq 0.05$.

The comparison of the magnitude of the mean differences along the diameter classes and cutting angle classes provided a criterion to select the appropriate diameter and cutting angle that possessed the highest penetration angle.

On this basis, the optimal diameter and cutting angle for the Bamboo devices would be the 750 mm diameter and cutting angle of 45°. However, in case of diameter classes of 650 mm and 700 mm were more or less equal mean differences compared to diameter class 550 mm.

Table 4-20: Multiple comparison matrix of mean penetration differences between diameter class and degree.

Diameter class (mm)	**550**	**600**	**650**	**700**	**750**	**800**
550	0					
600	4.86*	0				
650	7.94*	3.08*	0			
700	6.78*	1.91*	-1.16*	0		
750	0.61*	-4.26*	-7.33*	-6.17*	0	
800	5.26*	0.39*	-2.68*	-1.52*	4.65*	0
Angle class (degree)	**0**	**15**	**30**	**45**	**60**	**75**
0	0					
15	-2.24*	0				
30	-3.59*	-1.35*	0			
45	-8.98*	-6.73*	-5.39*	0		
60	-4.39*	-2.14*	-0.79*	4.59*	0	
75	-1.89*	0.35*	1.70*	7.08*	2.49*	0

(* Denotes that the mean difference of cutting angle is significant at $p \leq 0.05$ level).

4.7 Field Experiment 2: Evaluation of Device Performances with Forage plants

Results of the field experiment carried out to assess the performance of the Bamboo plant device are presented in the proceeding text (4.7.1. 4.7.6). The plant growth performances of the Bamboo device on the surface of the soil (T2), submerged in soil (T3), standard (Std.) polybag (T4), polybag (550 mm) (T5), are compared with the control (T1). The plant height, number of leaves per pot (number of leaves /pot), number of tillers per pot (number of tillers / pot), and the days taken for reaching the flowering stage were observed for the period of 6 weeks from the date of the transplanting of the plants which were collected from the field.

4.7.1 Effect of Treatments on plant height

The variation of the plant height along the treatments is illustrated in Figure 4-10 and Figure 4-11, and according to the graphs Gini thana indicated a comparatively higher plant height across all the treatments. However, there were slight differences in the magnitude of the height. The maximum plant height was observed for the Gini thana grown in the bamboo device of 550 mm (T2) which was placed on the soil surface.

Similarly, the variation of the height of Bajiri across the different treatments indicated that the highest plant height is reported for the bamboo device of 550 mm (T3) which was submerged in soil. The plant height of the rest of the treatment was more or less equally varied across the control (T1), bamboo device (550 mm) on the soil surface (T2), standard (Std.) polybag (T4), and polybag (550 mm) (T5). However, the plant height of the Gini thana was grown in the Std. polybag (T4) was slightly different when compared to the rest of the treatment. These results inferred that the highest plant height of Gini thana is associated with the treatments.

The variation of plant height of Ali maana grown under different treatments indicated a considerable variation across the treatments. The highest plant height was observed for the Ali maana plant stood out from the rest, and the lowest plant height was observed for the Ali maana plants grown in T5. Meanwhile, the plant height of the plant grown in T4 and T3 were more or less similar between the treatments. A comparison of plant height across the different treatments indicated that a bamboo device of 550 mm that was placed on the soil surface (T2) was the best treatment.

The plant height of Batadella across the treatment showed a considerable variation in the plant height and that was more or less high in T2, T3, and T4. The plant height of Batadella grown in soil (T1) and T5 was intermediate. However, the plant height of Batadella in T2, T3, and T4 form a group in which plant heights were more or less similar implying the suitability of devices for the purpose of transplanting forage grass.

In addition, the variation of plant height indicates that Beru possesses the higher value in T2 and the lowest in T5. Comparatively, the plant height values of T1 are lower than that of the rest of the treatment. However, the values for the plant height of T2 and T3 were more or less equal and indicated that these devices are supportive to the plant establishment in a particularly targeted habitat. In summary, T5 shows the lowest plant height for the Beru plant suggesting that it is inappropriate for the transplanting of plants.

The variation of the plan height of Illuk was between the treatments, the values of the height of T5 was the lowest and the values were more or less equal through the treatments (T1, T2, T3, and T4). Meanwhile, the plant height distribution of

Thunhiriya also indicated a similar variation of plant height of Illuk across the treatment. The variation of the height of Wel maruk plant across the treatments indicated that there was a considerable similarity among the treatments T1, T2, T3, and T4 except for T5. However, there was a discernible difference among the treatments.

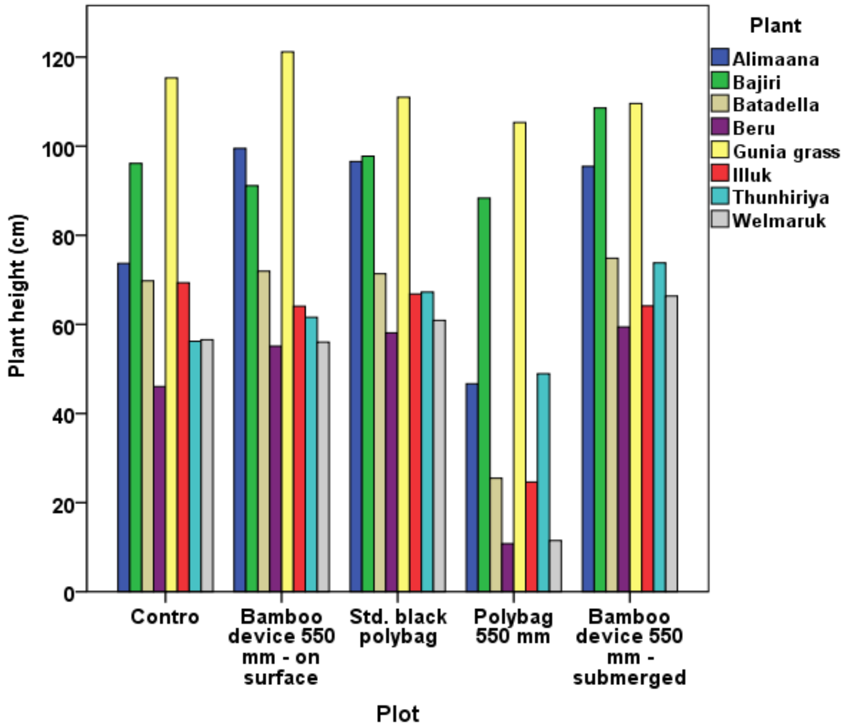


Figure 4-10 : Graphical presentation of variation in plant height along the different treatments.

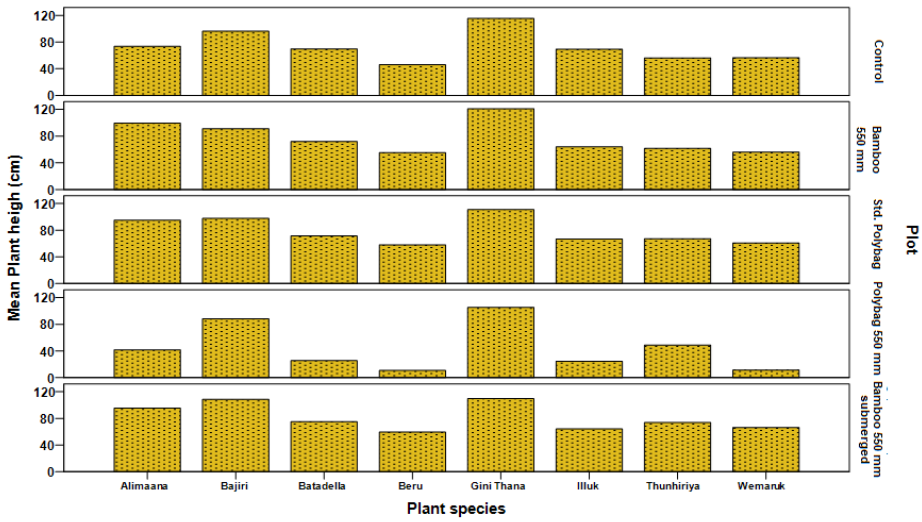


Figure 4-11: Graphical illustration of variation of height of individual plant species in each treatment.

4.7.2 Effect of treatment on number of leaves per pot

The distribution of the leaves/pot across the treatment indicated that there was a prominent difference between the Batadella and the rest of the plants (Figure 4-12 and Figure 4-13). The number of leaves / pot is considerably higher in Batadella across all the treatments except T5. The highest number of leaves/ pot was observed for T1, T3, and T4. Comparatively the highest number of leaves/ pot was observed in T4. The variation of the number of leaves / pot except for T5, was more or less similar across the treatment and the number of leaves / pot of Gini thana and Illuk, were comparatively higher in T1 and T4. On the contrary, number of leaves is lower in Thunhiriya plant in general and the highest number of leaves / pot occurred in T2. In particular, the distribution of the number of leave / pot is more or less equal between the T1, T2, T3, T4 except T5 in Bajiri and Beru. The highest number of leaves /pot in the case of Beru was observed in T3 and T4; Bajiri possesses a higher number of leaves/pot in T4. Ali maana plant showed the highest number of leaves in T2 whereas the lowest in T5. Comparatively, T1, T3, and T4 showed a similar distribution pattern of leaves/pot in each treatment except T5.

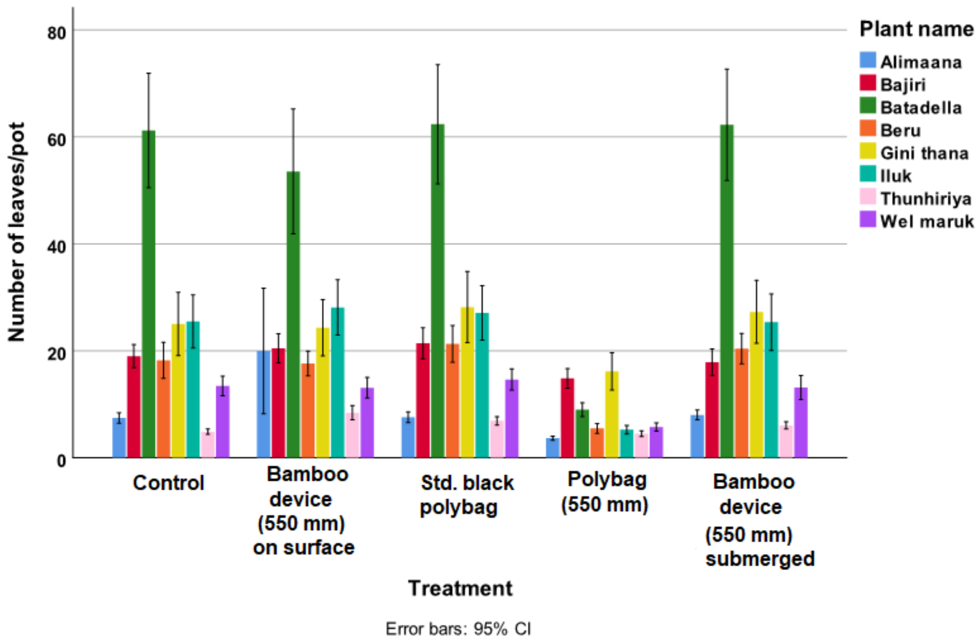


Figure 4-12 : Graphical illustration of the variation of No. of leaves / pot by the treatments.

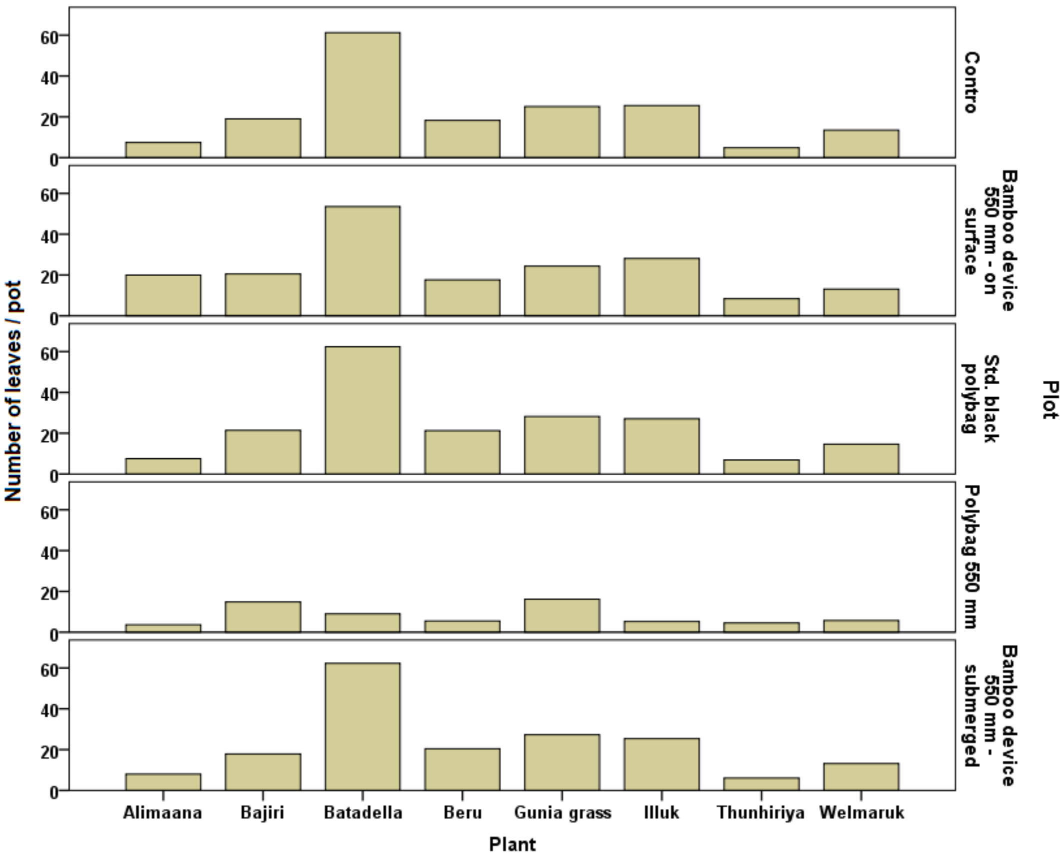


Figure 4-13: Graphical illustration of variation of No. of leaves/pot of individual plant species in each treatment.

4.7.3 Effect of treatments on tillers of plant per pot

The variation of the number of tillers per pot (number of tiller / pot) across the treatment for each forage plant is depicted in Figure 4-14 and Figure 4-15. The close observation of Figure 4-14 revealed that Batadella stood out from the rest of the forage plants having a higher number of tillers / pot. The plot-wise comparison of the number of tillers of Batadella indicated that T5 possessed the lowest number of tillers/pots, meanwhile, the number of tillers / pot of the treatment T1 -T4 indicated a similar number of tillers. Further, the number of tiller/pot of Batadella in T2 was the highest value observed and it suggested that T2 is the most suitable device for transplantation of forage grass. Similarly, the distribution of the number of tillers / pot of Gini thana indicated a similar trend across the treatment and the highest number of tillers / pot were observed in T2 and the lowest value for the same is reported for T4. A comparison of the number of tiller/pot across the treatments T1, T2, T3, and T4 indicated that treatment T2 was higher than the same in the rest of the treatments. The distribution of the number of tillers/pot in Wel maruk plants across the treatment showed that the number of tillers/pot was highest in T3 and lower in T2.

Since, Wel maruk plants in T5 did not survive, there was no observed number of tillers/pot. Comparatively, the number of tillers / pot of the T3 stood out from the rest of the treatments having the highest value. The distribution of tillers / pot of the plant Beru, ranged from the minimum for T1 and the highest in T3. There were no recorded values for the number of tillers / pot for Beru in T5 because none of the plants survived. Out of the other treatments where Beru survived, the number of tillers / pot was highest in T3 which is very close to T2. Similarly, the distribution of the number of tillers/pot of the Illuk varied from the highest in T2 to and lowest in T1.

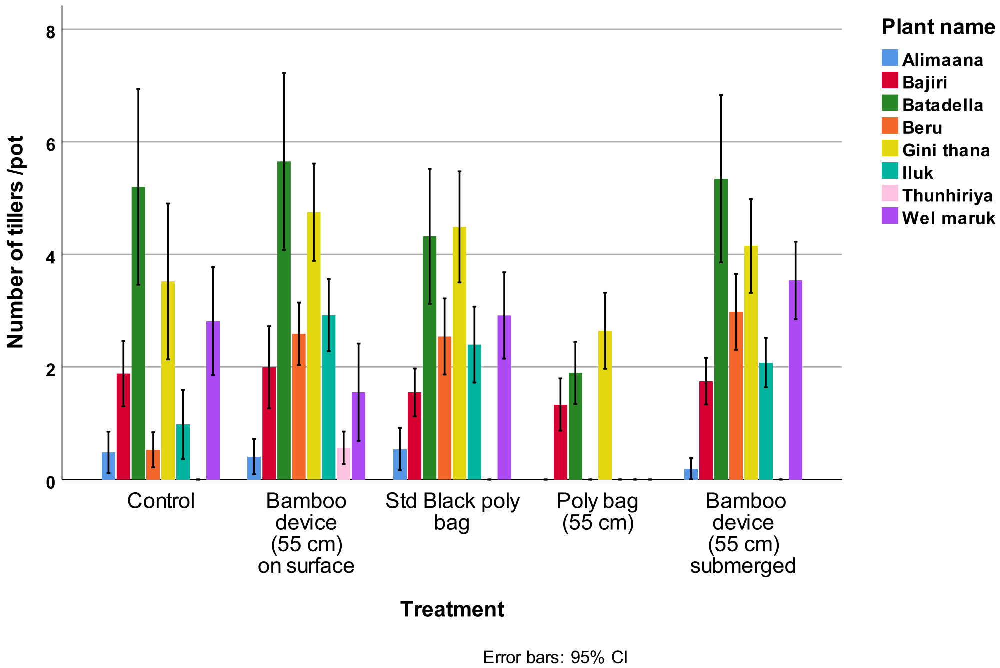


Figure 4-14: Graphical illustration of the variation of the No. of tillers per pot with the treatments.

Meanwhile, there were no observations on the number of tillers / pot in T5 where the plants did not survive. Further, a comparison of T1, T2, T3 and T4 indicated that T2 was higher than the other treatment.

The distribution of tiller number / pot for Thunhiriya indicated that a special type of variation in which observations of tillers that emerged were made in T2. In the rest of the treatments, there were no tillers emerged in T1, T3, T4, and T5. The variation of the number of tillers / pot was the highest in the T2 and the lowest in the T5 and, generally, tillers appeared in almost all the treatments. The number of tillers / pot for Ali maana ranged from the highest in T4 and the lowest in T3. Apparently, no tillers appeared for Ali maana in T5 because the plant did not survive in T5.

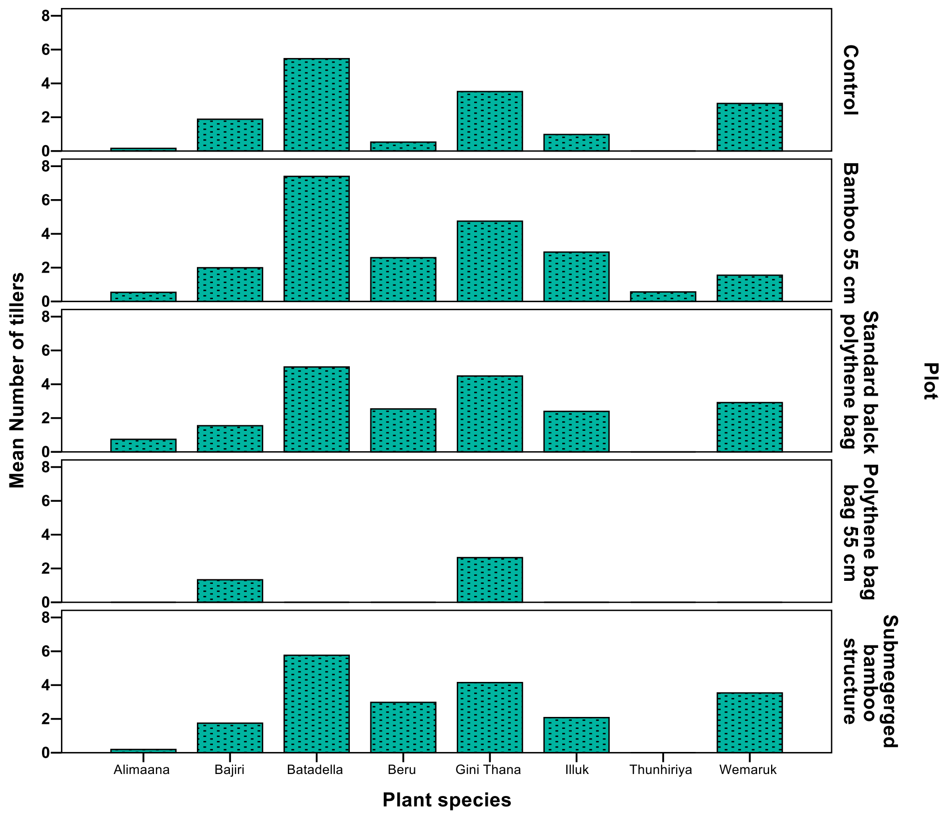


Figure 4-15: Graphical illustration of variation of No. of tillers per pot of individual plant species in each treatments.

4.7.4 Effect of Treatments on number of days taken to reach plants' flowering stage

The variation in the number of days taken for reaching the flowering is shown in Figure 4-16 and Figure 4-17. The careful observation of the pattern depicted in the figure revealed that in general Ali maana, Gini thana, Bajiri, Wel maruk and Thunhiriya have taken a considerable number of days for flowering. Meanwhile, Batadella, Beru, Illuk, Wel maruk have taken comparatively fewer number days for flowering. In the case of Gini thana in T5 has taken the highest number of days for flowering and the least number of days for flowering in T2. Meanwhile, the days taken for the flowering of Ali maana plant are highest in T3 and the least number of days taken in T4. Similarly, in T2 and T4 Ali maana plant took a more or less equal number of days for reaching the flowering stage Bajiri and Gini thana only showed the flowering stage in T5, however, under T5, those plants have taken a considerably longer period time for flowering. The rest of the plants were not survived up to the date of flowering, however even though Thunhiriya plant survived in T5, but no flowers were produced within the study period.

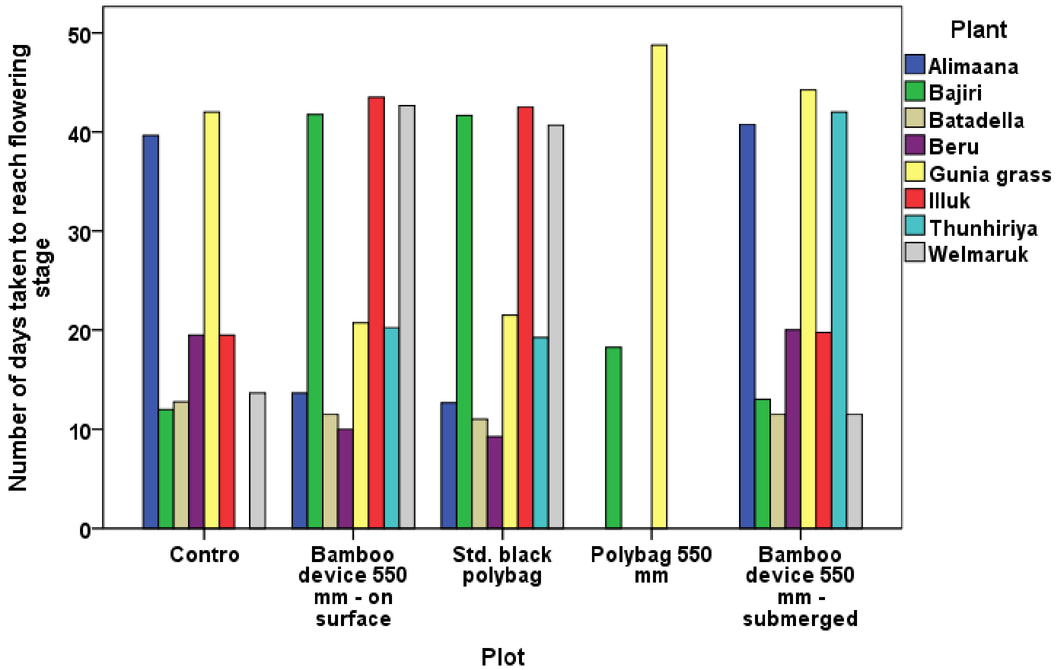


Figure 4-16: Graphical illustration of the variation in the No. of days taken for flowering stage with the treatments.

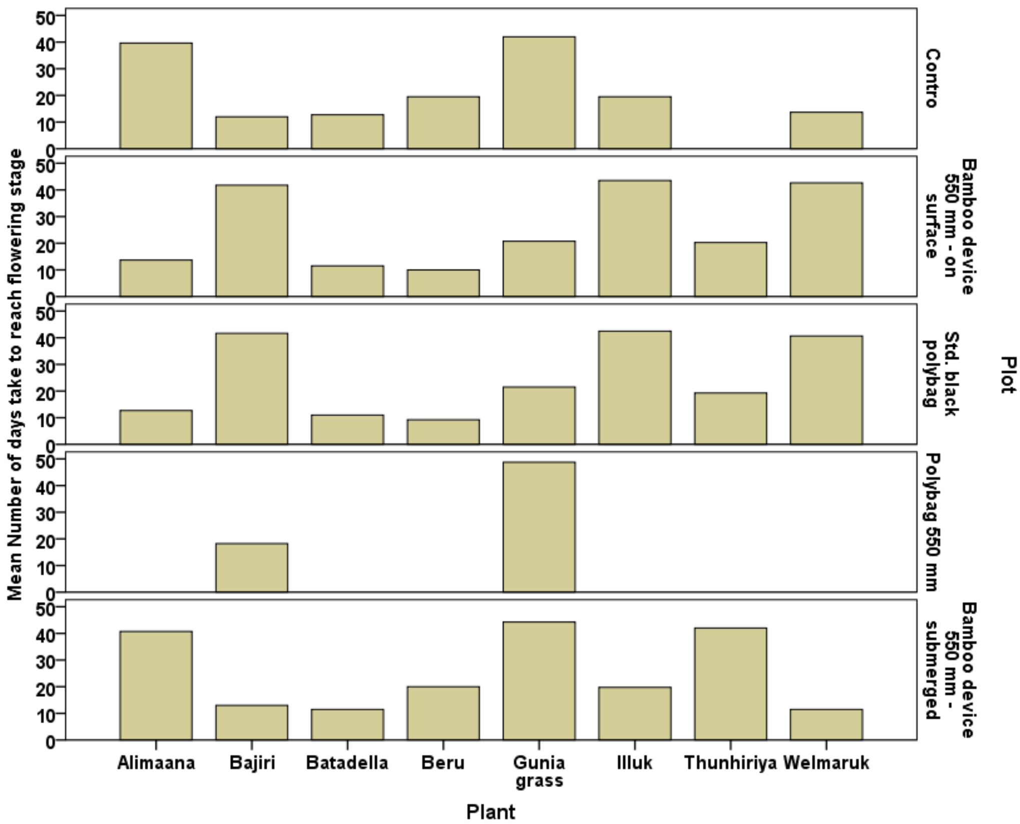


Figure 4-17: Variation in the No. of days taken for reaching the flowering stage by individual plant species in each treatments.

4.7.5 Two Way Analysis of variance (Two-Way-ANOVA)

During the descriptive analysis, it was found that there are variations in plant height, number of leaves / plot, number of tillers / plot and number of days taken for reaching the flowering stage along the treatments (Appendix I to Appendix L). These relationships are further analyzed using inferential statistics. Depending on the type of data, and the objective of the study, Two-way-ANOVA was performed on the dataset.

Summary statistics of the Two-way-ANOVA carried out on plant height, number of leaves / plot, number of tillers / plot and number of days taken for flowering stage were shown in Table 4-21.

Table 4-21: Summary of Two-Way ANOVA result of results of measured plant growth parameters.

Source	Sum of Squares	df	Mean Square	F	Sig.
Plant height (cm)					
Plant	436537.30	7	62362.47	38.45	s
Treatment	73334.04	4	18333.51	11.30	s
Plant x Treatment	44010.40	28	1571.80	0.97	ns
Number of leaves/pot					
Plant	98965.38	7	14137.91	76.90	s
Treatment	11187.40	4	2796.85	15.21	s
Plant x Treatment	14206.47	28	507.37	2.76	s
Number of tiller/pot					
Plant	2129.93	7	304.28	78.25	s
Treatment	232.18	4	58.04	14.93	s
Plant x Treatment	372.78	28	13.31	3.42	s
Number days taken to reach flowering stage					
Plant	6668.48	7	952.64	191.64	s
Treatment	190.66	4	47.67	9.59	s
Plant x Treatment	14814.73	21	705.46	141.92	s

(S: Significant at $p \leq 0.05$ and ns: Not significant at ≥ 0.05).

The variation in the plant height indicated a statistically significant difference between treatment ($p \leq 0.05$) and similar differences also observed for the plant species at $p \leq 0.05$.

In addition, the interaction between treatment and plant species indicated the statistically insignificant difference ($p > 0.05$). The variance between the treatment and number of leaves / pot and plant species and number of leaves / pot is significant at $p \leq 0.05$. Similarly, the same statistical differences in number of tillers / pot, and number of days taken for flowering is also observed. Further there were some significant interactions between plant species and treatments for all the variables analyzed as shown in Table 4-21.

4.7.6 Multiple comparison of means across treatments

The Two-Way-ANOVA indicated that there were statistically significant differences between the treatments and plant height, number of leaves / plot, number of tillers / plot and number of days taken for reaching flowering stage (Table 4-21).

However, the results of the ANOVA indicated the overall differences of similarities between the treatment and the variables under consideration. Therefore, it is necessary to locate the exact place where the significant difference occurred. The mean comparison of plant height across the different treatments indicated that there were significant differences between certain pairs of treatments (Table 4-22 to Table 4-25). For instance, the height of 550 mm of polybag (T5) is significantly different from the rest of the treatment whereas there are no discernible differences between each treatment (Table 4-22).

In general, both submerged (T3) and on surface (T2) Bamboo devices with the height of 550 mm and the rest of the treatment except for the treatment of polybag (550 mm) were not significantly differ for plant height $p > 0.05$.

This implies that plant height behaves in a similar way across the Bamboo devices rather than the rest of the treatments used in the study.

The mean comparison of number of leaves per plot between the pairs of treatments is shown in Table 4-23 and Table 4-26. The behavior of the number of leaves per pot across the treatments reflected the same pattern that was observed for the plant height (Table 4-22).

In brief, both submerged (T3) and on surface (T2) Bamboo devices of 550 mm and the rest of the treatment except for the treatment of Polybag (550 mm) (T5) were not significantly differ for the number of leaves/pot. This indicated that the number of leaves/pot performs in a similar way across the Bamboo devices rather than the rest of the treatments used in the study excluding (T5).

Table 4-22 : Multiple comparisons (LSD) of plant height across the treatment.

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.
Control (T1)	Bamboo device (550 mm) on surface (T2)	-3.61	3.90	0.36
	Std. black polybag (T4)	-4.16	3.91	0.29
	Polybag (550 mm) (T5)	8.80	4.66	0.06
	Bamboo device (550 mm) submerged (T3)	-7.13	3.90	0.07
Bamboo device (550 mm) on surface (T2)	Control (T1)	3.61	3.90	0.36
	Std. black polybag (T4)	-0.55	3.84	0.89
	Polybag (550 mm) (T5)	12.41*	4.60	0.01
	Bamboo device (550 mm) submerged (T3)	-3.53	3.82	0.36
Bamboo device (550 mm) submerged (T3)	Control (T1)	7.13	3.90	0.07
	Bamboo device (550 mm) on surface (T2)	3.53	3.82	0.36
	Std. black polybag (250 mm) (T4)	2.98	3.84	0.44
	Polybag (550 mm) (T5)	15.93*	4.60	0.00
Std. black polybag (250 mm) (T4)	Control (T1)	4.16	3.91	0.29
	Bamboo device (550 mm) on surface (T2)	0.55	3.84	0.89
	Polybag (550 mm) (T5)	12.95*	4.61	0.01
	Bamboo device (550 mm) submerged (T3)	-2.98	3.84	0.44
Polybag (550 mm) (T5)	Control (T1)	-8.80	4.66	0.06
	Bamboo device (550 mm) on surface (T2)	-12.41	4.60	0.01
	Std. black polybag (T4)	-12.95*	4.61	0.01
	Bamboo device (550 mm) submerged (T3)	-15.93*	4.60	0.00

(* Denotes the mean difference is significant at the 0.05 level).

Table 4-23 : Multiple comparisons (LSD) of the number of leaves /pot the treatment.

(I) Treatment	**(J) Treatment**	**Mean Difference (I-J)**	**Std. Error**	**Sig.**
Control	Bamboo device (550 mm) on surface	-0.6	1.31	0.65
	Standard black polybag	-1.29	1.32	0.33
	Polybag (55 cm)	12.33*	1.61	0.00
	Bamboo device (55 cm) submerged	0.1	1.31	0.94
Bamboo device (55 cm) on surface	Control	0.6	1.31	0.65
	Standard black polybag	-0.69	1.29	0.60
	Polybag (55 cm)	12.93*	1.59	0.00
	Bamboo device (55 cm) submerged	0.7	1.29	0.59
Standard black polybag	Control	1.29	1.32	0.33
	Bamboo device (55 cm) on surface	0.69	1.29	0.60
	Polybag (55 cm)	13.62*	1.59	0.00
	Bamboo device (55 cm) submerged	1.38	1.29	0.28
Polybag (55 cm)	Control	-12.33*	1.61	0.00
	Bamboo device (55 cm) on surface	-12.93*	1.59	0.00
	Standard black polybag	-13.62*	1.59	0.00
	Bamboo device (55 cm) submerged	-12.24*	1.59	0.00
Bamboo device (55 cm) submerged	Control	-0.1	1.31	0.94
	Bamboo device (55 cm) on surface	-0.7	1.29	0.59
	Standard black polybag	-1.38	1.29	0.28
	Polybag (55 cm)	12.24*	1.59	0.00

(* Denotes the mean difference is significant at the 0.05 level).

The number of tillers/pots were varied differently across the treatment as shown in mean separation test results shown in Table 4-24 and Table 4-26. The number of tiller/pot in Polybag (550 mm) (T5) significantly differed from the treatment both on surface (T2) and submerged Bamboo devices (T3), Control (T1) and Standard polybag (T3) at $p \leq 0.05$. Further, there was significant difference among the both standard polybag (T4), and submerged (T3) Bamboo device with the control (T1) while there is a significant difference between the submerged Bamboo device (T3) and the Polybag of 550 mm (T5).

Table 4-24: Multiple comparisons (LSD) of the number of tillers /pot the treatment.

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.
Control	Bamboo device (550 mm) on surface	-0.58*	0.19	0.00
	Standard black polybag	-0.39*	0.19	0.04
	Polybag (550 mm)	0.82*	0.22	0.00
	Bamboo device (550 mm) submerged	-0.52*	0.19	0.01
Bamboo device (550 mm)on surface	Control	0.58*	0.19	0.00
	Std. black polybag (250 mm)	0.20	0.19	0.30
	Polybag (550 mm)	1.41*	0.21	0.00
	Bamboo device (550 mm) submerged	0.06	0.19	0.74
Standard black polybag	Control	0.39*	0.19	0.04
	Bamboo device (550 mm) on surface	-0.20	0.19	0.30
	Polybag (550 mm)	1.21*	0.21	0.00
	Bamboo device (550 mm) submerged	-0.13	0.19	0.48
Polybag (550 mm)	Control	-0.82*	0.22	0.00
	Bamboo device (550 mm) on surface	-1.41*	0.21	0.00
	Std. black polybag	-1.21*	0.21	0.00
	Bamboo device (550 mm) submerged	-1.34*	0.21	0.00
Bamboo device (550 mm) submerged	Control	0.52*	0.19	0.01
	Bamboo device (550 mm) on surface	-0.06	0.19	0.74
	Std. black polybag	0.13	0.19	0.48
	Polybag (550 mm)	1.34*	0.21	0.00

(* Denotes the mean difference is significant at the 0.05 level).

The number of days taken for the flowering stage and its variation across the treatments depicted in Table 4-25 and Table 4-26. A careful observation of the table revealed that there was no Significant difference between both on surface (T2) and submerged (T3) Bamboo devices (550 mm) ($p > 0.05$). The rest of treatment pairs indicated a statistically significant difference ($p \leq 0.05$).

Table 4-25: Multiple comparisons (LSD) of the number of days taken for flowering across the treatment.

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.
Control	Bamboo device (550 mm) on surface	-2.67*	0.61	0.00
	Std. black polybag	-1.44*	0.62	0.02
	Polybag (550 mm)	-10.83*	0.91	0.00
	Bamboo device (550 mm) submerged	-3.08*	0.61	0.00
Bamboo device (550 mm) on surface	Control	2.67*	0.61	0.00
	Std. black polybag	1.23*	0.58	0.04
	Polybag (550 mm)	-8.17*	0.89	0.00
	Bamboo device (550 mm) submerged	-0.41	0.57	0.48
Std. black polybag	Control	1.44*	0.62	0.02
	Bamboo device (550 mm) on surface	-1.23*	0.58	0.04
	Polybag (550 mm)	-9.40*	0.89	0.00
	Bamboo device (550 mm) submerged	-1.64*	0.58	0.01
Polybag (550 mm)	Control	10.83*	0.91	0.00
	Bamboo device (550 mm) on surface	8.17*	0.89	0.00
	Std. black polybag	9.40*	0.89	0.00
	Bamboo device (550 mm) submerged	7.76*	0.88	0.00
Bamboo device (550 mm) submerged	Control	3.08*	0.61	0.00
	Bamboo device (550 mm) on surface	0.41	0.57	0.48
	Std. black polybag	1.64*	0.58	0.01
	Polybag (550 mm)	-7.76*	0.88	0.00

(* Denotes the mean difference is significant at the 0.05 level).

Table 4-26: Summary of mean comparison of measures data for plant growth parameters across different treatments.

Plant height (cm)		**T1**	**Bamboo device (550 mm)**		**Black polybag**	
			T2	**T3**	**T4**	**T5**
T1		0				
Black polybag	T4	-4.156	-0.548		0	
	T5	8.798	12.406*		12.954*	0
Bamboo device (550 mm)	T2	-3.608	0			
	T3	-7.133	-3.525	0	-2.977	-15.931*
Number of Leaves/pot		T1	Bamboo device (550 mm)		Black polybag	
			T2	T3	T4	T5
T1		0				
Black polybag	T4	-1.29	-0.69		0	
	T4	12.33*	12.93*		13.62*	0
Bamboo device (550 mm)	T2	-0.6	0			
	T3	0.1	0.7	0	1.38	12.24*
Number of Tillers/pot		T1	Bamboo device (55 cm)		Black polybag	
			T2	T3	T4	T5
T1		0				
Black polybag	T4	-.39*	0.2		0	
	T5	.82*	1.41*		1.21*	0
Bamboo device (550 mm)	T2	-.58*	0			
	T3	-.52*	0.06	0	-0.13	0.212
Days taken for flowering stage initiation		T1	Bamboo device (550 mm)		Black polybag	
			T2	T3	T4	T5
T1		0				
Black polybag	T4	-1.44*	1.23*		0	
	T5	-10.83*	-8.17*		-9.40*	0
Bamboo device (550 mm)	T2	-2.67*	0			
	T3	-3.08*	-0.41	0	-1.64*	7.76*

(* Denotes the mean difference is significant at the 0.05 level).

4.8 Discussion

The overall work-done and results obtained throughout the research study followed by the methodology, are discussed under the sub headings from 4.8.1 to 4.8.4.

4.8.1 Construction of plant database

Elephant forage plant database was developed by using comprehensive literature surveys, field inspections and face to face interviews. The information collected from these surveys were used to compile a database for Elephant forage plants.

Major external and internal factors affected to plant growing were gathered through weed catalogs and standard forage guide books. The information related to those characters were concentrated from intensive literature surveys. Twenty-two plant species, belonging to five families representing 14 grasses, five sedges and three herbaceous were identified which are chosen from easily available data and commonly visualized forage plants in elephant ranging forests and areas in Sri Lanka. Priority for constructing the elephant forage plants database was given for the fast growing, soft wood herbaceous forage plants and weeds as grasses, herbs and sedges. Development of an elephant forage plant database is important in awareness of people living in the HEC prevalent areas of the island and further research studies relating to the elephant conservation and elephant forages.

4.8.2 Questionnaire survey for the evaluation on perceived palatability of elephant forages

Questionnaire was developed from the constructed plant database including 22 herbaceous forage plants. It was prepared for conducting an electronic base survey due to the pandemic situation of the country. Questionnaire was validated through experts and piloting and calculating reliability (Cronbach’s $\alpha = 0.92$) and including Sinhala language and common names for easiness of plant type identification.

Since the names of plant species are region-specific, the questionnaire was modified by inserting photographs of relevant plants, and vernacular names of each plant species after getting feedback from the majority of respondents.

Field expertise for instance, range officers of Department of Wildlife Conservation, officers of Mahaweli authority, ecologist, veterinarians, naturalist and wildlife – researchers, academics were chosen as the targeted population of this study. It was noted that most of the responders encountered in the field visits, especially the farmers, are mainly considered only the crops that they cultivate. Therefore, the farmers were not included in the target population. The sample included a total of 82 responders and two of the responders were removed since they were not belonging to the category of expert. Thus, the refined sample included only 80 responders.

The sample included a higher number of male responders (81.25 %) and a considerably lower number of female responders(18.25 %), and this may be due to the poor female participation in the workforce in the fieldwork in the wildlife-related professions [124]. The difference between the responses and the gender of the responders did not vary considerably across the samples. This may be due to the higher representation of males as field experts in the sample population. The number of responders perhaps indicated the extent of the wildlife-protected areas included in the study. For instance, Northwestern, North Central, Central, and Uva provinces represented higher numbers of responders and were 28.75 %, 21,25 %, 16.25 %, and 12.50 % respectively. The Western Province has not been considered since there were no wild elephants ranging areas.

As far as plant types are concerned, there was a considerable difference in distribution of the selected plants mainly occurring in secondary forests, grasslands, and wetlands in the seven provinces. There was a higher occurrence of grasses (63.64 %) compared to sedges (22.73 %) and herbs (13.64 %), reported in the study. This could be attributed to the fact that the grasses are capable of a wider range of ecological conditions and are much more resistant to drought than the sedges. Further, grasses which often grow in association with marshland and inland water bodies are adapted to periodic emergence and disappearance with the fluctuation of availability of water [125], [126]. The spatial distribution of these plants indicates an ecological provenance and the occurrence of certain plants such as *Sacciolepis interrupta* (Beru), which is more or less confined to the wetland of the drier areas, and the invasive grasses such as naturalized *Panicum maximum* (Gini thana), as widely distributed in the island irrespective of the climatic conditions.

Further, the emergence of the plant species included in the study is associated with the prevailing climatic condition of the island, and much of the sedges and grasses growing in the wetland and the inland reservoirs disappear during the droughts and reappear in the rainy periods. Therefore, the availability of certain plant species chosen indicated a seasonality. Thus, there was between province (spatial) variation of abundance of elephant fodder plants across the provinces than the variation within the province [127].

Based on the perceived palatability levels, the following plants can be placed in descending order of palatability: Ali maana (8.22%), Beru grass (7.53%), Guinea grass (7.00%), and Bajiri (6.66%) (Table 4-4). However, the palatability could be varied with plant species, which is governed by the prevailing climatic conditions of the area under consideration. Previous studies also support these findings [126], [128]. Thus, elephants inhabited in different provinces of the different climatic regions of the country may depend on the available plant species under different climatic conditions [127]. Further, the availability of such plant species directly or indirectly affects the roaming of elephants, which in turn aggravates the HEC and other socio-economic grievances brought by the wild elephants. In addition, diversification of particular elephant forage plant species would sustain the availability of fodder plants irrespective of the seasonal variation of the climate. For instance, a mixture of forage plants, including drought-resistant and submerge-resistant, would be an effective way of maintaining year-round forage availability.

4.8.3 Forage plant matrix and Forage Selection Index (FSI)

The information collected from the field inspections and intensive literature survey, used to compile a database for Elephant forage plants, which was taken to construct a forage selection matrix as a field key for preliminary identification of grazing forages in terms of qualitative approach. Through the preliminary effort, the database was further used to develop a matrix including an array of forage plants.

Since, Forage Selection Index (FSI) was developed from elephant forage database and forage selection matrix. Further, plant Matrix can be used to identify the forage plants abundance in the elephant's rangeland to secure sustainable forage availability to improve the carrying capacity. Forage selection index (FSI) can be given a quantitative approach for selecting a suitable plant for grassland management purposes. A number of studies have been reported the elephant forage plants, including wide array of plants ranging from tree, shrubs, herbs, grasses and sedges[129], [130],

However, forage preference for the same plant can be varied with the availability and the prevailing climatic conditions of the area under consideration. Previous studies also support this finding [126], [128]. Thus, elephants occupied in different provinces of the different climatic regions of the country may depend on the available plant species under different climatic conditions [127]. Further, the availability of such plant species directly or indirectly affects the roaming behavior of elephants for palatable forage plants, which in turn aggravates the HEC and other socio-economic grievances caused by the wild elephants.

4.8.4 Field Experiment 1: Designing and Optimization Bamboo Planting Device

During the plant material selection for the construction of the device, an attention was paid to the biodegradability, eco-friendliness, ease of availability, cost effectiveness and availability, anatomy of the material which provide strengths and stability with a lumen [112], [131],[132]. Since, these requirements were material fulfilled by the mature Bamboo stems. The material chosen for the designing were based on the secondary data that is proved through the optimization procedure [132], [133].

It was assumed that the possible human errors associated with free-fall dropping was minimized since the same person is involved in the free-fall experiment. Further, it was assumed that the influence of air quality such as moisture, density, and wind speed, direction etc., are constant during the field experiment. Three samples were made for the same structure to minimize the structural errors, especially positions of nodes of the bamboo stems.

The optimization was carried out for different diameters (550 – 800 mm) and cutting angles (0° -75°). The height of the device (550 mm) and free-falling height (5m) were maintained as constants.

As the proposed height, 550 mm was chosen because the length between three nodes is around 400 mm and approximately, another 150 mm were required for angle cutting purposes in terms of the practicable easiness and feasibility to carry out the research to break the nodal membrane. (To have a minimum number of nodal diaphragms for a device).

The findings of the study indicated that there are chances of ripping the soil - contacted area of the devices during the free-fall (diameter of 550 mm). Also, the devices with low diameters had a considerable possibility to be cracked due to the immaturity associated with low lignin content of the bamboo culms used in the device. In addition, the heterogeneity of the tissue distribution within the bamboo shell, such as fibers and parenchymal cells, also led to variation in the moisture content of the bamboo shell which determined the potential areas of cracks. In immature Bamboo, heterogeneity of the material can be considered as one of the contributing factors of cracking during the field experiment [133],[134],[135].

Even though the penetration depth is higher with low diameters (550 mm) in the devices, the internal space of the device is not sufficient enough for the growth of a forage plant until the flowering stage. The optimization process indicated that the best diameter and the best cutting angle for better penetration depth were between 650- 750 mm and 45° respectively. However, lower the diameter and cutting angle at 45°, produced the higher penetration depth, which could be attributed to the geometry of the device [136] and the characteristics of the substrate [137]. Considering the practicability and the feasibility of the field experiments, the range of 650 to 750 mm were chosen as the suitable diameters for the planting devices.

Further, it was observed during the field experiment that larger cutting angles such as 60°, 75° with a larger diameter of 8.0 cm showed a considerable rotation as well as less penetration depths. This may be attributed to the fact that the radial and longitudinal variation in the density of the bamboo shell which in turn affect the position of the center of gravity.

However, the penetration of granular substrate by objects with geometrical forms of the impact surfaces such as soil are even complex [138]. On this basis, the bamboo device with diameter of 6.5-7.5 cm and the cutting angle of 45^{o} indicated, for the moment, the best performance for the desired objective of study and could be considered as a tool for continuation of the planting mechanism [139].

4.8.5 Field Experiment 2: Evaluation of Device Performances with Forages

Field experiment was carried out growing forage plants in the devices to evaluate the Bamboo device performance by measuring the plant growing performances. In this experiment, sunken beds were prepared to retain water similar to the nature of marshland[140]. Plant height, number of leaves and tillers per pot, number of days taking to reach flowering stages are taken as plant growth parameters.

Further, plant height is an indicator of vegetative growth that is directly influenced by plant production management strategies [141]. During the experiment period, slight drought conditions and hot weather prevailed in the field. So, watering and other culturing practices were carried out twice a week. The polybag with 550 mm height was taken in this study to grow plants, in order to compare the device performance with the proposed height (550 mm) of the bamboo device. Black polybag is used in this experiment to minimize the light transparency that is matching with the outer cover of the Bamboo device.

A considerable difference between the plant growth performance was observed in almost all the forage plant species grown in 550 mm polybags. The forage plants grown in the rest of the treatments, as bamboo devices that are kept on soil surface and submerged soil indicated inconspicuous plant growth performance difference apart from the control treatment (plant directly grown in the soil). This difference in growth performance could be attributed to the water stress caused by the differences in the structures and materials used in the experiments.

In both devices of black polybag and the bamboo shell protect the plant from the excess heat buildup within the device since these pots act as a heat insulator,[142],[143].

But, the moisture retaining capacity, comparatively thicker wall consisting of higher volume of parenchymatous cell mass of the structure of Bamboo have a possibility to release continuous moisture content at a certain period of time until the plant establishment while securing the plant avoiding the wilting point[144]. Furthermore, the thick wall of the Bamboo reduces the soil water evaporation in the potting medium, because it acts as a thermal insulator. In addition, the walls of the polybags in black color act as a thermal sink and retain the heat within the structure. This may increase the soil temperature in soils of the container, increase the water evaporation and the water stress condition of the planting device reduce the plant growth[145]. Further, the lack of the cooling effect on water vaporization in polybags which leads to increase the temperature within the pot. Therefore, a number of studies carried out on the plant growth, evidenced the negative effect of the black polybag as a growth container [146],[142],[143].

The growth performance of Ali mana, Gini thana, Bajiri, Wel maruk and Thunhiriya indicated comparatively better growth performances in Bamboo mediated devices. This discrepancy could be attributed to the genetic makeup and the traits of the forage plant [147],[148],[148]. Further, plants such as Gini thana and Ali mana, which have been reported to be invasive plants, thrive well in devices constructed using bamboo material and proven to be the best planting mechanism for these forage plants.

According to the analysis of results, devices made on Bamboo material showed significant effect as well as Std. size poly bag on vegetative and yield parameters at all stages of measurements whereas, 55 cm black poly bag and control were not significant effect on growth parameters. Further, Bamboo device treatments with submerged and on surface were not significantly different for the vegetative and yield parameters.

The results of these studies support the finding of the present study. On this basis the bamboo mediate device providing “mulching effect” demonstrated its suitability for the establishing elephant forage plant in inaccessible elephant ranges to increase the forage abundance.

4.9 Research findings

The results and findings of the study could be considered as baseline data because such studies have not been reported in the literature in the Sri Lankan context. The result of the study could be used to derive the following findings.

i. The importance of identifying and preparing a database of elephant forage plants is crucial for enriching the wildlife forage availability *in situ*, and retain the elephant within range minimizing to abate the HEC.

ii. The palatability of elephant forage is a main aspect of elephants' behavior and study introduced a novel method of assessment of elephant forage plant palatability in terms of qualitative approach through Plant Matrix as a Field Key.

iii. *Pennisetum purpureum* (Ali maana), *Sacciolepis interrupta* (Beru), *Panicum maximum* (Gini thana), and *Echinochloa glabrescens* (Bajiri) could be considered as most palatable forage species out of the selected plants for the Sri Lankan elephants in accordance with the human perception, even though Sri Lankan elephants feed on a variety of forage plants.

iv. Forage Selection Index (FSI) was developed in order to get a measurable or numerical value for selecting forage plants to introduce for the purpose of field establishment. *Pennisetum purpureum* (Ali maana), *Panicum maximum* (Gini thana), *Sacciolepis interrupta* (Beru), *Schoenoplectus grossus* (Thunhiriya) respectively, performed for the suitability of forage plants out of the selection.

v. The devices constructed from the Bamboo for the purpose of establishment of elephant forage plant proved to be appropriated for the purpose.

vi. The bamboo device of 550 mm height, with double cutting angles (shape 2), angle of 45° and 7.5 cm diameter performed better during the optimization process indicating higher penetration depth for the free-fall aerial dropping method.

vii. Bamboo device performed comparatively higher with control and 550 mm height of poly bag and performed more-or-less similarly to the Std. polybag in the evaluation of device performance for the majority of plants chosen in the study and the both on surface and submerged Bamboo devices showed in the overall assessment.

viii. The forage plants such as *Panicum maximum* (Gini thana), *Pennisetum purpureum* (Ali maana), *Echinochloa glabrescens* (Bajiri), *Echinochloa crusgalli* (Wel maruk) and *Schoenoplectus grossus* (Thunhiriya) were the best candidates for the establishment of elephant forage plants in ranges using the constructed bamboo device out of selected plants in the present study.

4.10 Summary

Plant database was constructed to identify common forage plants of Elephants in Sri Lanka by using comprehensive literature survey and field observations (Appendix B).

The perceived palatability, yield and method of propagation produced a dendrogram with three groups of plants. The first groups included the forage plants such as *Isachne globosa* (Batadella), Echinochloa glabrescens *(*Bajiri), Cyperus iria (Thunessa), *Ischaemum rugosum* (Gojarawalu), *Alysicarpus vaginalis* (Asvenna) and *Imperata cylindrica* (Illuk) and *Sacciolepis interrupta* (Beru). The second group formed from the plant species such as *Panicum maximum* (Gini thana), *Pennisetum purpureum* (Ali maana), *Panicum repens* (Etora), *Schoenoplectus grossus* (Thunhiriya) and *Cyperus rotundus* (Kalanduru). The third group included *Eleusine indica* (Bela thana), *Dactyloctenium aegyptium* (Putu thana), *Echinochloa crusgalli* (Wel maruk), *Cyperus haspan* (Halpan), *Fimbristylis miliacea* (Mudu halpan), *Achyranthes aspera* (Gas Karalheba), Bacopa *monnieri* (Lunuwila) and *Leersia hexandra* (Levu). Based on the magnitude of the scores *viz.*, Low, medium and high classes, *Pennisetum purpureum* (Ali maana), *Sacciolepis interrupta* (Beru) *Panicum maximum* (Gini thana) standed out with high palatability scores.

In summary, the result indicated that there was a between plant variation of perceived palatability (Table 4-4). Plant selection matrix was constructed to evaluate suitability of forage plants by qualitative approach whereas Forage Selection Index was developed to get a measurable value for forage selection (Table 2-1 and Figure 4-6).

Deviation geometric shapes of the planting devices, Shape 2 indicated a comparatively higher penetration depth rather than Shape1 at the angle of 45°. The comparison of mean penetration depths across the different diameters indicated that the highest penetration depths was observed for the diameter class 550 mm, however, is not suitable for a planting pot since insufficient plating volume and lack of strength. The diameter class 750 mm showed the second-best penetration depth which provides the adequate space for potting a plant. Plant height, number of leaves / pot, number of tiller/pot, number days taken to reach flowering stage indicated that there are statistical significance differences between the treatments and plant species. Bamboo device (550 mm) on soil surface, submerged into soil and Std. black polybag indicated a more or less similar behavior as of control. Plants treated with polybags (550 mm) showed a poor plant growth.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

HEC is currently becoming one of the most active and controversial problems. Therefore, sustainable and coexistence strategies are more important to mitigate this problem and one possible approach towards a more sustainable mitigatory method is to promote the use of increase in forage availability. The following collusion derived from the results and findings of the study conducted on the proposed mechanism for establishment of elephant forage plants in ranges where accessibility is limited. In addition, diversification of particular elephant forage species, would sustain the availability of forage plants irrespective of the seasonal variation of the climate, also a considerable alternative for the HEC.

Wild elephants prefer grass forage plants over the sedges and herbaceous plant species. Among these grasses *Sacciolepis interrupta* (Beru) a common grass in the wetland of the drier areas, and the invasive grasses *Panicum maximum* (Gini thana) play a major role in elephant food security. The year-around abundance of availability of *Panicum maximum* (Gini thana) and *Pennisetum purpureum* (Ali maana) alleviate the elephant forage shortage during unfavorable climatic condition since much of the sedges and grasses growing in the wetland and the inland reservoirs are disappeared during the droughts and reappear in the rainy periods. The elephants inhabited in the different climatic regions of the country depend on the available plant species under different climatic conditions. Hence, diversification of particular elephant forage species, would sustain the availability of forage plants irrespective of the seasonal variation of the climate, also a considerable alternative for the HEC.

The forage selection matrix key is a general tool for the identification of elephant forages in the field using qualitative characters of plants. The FSI is also an index which can be used to determine the forage preference by elephants. Both tools provide valuable methods in determination of forage plants preferred by elephants in ranges that could be used in elephant range that could be used in elephant conservation and forest management.

Due to the biological, chemical, structural, physical and mechanical properties of Bamboo culms and its biodegradability, it can be considered as one of the best materials and sustainable solutions for developing a device for the establishment of elephant forage plants. The free-falling requires material with strength and once the devices are implanted in soil, the device should be biologically decayed. Both requirements are fulfilled by the Bamboo shells.

The proposed bamboo device can be used to establish short-term forage plants, since The hard shell cover of the bamboo device protects the plant from its young stage until flowering stage by avoiding damages to the plants from the elephants including the other herbivory animals in the fields. In addition, Bamboo shells protect the plant from the excess heat buildup of evaporation of water and retain the soil moisture within the device since these pots act as a heat insulator as well as storing water in the bamboo shell. The bamboo device with 650 -750 mm in diameter and with cutting angle of 45^{o} provide the most suitable planting mechanism for plant establishment in inaccessible elephant rages. During the designing process of devices for plant establishment in inaccessible range areas, the geometry of the device and the characteristics of the substrate have to be taken into consideration to increase the efficacy of the device.

The forage plants grown in the rest of the treatments, as bamboo devices that are kept on soil surface and submerged soil indicated inconspicuous plant growth performance difference apart from the control treatment (plant directly grown in the soil). The growth performance of many grassy forages such as Gini thana and Ali mana, thrive well in constructed bamboo devices and have proven to be the best planting mechanism for the forage grasses.

Hence, the findings of these studies also emphasize the importance of identifying grazing forages, in particular to elephant food behaviors. Thus, the identification of forage plants guides the seasonal and ecological distribution of elephants, providing valuable information to wildlife managerial personnel and policymakers on the HEC.

5.2 Recommendations

Based on the findings of the study the following recommendations were grasped.

i. Preparation of elephant forage plant databases is essential for the identification and establishment of their zonal distribution in the country.
ii. The palatability of the elephant forage grass required to be assessed for providing better forage plants in elephant rage to minimize the elephant's roaming for their feeding behavior.
iii. The proposed bamboo device needs to be further optimized and stimulated for the different free fall heights and to assess the behavior of structure for the purpose of areal dropping.
iv. The plant growth performance optimized through extensive field trials before implementation of the devised for the purposes envisaged.
v. For the purpose of field implementation, it is necessary to conduct feasibility studies and impact analysis in the real environment.

5.3 Limitations

The following limitation of the study is to be considered and due allowance should be made during the interpretation of the results.

i. Plant database was created using a limited number of plant species due to the time constraint but, the limited number of plants included in the plant database might have led to difficulties in generalization.
ii. Perceived palatability was assessed through response data on the observations of the wildlife experts and these data should be confirmed through laboratory analysis. For a holistic approach, it is required additional information on the forage palatability through laboratory investigation on different aspects such as chemical, physical composition of the forage plants.
iii. The performance of the devices was tested for a constant height of 5m, since, it is necessary to assess the variation of the device performance with changing the dropping height. The proposed bamboo device needs to be studied with different free fall height, substrate characteristics, the terminal velocities and forces operated against the penetration origin from the substrate.

iv. The stability of the proposed bamboo device is required to be tested specially for rotation during the free fall, and oblique penetration etc., to improve the devices for free fall from higher altitudes.

5.4 Future Developments and Possibilities

Further studies are required on the followings,

i. The material chosen for the designing and developing bamboo cell mediated structure should be well examined for mechanical, physical, chemical and biological properties for further improvements of the proposed device.
ii. The variation of mechanical properties along radial and longitudinal directions of the bamboo culm and age-wise variation mechanical properties of the bamboo studied for the bamboo species expected be used for developing the device.
iii. The geometry of the proposed device should be reassessed specially the length, diameter, cutting angle optimum penetration of 15-20 cm depth for the reason that too shallow and too deeper penetrations would adversely impact the plant growth.
iv. Since the perceived palatability scores of the forage plant species represent the opinion of the respondents, the laboratory analyses, as well as field analyses of the selected grasses for their functional types, chemical composition, physical properties, and the variation of these properties with the soil and climatic parameters, are of importance in the determination of elephant forage preferences.

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Appendix- A: Application to Receive Information from the Government (RTI).

RTI 01

Note that completion of this Form is not a compulsory requirement to make a request for information and that any written letter, e-mail or a verbal request with the essential information to identify the requested information is sufficient.

Application to receive Information

Information Officer,

01. Name of Requestor - U.D. Tharangi
02. Address – Pro - Green lab, Department of Civil Engineering, University of Moratuwa
03. Contact No. (if any) - 0766879318
04. Email Address (if any) - tharangi.uyanahewa90@gmail.com
05. Details about Information requested
    I. Specific Public Authority: Department of Wildlife Conservation, Battaramulla
    II. Information requested.

    Records for Number of officially and manmade(unofficially) created Elephant fences /types and lengths of fences, total area covered from fences as GN wise /divisional wise) year wise.

    Records for Human induced Elephant mortality and causes for deaths (GN wise/ divisional wise) year wise

    Records for Elephant induces human mortality and causes for deaths (GN wise/ divisional wise) year wise.

    Records for Elephant induced property losses, causes and estimated value (GN wise/ divisional wise) year wise.

06. Specific period information is requested (if applicable): From 2009 to 2021

07. Manner in which information is requested–

    i. Inspect relevant work, documents, records
    ii. Take notes, extracts or certified copies of documents or records
    iii. Take certified samples of material
    iv. Obtain information in the form of CD/DVD/storage media/tapes/video cassettes/ any other electronic mode/ printouts where such information is stored in a computer or in any other device.

08. Language in which requestor prefers access: English

09. Does the information request concern the life and personal liberty of a citizen? (Yes/No)

    If Yes, give reason for belief -

    ……………………………………………………………………………………………

10. Any other details- Data is required for the research purposes only
11. Relevant documents attached (If any)
    I. Request letter from University of Moratuwa
12. Is the requestor a citizen of Sri Lanka? (Yes/~~No~~)

Date: - 2021.08.12 Signature: - Dulini

Appendix- B: Plant Database.

(a) Detailed table for Plant database.

Description	Life Cycle	Propagation	Flowering & Pollination	Rate of growth per seed & Seed Nature	Optimal Growth	Yield	Palatability	Grown Areas	Habitats	Tolerance /Resistance ability	Climatic requirement	Altitude	Soil requirement
Gas karal heba (*Achyranthes aspera* L.)													
Branched herbs or under shrubs, Stem with woody base, erect /procumbent [149].	Perennial [102].	By seeds[150].	Self-pollination, hermaphrodite; disseminated by water & animals [151], [150].	Low due to high mortality of seedlings through seeds in early stage [152].	Up to ~ 4 m in favorable conditions, commonly 1-2 m in height [149], [153].	Fresh Annual yield is 35 tons/ha & Dry yield 3.85tons/ ha [150], [154].	Appetizer; cure various types of gastric disorders, Forage [150], [155].	Native Tropical & subtropical regions of the world [150], [102].	Thrive in open dry places, urban areas, disturbed & waste areas due to its high adaptability [149], [156].	Plant resistance to pests, & survive drought [150], [157], [158].	Warm climate, full sunny conditions, 10-30°C, Optimum germination is at 20°C,rainfall: 700 - 1,300 mm [150],[159].	900 to 2100 m [14]	Light (sandy), medium (loamy) & heavy (clay) soils, prefers moist soil, Optimum pH of 6.2, suitable pH: acid, neutral & alkaline soils, pH ranging from 4 to 8.2, [151].
Thunhiriya (*Schoenoplectus grossus* (L.f.) Palla)													
Sedge, aquatic, bushy,nativeherb; potential as hyper accumulator used in phytoremediatio	Perennial [16].	Rhizomes, stolon, corms in combination; vegetative propagules survive for	Wind pollinated; pollens with thin-walled, pear-shaped [163].	0.08 to 0.12 mg/ day; seed aborts in 2 to 3 weeks after flowering [164] [20].	10-18 weeks after planting / in unfertilized soil & grows up to 2 m	unfertile soil,114.3 ramets/ m2; 24-weeks afterplanted ,(10.89 g/ plant) [162].	Palatable due to succulence parts [166].	Tropical & subtropical regions of the world [161].	Marshy areas, agricultural lands, water bodies [161].	Adapted to a watery environment; poor drought tolerance [161].	10–30 °C; Annual rainfall of 2040 mm[161], [167], [168].	1500 –2100 m [165].	Wetland/moist, some adapts to saline, sandy, loamy & clay soils, pH (4 - 10) [169].

n technology [160], [161].		yrs [162], [110].			high [165], [162].								
Halpan (*Cyperus haspan* L)													
Succulent sedge, roots are fibrous (annual), when perennates, shorter rhizomes are produced [170].	Annual to perennial [168].	By seed & division of rhizome [170], [171]	Pollinated by wind or general floral agents, frequently flower in first yr after germination of seed [170].	0-345,000 seeds m−2/yr, comparatively seed production is high than the other species of the same growth habit [28], [29].	Almost fleshy growth & culms are in tuft or dispersed, 10 - 60 cm tall, [170].	4800 plants /acre, fiber yield of 2.64 t/ha DAS [174], [175].	Excellent survival food in times of need. Edible food [170].	Tropics & subtropics [170].	Seasonally emerged in permanently wet grassland, marsh/waste places, dry fields, rice fields [170].	Calcareous soil tolerance medium (normal),fire resistance [174].	Grow in full sun or partial shade exposure; the Warm climate, humid, & frost-free, T= 16 & 24 °C & annual minimum precipitation rate of 20 % at the driest climate station within the plant's known region of distribution. [169], [174] [173].	From near sea level to 1,600 m [175].	Clay, loamy, moisture-retentive, as well as on thin wet soil over rock & in ditches, pH :Acid, alkaline, neutral [176].

Thunessa (*Cyperus iria* L.*)*													
A smooth sedge, tufted & tall, commonly an amphibious herb with stolon [177], [178]	Annual [178]	By seeds, tillers, vegetatively [172], [179]	Pollen & spores of insect, mostly accumulated in flowers [180], [181].	3000 to 5000 seeds/plant, 40% of fresh seeds germinate directly & dormant seeds take a short period of after-ripening [179] [182].	Reached a maximum growth at 70 d after vegetatively propagation, increased until 130 d after germination up to 20 cm - 1 m high [180].	In poor soil, 114.3 ramets m^{-2} net populations, 24 weeks after plant 10.89 g/ plant [162].	Used as a fodder [183].	Native of tropical Asia, later widespread in subtropical Asia [179].	Terrestrial, wet-mesic to dry-mesic, disturbed, soils, lowland & irrigated rice fields [184], [185].	Abiotic & biotic stresses [180].	Warm climate, highest germination % at 20/30 °C alternating, (Germinated at t = 15-40° C), mean annual rainfall 2500 mm while monthly rainfall ranges between 25 mm to over 400 mm [179], [182]	lower altitudes [186].	Saturated or aerobic-moist soil, pH – 6.3 [182], [186].
Kalanduru (*Cyperus rotundus* L.*)*													
Erect, fibrous rooted sedge, when temperatures &	Herbaceous perennial	Tuber survived *ca.* 7 year on undisturbed	Flowering ranged from 3 to 8 weeks of emergence,	Poor seed are viability; rarely germinate on	Fast growth with crowded	30-40 million tubers/ha per week,	Palatable [63]	Native to the tropical, subtropic	[198]	Survive high temperatures, herbicide tolerance,	Growing under different climatic	Growing in almost every	All types of soils, it is most effective on dry soils, Growing in

light intensity rise, C4 metabolism which makes it increasingly competitive [187], [188]	weed [188]	sites, bulky populations of shoots, a single tuber produce 600 plants /year [189], [190], [191] [192],	cross pollinated, often *via* insect, wind [189], [193].	averages in the range of 1-5 %, higher capability in vegetative propagation, production of seed surpass 100 million/ha/year [189].	colonies due to rhizomes & tubers, often grown upper 15 cm of soil, grow down more than 30 cm under favorable conditions [194], [195], [196].	2.73kg/m2 of total dry matter (above ground) [190], [197].		al Old World & invading new habitats [194].		insidious & its herbicide tolerance [198].	conditions remains high, maximum growth under warm climate, temperatures & high light conditions, 13-43°C, annual rainfall of 1556-4000 mm [187], [198], [199], [200].	altitude & range at increasing latitudes & altitudes [189].	almost every pH [189] [201].
Mudu halpan (*Fimbristylis miliacea* (L.) Vahl)													
Erect sedge with fibrous root system, outcompete native vegetation [202].	Annual or perennial [202].	By seeds, seedlings emerged at 3 days after planting & no vegetative propagation[202], [203].	By water, wind & human-related activities.], flowering & fruiting throughout the year [177], [202].	10,000 seeds/plant, prolific seed producer, widespread, germinate soon after reaching .Seeds remain viable for more than one year, seed emergence occurred 3	Seedlings emerged at 3 days after planting of seeds ,90 cm high [202], [204].	500 to 1000 plants per m^{-2} [205], [206].	Palatable [38]	Common throughout the tropics, [177].	Occurs in damp, open waste places [202].	Tolerance to stress & high reproductive capacity [206].	mean annual tem. 12 to 33 ºC, about 650 mm annual rainfall [185], [189], [207].	Up to 1500 m [208].	Clay texture rice fields soil, pH Acidic [205], [209].

				days after sowing[177], [202], [203].									
Asvenna (*Alysicarpus vaginalis* (L.) DC)													
Herbaceous legume, grown for green manure (N-fixing legume) , effective erosion control on newly established terraces [178], [206], [210].	Low growing annual or short-lived perennial [178].	By seeds, one per pod, propagated by using the cuttings in the mixed substrate [206], [211].	The cross-pollination is by insect pollinators[212] [79]	Seed rate of 6kg/ha had the optimum performance, seed requires an after ripening period of 16 weeks to overcome physiological dormancy [213], [214].	40 - 80days after sawing ,up to 0.6-1 m in height [215], [216], [217].	In Sri Lanka, 12.5 t DM/ha with N & P fertilizer[216].	Native range as a fodder, mainly grown for pasture & hay [214], [218].	Native to Africa, Asia, Malesia, & Australia [210].	Extremely variable in habit [178], [210].	Requires well-drained soils [210].	Tropical regions where mean annual temperature ranged from 18.3-27.4 C & annual rainfall 910-4290 mm[206], [219].	Up to 1380 m [206].	Coralline sands to clays, heavy soil, pH of 5.5-8.7 [206].
Gira thana (*Echinochloa colona* (L.) Link)													
Tufted, erect to spreading & semi-prostrate, vigorous C4species [220].	Annual [221].	Reproduction effort:4–5 weeks after germination, nodal	Self-pollination, flowering 4 weeks after	42 000 seeds/plant, seed maturity & dispersal ~45 days after	Rapid growth up to 30-100 cm high	Highest mean fiber yield of 2.64 t/ha [185].	Natural forage, valuable fodder	Tropical Asia [227] [94].	Marshlands -irrigated fields [220].	Dormancy mechanism , adapt to a wide range of	25–28 'C, 400 mm to about 1200 mm [222],	Low altitudes (2000 m	Light (sandy), medium (loamy) & heavy (clay) soils, pH-6 - 8 , acid,

		cuttings & stalks [222], [223].	germination[222], [224].	germination, seed dormancy [222].	[222], [225].		[220], [226].			environments [222].	[187], [225].	above sea level) [187].	neutral & basic (alkaline) [151].
Wel maruk (*Echinochloa crusgalli* (L.) Beauv)													
Tufted, erect, C4 weed. [220], [227].	Annual grass [228], [221].	By seeds, no vegetative propagation [229], [222].	Self-pollinating & flowering in a variety of photoperiods with day-lengths ranging from 8 to 16 hours[229], [222], [230].	Under the flooded settings, seed output is higher in 4-5 weeks after seed germination, 40 000 seeds /plant, with a seed's maturation & dissemination occurring 45 days after germination & dormancy occurring 6 months [220], [229], [222].	Faster growth under flooded environments. Height: 1.5 meters. [231], [229].	Up to 4–11 t/ha of fresh wgt.. dry matter yields are influenced by planting rate 40 kg/ha is the most suitable. [231], [232].	Has introduced into many countries as a fodder & protein source; a potential forage. [218], [220].	Tropical/sub tropical/temperate region/subtropical [220] [87]	Rice fields & wetlands [220] [87]	Adapted to flooded, anaerobic conditions such as rice fields & wetlands, used for reclamation of saline soil [222], [227], [229].	15–30 'C optimal growth temperature, annual precipitation ranges from 310 mm to 2500mm [[206], [222], [227].	From sea level & 2500 m [233].	Poorly drained soil, suitable for alkaline areas, referable soil pH 4.8 to 8.2[234], [231].

Bela tana (*Eleusine indica* (L.) Gaertn.)													
Short grass shrub, branching at the base [178], [235].	Tufted annual or weakly perennial grass [110].	Mainly by seeds, no vegetative propagation [236].	Flowers are pollinated by wind, first inflorescence (45 Days after sowing) [237], [238].	50,000 seeds/plant, seeding rate of 5.56 kg/ ha, propagated by seed [110], [239].	Fast emergence of new tillers after 38 & 43 Days of sowing, grows up to 0.3-0.6 m tall[239], [237].	With harvests during dr season, produce up t 30 t/ha o fresh matte while producing 1.83–3.82 t/ha of dr matter. [231 [236]	Edible plant parts (Edible Seeds) [239].	Tropics & sub-tropics [239].	Disturbed areas & wastelands [110].	Disturbed areas, generate new individuals[237].	Sub/tropical/temperate region, germination at alternating, T of 20-30°C, mean annual rainfall 200-2000mm [185], [110], [240].	Sea level to about 1200 m [185].	Compacted, poorly drained soils : light (sandy), medium (loamy) & heavy (clay) soils, pH: 6.0 to 6.8 [151], [241].
Illuk (*Imperata cylindrica* (L.) Beauv)													
Rhizomatous. upright annual grass [178].	Perennial weed [178].	By seeds & rhizomes, Ramet growth is considerably faster than seedling growth [178], [241].	By wind dispersal of seeds, highly variable & frequently produced flowers or others never produced flowers [178], [241], [242].	High seed viability, weeks after ripening , 3000 seeds per plant[241], [243].	After 6 weeks up to 3m[243], [244] [118, 117].	High yielding forage legume that can produce 10-20 t DM/ha [217].	Low quality forage [244].	Native to tropical & subtropical areas [244].	Agricultural, forest & waste lands [178].	Rhizomes are very resistant to heat & breakage, adapted to a variety of environmental conditions, to full sun, fire, drought resistance [244], [243], [245].	Tropical & subtropical regions, 30°C, with minimal growth at 20°C & 40°C, & 500–5000 mm of precipitation [244].	2000-2700) m [244] [118]	Wet soil of good fertility, pH of 4.0-7.5, in light-textured acid soils with a clay subsoil to slightly alkaline. [244].

Batadella (*Isachne globosa* (Thunb.) Kuntze)													
Native grass to SL [178].	Perennial [178].	By nodes, fresh seed & rooted pieces [246], [247].	Florets are water & wind dispersed, full sun to flower, requires full sun to flower [247].	Period of 1-2 weeks for ripening [247], [248].	Reach to over 1 m height forming mats or cushions after fourth week of growth [246], [247], [249].	150 to 300 kg/ha [248] [250], [250].	Palatable to cattle, cultivated as a forage grass [208], [246].	Sri Lanka, Malaysia, Indonesia, Thailand, Vietnam, Australia, & India [251].	Grows in mud/shallow water between floating mats of plants in marshes & stagnant water bodies, often immersed in water [246].	Thrive in flooded anoxic soils[246]	Temperate to subtropical regions & tropical regions, temperature 21–27 °C, rainfall : about 2250 mm [246].	Up to 1,800 m [252].	Flooded anoxic soils, pH to 5.5 – 6.0 [246], [253].
Rila thana (*Ischaemum timorense* Kunth)													
Grass species generally used for lawns [110].	Annual or short-lived perennial grass [216].	By seed & stem fragments, buds at nodes sprout shoots. [216].	*	Seed production 3–6 kg/ha; 6 months of dormant period after harvest [245].	15-60 cm tall, up to 1 m high [110], [211]	Produce 30 t/ha/year of fresh forage & 7.2 to 8.3 t/ha of dry matter [254], [255].	Forage, good species for permanent pasture [216], [245].	Originated in tropical Asia, temperate [256]	Common in turf, in other grassy areas & often found on heavily grazed communal land. [257], [245].	Tolerates low soil fertility & high soil acidity [216].	800-2000 mm annual rainfall [216].	Up to 2,000 m [245]	Light to medium textured soils, not in heavy clay soil, often of low fertility, pH, 4 to 7 [245].

Levu (*Leersia hexandra* SW)													
Tufted, aquatic or swamp grass, the dense mat of vegetation [189], [258].	Perennial [110].	By seeds (rare), reproduces predominantly vegetatively, by creeping rhizomes [258].	Insect pollinated, flowering depends upon the climate [258].	Very Rare[258].	High regeneration capacity & rapid growth rate from 30 cm to 1 m high [258] [259].	Produce ca. 9 t/ha of biomass, crude-protein content 12.4% & low fiber content 30.9% [185], [259].	Cultivated in paddy fields as green forage, [260], [258].	Tropical & subtropical regions of the world [110].	Common in wet areas [110].	Tolerate both wet & dry conditions [260].	Tropical & subtropical, temperature: 25 °C/18 °C day/night temperature, annual precipitation ranges from 310 mm to 2500mm [258], [259], [261].	Altitudes, ascending to 1,500 m [260].	Silt ,water & enrich soil, pH: 6.2 [210],[260].
Guinea thana (*Panicum maximum* Jacq.)													
Loosely tufted, culms erect or geniculate ascending, C4 plant [262].	Perennial [145].	By seeds & tillers, propagates *via* its tillers [262], [263].	Very long flowering season, pollinated by wind & self-fertile [151], [264].	9,000 seeds/plant, fresh seeds less viable, increased by storing the seeds in dry for 6 - 18 months [265], [266].	Tall, strong plant; shoots reaches up to 3.5 m ,fast growth [267].	High yield 70-80 tons/ha, dry yield: 25-35t/ha [263], [127] [268].	Highly palatable. Regarded as the most valuable fodder plant, used to make hay & pasture [263].	Tropical region of the world [263].	Prefers shade & damp areas, require water regularly [263].	Tolerates hot & dry conditions [245].	Dry to wet subtropical to tropical, 30–40 °C, warm moist climate receiving more than 900 mm rainfall [269], [267].	1200 m [154].	Fertile soil & well adapted to a wide variety of conditions, sand to clay soils with moderate to high fertility, pH of 4.3 to 8.4 [263], [269], [267].

Etora (*Panicum repens* L.)													
Rhizomatous grass species[270].	Perennial [39]	By tillering from rhizomatous, small fragments & extensive spread [270].	Very rare flowering & seed production [271].	No seeds[272].	Rhizomes forms in a few weeks after 4 weeks of new plant established, at 5-20 cm depth of soil up to 1m [272], [273], [274].	20 tons/ha of dry weight in one year [275].	Animal feed, fodder, forage [271].	Tropical & sub tropics [270].	Terrestrial, wetland, & aquatic environments [270].	Drought tolerance, Special soil tolerances [185], [276].	temperature: of 20 & 30°C, dry season duration- number of consecutive months with < 40 mm rainfall [270], [277].	1000-1400 m above mean sea level [270].	Dry sandy soils to wet marshes, pH between 4.2 & 6.7 [270], [278].
Bajiri (*Echinochloa glabrescens* Kossenko)													
C4 perennial grass, tufted, erect & jointed [279], [280].	Polyploidy annuals whose genetic systems maintain high biochemical	By seeds & vegetative fragments probably dispersed by water" [282], [283].	Self-pollinating, flowering starts 3 or 4 weeks after germination[280].	4800 seeds/ plant, the ability to germinate at all temperatures, could emerge throughout the year & the first seeds come to maturity	Took 67 d to panicle emergence up to 75 - 100 cm tall [283], [282].	5t/ ha, about of 100 t/ha/year for c4 plants (DM)], 280 plants/ m^{-2} [229], [279], [279]	Natural forage, edible [151], [220].	Tropical & subtropical regions [285].	Closely tufted habit in wetlands & dry habitats, grow in high-nutrient, waterlogged conditions	Drought tolerance, salinity resistant [231].	The plants grown in full sunlight, 27/21°C, annual rain fall: 1300–1350 mm [171], [231], [285].	sea-level to 2000 m [282].	Tolerates high salinity, referred sandy, loamy, heavy clay soils, & low of 6.6 [151], [279], [286].

	variability Annual [281].			45 days later [284].					[178], [221].				
Gojarawalu (*Iachaemum rugosum* Salisb.)													
C4 grass, grows in tuft, vocationally with silt roots, rooting at nodes, tropics[178] [287].		Vegetative growth apparent during the first 11 weeks of the life cycle [288].	Cross-pollinated, ripening of the first spike emerged after 10 weeks of seeding [288].	Seed - 6000 - 18 000 seeds/genet per year) [189].	Tillers increasing after 14 days after sawing , 1.5m [287], [289].	277 plants m^{-2} or 6.68t/ha [289], [290], [291].	Used as forage [178].	Tropical Asia [292].	Wet & frequently slightly saline grassy places & other moist places[288].	Environmental stresses - low salinity & mild drought (-0.2 MPa), affect the germination [293].	Seed germination 25–30 ºC, 60 mm total annual precipitation driest month < 100 mm [178], [288], [292], [294].	Up to 2400 m [176]	Moist paddy soils & strongly desiccating soil, tolerate acid soils of pH 4.0 [178], [288].
Ali maana (*Pennisetum purpureum* K. Schumach.)													
Rhizomatous, tufted perennial grass] [185], [295].	Perennial [295].	No seeds, 50-100 stalks / plant, largely by vegetative methods as stalk cutting &root culms divisions [295].	Cross pollination, blooming begin the stigma emerge from 2 to 4 days before the stamens [295].	There is little (3 million seeds/kg), or no seed formation, fast-growing , robust, [185].	Grows strong, reach up to 4 m within 3 months, annual productivity higher [296],	Under high fertilizer, yields range from 20 to 80 t Dry matter/ha/year & without 2-10 t	More palatable due to its greater succulence & higher moisture contents	Tropical & subtropical [299].	Wide range of dry or wet conditions [295].	Disease resistance, abiotic stress (drought) tolerance, very adaptable [295].	25 °C to 40 °C, rainfall 200-4000 mm [295], [299], [299].	Up to 1219 m. Ideal conditions below 762 m [295].	Grows well in silt loam, clay, deep soils e.g., friable loam, poorly drained clay or drained sandy soils. Fertile & well-drained, medium to deep ash soils favor the growth,

					[297], [297].	DM/ha/year [298].	/multipurpose forage crop in tropics due to its high productivity [295], [220].						pH in the range of 4.5 to 8.2 [295] [298].
Beru (*Sacciolepis interrupta* (Wild.) Stapf)													
Tall reedy grass [300], [301].	Annual or perennial herb [302].	Regeneration capacity ,different plant parts like seeds, culm cuttings with nodal roots & root clumps [302].	By insects, flowering & fruiting throughout the year [302].	Germination percentage of 68% with continuous light, seeds have high level of innate dormancy, 30 days after sowing [302].	Rapid growth, emergence rate is best 14 DAS, vegetative propagated plants compared to seed propagated ones, whereas plant height is greater in seedlings [302], [303].	18 t/ha/yr., an aquatic fern growing interspersed [303], [304].	Elephant feed, pasture improvement & as a fodder grass [300], [303].	Has a mainly Asian distribution, Intermediate zone, tropical grass weed [302].	Abundant in tanks, marshy places [305].	Toxic & drug resistance, high tolerance range for the aquatic species [306], [307].	Continuous light, warm, higher temperature of 38 ºC max, annual rainfall (1,750 - 2,000 mm) [302], [308].	1100–1400 m [309].	Sandy clay loam in texture, pH 5.6 [310].

Putu thana (*Dactyloctenium aegyptium* (L.) Wild.)													
A creeping C4 grass, grass, shoot straight, a weed & invasive species [178], [288].	Annual [205].	By seeds mainly, vegetatively by stems from in which root at the lower nodes [189].	By water run-off, wind, & seed-eating insects, birds & mammals. In warm regions it flowers all year round [189].	66,000 seeds/plant, high germination percentages in seeds[189], [311].	Usually about 30 cm up to 75 cm high [178], [252].	Ranging from 3 to 6 t DM/ha [197].	Widely used as forage, fodder & hay production. [178], [312], [226].	Tropical & subtropical areas [313].	Disturbed areas with light sandy soils where water accumulates [313].	Salt tolerant, drought-resistant [226], [314].	Tropical, temp15 to 40°C, 400-1500 mm rainfall annually [313], [315].	From sea level to 2100 m [315].	Wide array of soil types & in sandy to sandy loamy soils, pH ranged from 4 to 5 [173], [314].
Lunuwila (*Bacopa monnieri* (L.) Pennel)													
Creeping herbaceous succulent plant[178], [316].	Perennial [178].	Natural regeneration through seeds, vegetative s is slow, 62,500 nos/ha. of cuttings [317], [318].	By insects flowering occurs throughout the year [319].	Seed germination deepens on the sunlight, distinct seed dormancy period is observed [319], [317].	Grows relatively slow under aquarium conditions ,0.3 to 1.22 m [320].	Fresh yield is 22.5 tons/hectare, reduced to 5.5 tons/hectare on drying [321],[322].	Palatable [321].	Native to the swampy areas of tropics[316].	Aquarium plant, wet/semi shade [178]. [323]	Grow under salt stress conditions, abiotic stresses tolerance, halotolerant plant [324].	Tropical, temp 16 °C to 28 °C, average annual rainfall of 2,817 ± 406 mm [321], [325].	Up to 1300 m [244].	Adverse soil conditions as salt & water stress affected areas, pH ranging from 5.5. to 7.3 [326], [288].

Appendix C: Questionnaire form used in the E- Base Survey (Google Form).

6/28/22, 10:03 PM Palatability Rate Measurement of Elephant Fodder Plants (පෝෂ තෘණ සදහා අලින්ගේ රුචිකත්වය)

Palatability Rate Measurement of Elephant Fodder Plants (පෝෂ තෘණ සදහා අලින්ගේ රුචිකත්වය)

I'm U.D. Tharangi, postgraduate student of University of Moratuwa. This questionnaire is sent you to as a part of the research based on Elephant Human Conflict. It is very kindly requested you to fill this questionnaire and share among field experts and your cooperation in this regard would be greatly appreciated.

*Required

1. Email *

2.	Gas Karalheba [Achyranthes aspera] (ගස් කරල්හැබ)
	
◯	Intensely palatable තීව්‍ර ලෙස රුචිකත්වයක් දරයි)
◯	Strongly palatable (දැඩි ලෙස රුචිකත්වයක් දක්වයි)
◯	Moderately palatable (මධ්‍යස්ථ ලෙස රුචිකත්වයක් දක්වයි)
◯	Mild palatable (සාමාන්‍ය ලෙස රුචිකත්වයක් දක්වයි)
◯	Weekly palatable (දුබල ලෙස රුචිකත්වයක් දක්වයි)
◯	Unknown (නොදනී)
◯	Not in this region (මේ ප්‍රදේශයේ නැත)

3.	Hal pan [Cyperus haspan] (හල් පන්)
	
◯	Intensely palatable තීව්‍ර ලෙස රුචිකත්වයක් දරයි)
◯	Strongly palatable (දැඩි ලෙස රුචිකත්වයක් දක්වයි)
◯	Moderately palatable (මධ්‍යස්ථ ලෙස රුචිකත්වයක් දක්වයි)
◯	Mild palatable (සාමාන්‍ය ලෙස රුචිකත්වයක් දක්වයි)
◯	Weekly palatable (දුබල ලෙස රුචිකත්වයක් දක්වයි)
◯	Unknown (නොදනී)
◯	Not in this region (මේ ප්‍රදේශයේ නැත)

4	Thunessa [Cyperus iria](තුනැස්ස)
	
◯	Intensely palatable තීව්‍ර ලෙස රුචිකත්වයක් දරයි)
◯	Strongly palatable (දැඩි ලෙස රුචිකත්වයක් දක්වයි)
◯	Moderately palatable (මධ්‍යස්ථ ලෙස රුචිකත්වයක් දක්වයි)
◯	Mild palatable (සාමාන්‍ය ලෙස රුචිකත්වයක් දක්වයි)
◯	Weekly palatable (දුබල ලෙස රුචිකත්වයක් දක්වයි)
◯	Unknown (නොදනී)
◯	Not in this region (මේ ප්‍රදේශයේ නැත)

5.	Kalanduru [Cyperus rotundus](කලාදුරු)
	
◯	Intensely palatable තීව්‍ර ලෙස රුචිකත්වයක් දරයි)
◯	Strongly palatable (දැඩි ලෙස රුචිකත්වයක් දක්වයි)
◯	Moderately palatable (මධ්‍යස්ථ ලෙස රුචිකත්වයක් දක්වයි)
◯	Mild palatable (සාමාන්‍ය ලෙස රුචිකත්වයක් දක්වයි)
◯	Weekly palatable (දුබල ලෙස රුචිකත්වයක් දක්වයි)
◯	Unknown (නොදනී)
◯	Not in this region (මේ ප්‍රදේශයේ නැත)

https://docs.google.com/forms/d/1Sb5Q3UKMqgdUpt-hys5E3957dmScgHzp6uGeOG3kDFU/edit 1/23

Appendix C: cont'd.

18 Guinea thana [Panicum maximum](ගිනියා තණ)

- Intensely palatable තීව්‍ර ලෙස රුචිකත්වයක් දරයි)
- Strongly palatable (දැඩි ලෙස රුචිකත්වයක් දක්වයි)
- Moderately palatable (මධ්‍යස්ථ ලෙස රුචිකත්වයක් දක්වයි)
- Mild palatable (සාමාන්‍ය ලෙස රුචිකත්වයක් දක්වයි)
- Weekly palatable (දුබල ලෙස රුචිකත්වයක් දක්වයි)
- Unknown (නොදනී)
- Not in this region (මේ ප්‍රදේශයේ නැත)

19 Beru grass [Sacciopelsis interrupta](බෙරු)

- Intensely palatable තීව්‍ර ලෙස රුචිකත්වයක් දරයි)
- Strongly palatable (දැඩි ලෙස රුචිකත්වයක් දක්වයි)
- Moderately palatable (මධ්‍යස්ථ ලෙස රුචිකත්වයක් දක්වයි)
- Mild palatable (සාමාන්‍ය ලෙස රුචිකත්වයක් දක්වයි)
- Weekly palatable (දුබල ලෙස රුචිකත්වයක් දක්වයි)
- Unknown (නොදනී)
- Not in this region (මේ ප්‍රදේශයේ නැත)

20 Gira tana [Echinochloa colona](ගිරා තණ)

- Intensely palatable තීව්‍ර ලෙස රුචිකත්වයක් දරයි)
- Strongly palatable (දැඩි ලෙස රුචිකත්වයක් දක්වයි)
- Moderately palatable (මධ්‍යස්ථ ලෙස රුචිකත්වයක් දක්වයි)
- Mild palatable (සාමාන්‍ය ලෙස රුචිකත්වයක් දක්වයි)
- Weekly palatable (දුබල ලෙස රුචිකත්වයක් දක්වයි)
- Unknown (නොදනී)
- Not in this region (මේ ප්‍රදේශයේ නැත)

21. Lunuwila [Bacopa monnieri](ලුණුවිල)

- Intensely palatable තීව්‍ර ලෙස රුචිකත්වයක් දරයි)
- Strongly palatable (දැඩි ලෙස රුචිකත්වයක් දක්වයි)
- Moderately palatable (මධ්‍යස්ථ ලෙස රුචිකත්වයක් දක්වයි)
- Mild palatable (සාමාන්‍ය ලෙස රුචිකත්වයක් දක්වයි)
- Weekly palatable (දුබල ලෙස රුචිකත්වයක් දක්වයි)
- Unknown (නොදනී)
- Not in this region (මේ ප්‍රදේශයේ නැත)

22 Layu [Leersia hexandra](ලාසුතණ)

- Intensely palatable තීව්‍ර ලෙස රුචිකත්වයක් දරයි)
- Strongly palatable (දැඩි ලෙස රුචිකත්වයක් දක්වයි)
- Moderately palatable (මධ්‍යස්ථ ලෙස රුචිකත්වයක් දක්වයි)
- Mild palatable (සාමාන්‍ය ලෙස රුචිකත්වයක් දක්වයි)
- Weekly palatable (දුබල ලෙස රුචිකත්වයක් දක්වයි)
- Unknown (නොදනී)
- Not in this region (මේ ප්‍රදේශයේ නැත)

23 Belathana [Eleusine indica](බැලතණ)

- Intensely palatable තීව්‍ර ලෙස රුචිකත්වයක් දරයි)
- Strongly palatable (දැඩි ලෙස රුචිකත්වයක් දක්වයි)
- Moderately palatable (මධ්‍යස්ථ ලෙස රුචිකත්වයක් දක්වයි)
- Mild palatable (සාමාන්‍ය ලෙස රුචිකත්වයක් දක්වයි)
- Weekly palatable (දුබල ලෙස රුචිකත්වයක් දක්වයි)
- Unknown (නොදනී)
- Not in this region (මේ ප්‍රදේශයේ නැත)

Appendix C: cont'd.

Palatability Rate Measurement of Elephant Fodder Plants

To identify the level of palatability of Elephant fodders using eight main provinces and mainly focused on grasses and herbaceous plants.

24 Province (පලාත)

Tick all that apply.

- [ ] Northern (උතුර))
- [ ] North Central (උතුරු මැද)
- [ ] Western(වයඹ)
- [ ] Central(මධ්‍යම)
- [ ] Eastern(නැගෙනහිර))
- [ ] Sabaragamuwa (සබරගමුව)
- [ ] Uva (ඌව පළාත)
- [ ] Southern(දකුණ)

25 Area /location (ප්‍රදේශය)

26 Your name (ඔබගේ නම)

27 Occupation /Designation (රැකියාව)

28. Gender (ස්ත්‍රී පුරුෂ භාවය)Mark only one oval.

- ( ) Male
- ( ) Female

Google Forms

Appendix- D: Reliability analysis.

Reliability and item-related statistics of a pilot sample of the survey questionnaire.

Reliability Statistics	
Cronbach's Alpha	No of Items
0.918	21

Item-Total Statistics				
	Scale Mean if Item Deleted	**Scale Variance if Item Deleted**	**Corrected Item-Total Correlation**	**Cronbach's Alpha if Item Deleted**
Halpan	33.33	437.461	0.636	0.913
Thunessa	33.33	439.674	0.570	0.914
Kalanduru	33.33	445.929	0.616	0.914
Thunhiriya	33.33	447.589	0.568	0.915
Mudu halpan	33.33	444.057	0.579	0.914
Asvenna	33.33	431.461	0.681	0.912
Putu thana	33.33	438.099	0.648	0.913
Wel maruk	33.33	429.333	0.757	0.910
Bajiri	33.33	445.504	0.567	0.915
Illuk	33.33	446.270	0.610	0.914
Batadella	33.33	443.206	0.534	0.915
Gojarawalu	33.33	429.504	0.780	0.910
Ali maana	33.33	460.610	0.324	0.919
Etora	33.33	442.823	0.571	0.914
Rilathana	33.33	432.993	0.702	0.912
Guinea_thana	33.33	451.418	0.426	0.918
Beru_grass	33.33	478.397	0.029	0.929
Gira_tana	33.33	432.695	0.757	0.911
Lunuwila	33.33	426.440	0.630	0.913
Lavu	33.33	434.738	0.576	0.914
Bela thana	33.33	451.078	0.554	0.915

Appendix- E: Formats for data recording.

Bamboo Device Optimization																				
Proposed Shape (1/2)		Diameter (mm) x 10^2						Cutting Angle (Degree)						Replicate ID		Trial Number			Initial Weight (kg)	Penetration Depth (cm)
1	2	5.5	6	6.5	7	7.5	8	0	15	30	45	60	75	R1	R2	T1	T2	T3		

Plant Growth Performance														
Week	Plot Number					Plant Name	Replicate ID				Plant Height (cm)	Number of leaves / pot	Number of tillers /pot	Number of days for reaching flowering stage
	1	2	3	4	5		R1	R2	R3	R4				

Appendix- F: Comparison of mean penetration depth by shape of the device, angle class and diameter class.

Shape of the device	Angle class (degree)	Diameter class x 10^2 (mm)	Penetration depth (cm)	Std. Error
Shape 1	0	5.5	28.40	0.25
		6	32.03	0.52
		6.5	25.63	0.13
		7	27.50	0.30
		7.5	36.27	0.19
		8	31.63	0.24
	15	5.5	29.60	0.26
		6	32.23	0.09
		6.5	28.17	0.33
		7	27.60	0.26
		7.5	36.10	0.21
		8	30.57	0.29
	30	5.5	30.50	0.23
		6	33.43	0.18
		6.5	28.53	0.28
		7	29.17	0.33
		7.5	36.53	0.03
		8	31.83	0.15
	45	5.5	42.30	0.12
		6	34.40	0.60
		6.5	30.83	0.37
		7	35.17	0.33
		7.5	42.50	0.35
		8	34.37	0.15
	60	5.5	31.20	0.52
		6	33.37	0.46
		6.5	30.53	0.62
		7	30.07	0.43
		7.5	36.73	0.58
		8	26.70	0.20
	75	5.5	30.73	0.74
		6	28.63	0.30
		6.5	32.83	0.32
		7	31.40	0.10
		7.5	35.47	0.32
		8	27.27	0.12
Shape 2	0	5.5	28.40	0.25
		6	32.03	0.52
		6.5	25.63	0.13

		7	27.50	0.30
		7.5	36.27	0.19
		8	31.63	0.24
	15	5.5	44.70	0.42
		6	32.47	0.37
		6.5	27.50	0.29
		7	28.93	0.43
		7.5	39.50	0.29
		8	32.50	0.30
	30	5.5	46.30	0.12
		6	33.90	0.31
		6.5	31.13	0.61
		7	32.53	0.52
		7.5	36.93	0.22
		8	35.23	0.47
	45	5.5	47.03	0.47
		6	37.43	0.23
		6.5	34.73	0.27
		7	45.50	0.35
		7.5	45.73	0.33
		8	40.67	0.28
	60	5.5	47.60	0.32
		6	34.57	0.74
		6.5	31.73	0.42
		7	38.17	0.38
		7.5	36.20	0.67
		8	38.70	0.60
	75	5.5	49.23	0.66
		6	33.13	1.13
		6.5	33.47	0.32
		7	21.17	0.68
		7.5	30.50	0.95
		8	31.83	0.37

Appendix- G: Multiple comparison (LSD) of penetration depth by different diameter classes of Shape 2.

(I) Diameter class	(J) Diameter class x 10 ^{2}	Mean Difference (I-J)	Std. Error	Significance	95% Confidence Interval	
					Lower Bound	Upper Bound
5.5	6	4.864*	0.17	0.00	4.5	5.20
	6.5	7.939*	0.17	0.00	7.6	8.27
	7	6.775*	0.17	0.00	6.4	7.11
	7.5	.606*	0.17	0.00	0.3	0.94
	8	5.256*	0.17	0.00	4.9	5.59
6	5.5	-4.864*	0.17	0.00	-5.2	-4.53
	6.5	3.075*	0.17	0.00	2.7	3.41
	7	1.911*	0.17	0.00	1.6	2.25
	7.5	-4.258*	0.17	0.00	-4.6	-3.93
	8	.392*	0.17	0.02	0.1	0.73
6.5	5.5	-7.939*	0.17	0.00	-8.3	-7.61
	6	-3.075*	0.17	0.00	-3.4	-2.74
	7	-1.164*	0.17	0.00	-1.5	-0.83
	7.5	-7.333*	0.17	0.00	-7.7	-7.00
	8	-2.683*	0.17	0.00	-3.0	-2.35
7	5.5	-6.775*	0.17	0.00	-7.1	-6.44
	6	-1.911*	0.17	0.00	-2.2	-1.58
	6.5	1.164*	0.17	0.00	0.8	1.50
	7.5	-6.169*	0.17	0.00	-6.5	-5.84
	8	-1.519*	0.17	0.00	-1.9	-1.19
7.5	5.5	-.606*	0.17	0.00	-0.9	-0.27
	6	4.258*	0.17	0.00	3.9	4.59
	6.5	7.333*	0.17	0.00	7.0	7.67
	7	6.169*	0.17	0.00	5.8	6.50
	8	4.650*	0.17	0.00	4.3	4.98
8	5.5	-5.256*	0.17	0.00	-5.6	-4.92
	6	-.392*	0.17	0.02	-0.7	-0.06
	6.5	2.683*	0.17	0.00	2.4	3.02
	7	1.519*	0.17	0.00	1.2	1.85
	7.5	-4.650*	0.17	0.00	-5.0	-4.32

(* Denotes that the mean difference is significant at $p \leq 0.05$ level).

Appendix- H: Multiple comparison of penetration depth by different cutting angle classes of Shape 2.

(I) Angle class (degree)	(J) Angle class (degree)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
0	15	-2.24*	0.17	0	-2.58	-1.91
	30	-3.59*	0.17	0	-3.93	-3.26
	45	-8.98*	0.17	0	-9.31	-8.64
	60	-4.39*	0.17	0	-4.72	-4.05
	75	-1.89*	0.17	0	-2.23	-1.56
15	0	2.24*	0.17	0	1.91	2.58
	30	-1.35*	0.17	0	-1.68	-1.01
	45	-6.73*	0.17	0	-7.07	-6.40
	60	-2.14*	0.17	0	-2.48	-1.81
	75	0.35*	0.17	0.04	0.02	0.68
30	0	3.59*	0.17	0	3.26	3.93
	15	1.35*	0.17	0	1.01	1.68
	45	-5.39*	0.17	0	-5.72	-5.05
	60	-0.79*	0.17	0	-1.13	-0.46
	75	1.70*	0.17	0	1.36	2.03
45	0	8.98*	0.17	0	8.64	9.31
	15	6.73*	0.17	0	6.40	7.07
	30	5.39*	0.17	0	5.05	5.72
	60	4.59*	0.17	0	4.26	4.93
	75	7.08*	0.17	0	6.75	7.42
60	0	4.39*	0.17	0	4.05	4.72
	15	2.14*	0.17	0	1.81	2.48
	30	0.80*	0.17	0	0.46	1.13
	45	-4.59*	0.17	0	-4.93	-4.26
	75	2.49*	0.17	0	2.16	2.83
75	0	1.89*	0.17	0	1.56	2.23
	15	-0.35*	0.17	0.04	-0.68	-0.02
	30	-1.70*	0.17	0	-2.03	-1.36
	45	-7.08*	0.17	0	-7.42	-6.75
	60	-2.50*	0.17	0	-2.83	-2.16

(* Denotes that the mean difference is significant at $p \leq 0.05$ level).

Appendix- I: Mean height of plant across the treatment.

. Treatment	Plant Name	Mean (cm)	Std. Error
Control	Ali maana	73.7	4.25
	Bajiri	96.1	7.68
	Batadella	69.8	4.97
	Beru	46.0	5.59
	Gini thana	115.3	11.83
	Iluk	69.4	6.40
	Thunhiriya	56.2	7.69
	Wel maruk	56.6	6.91
Bamboo device (550 mm) on surface	Ali maana	99.5	8.22
	Bajiri	91.1	6.97
	Batadella	72.0	5.57
	Beru	55.1	4.72
	Gini thana	121.1	12.99
	Iluk	64.1	5.88
	Thunhiriya	61.6	8.97
	Wel maruk	56.0	6.68
Standard black polybag	Ali maana	96.5	8.56
	Bajiri	97.7	6.96
	Batadella	71.4	5.89
	Beru	58.1	4.18
	Gini thana	111.0	12.42
	Iluk	66.8	5.96
	Thunhiriya	67.3	9.36
	Wel maruk	60.9	6.33
Polybag (550 mm)	Ali maana	46.7	2.55
	Bajiri	88.4	5.82
	Batadella	25.5	1.84
	Beru	10.8	0.27
	Gini thana	105.3	10.34
	Iluk	24.6	0.24
	Thunhiriya	48.9	7.57
	Wel maruk	11.5	0.46
Bamboo device (550 mm) submerged	Ali maana	95.5	6.57
	Bajiri	108.6	9.11
	Batadella	74.8	6.00
	Beru	59.4	4.95
	Gini thana	109.6	10.82
	Iluk	64.2	5.46
	Thunhiriya	73.8	10.95
	Wel maruk	66.4	7.24

Appendix- J: Average No. of leaves /pot across the treatment.

Treatment	Plant Name	Number of leaves (Mean)	Std. Error
Control	Ali maana	7	0.48
	Bajiri	19	1.05
	Batadella	61	5.21
	Beru	18	1.63
	Gini thana	25	2.88
	Iluk	25	2.42
	Thunhiriya	5	0.24
Bamboo device (550 mm) - on surface	Wel maruk	13	0.88
	Ali maana	20	5.73
	Bajiri	21	1.33
	Batadella	54	5.69
	Beru	18	1.13
	Gini thana	24	2.56
	Iluk	28	2.52
	Thunhiriya	8	0.66
Standard black polybag	Wel maruk	13	0.93
	Ali maana	8	0.49
	Bajiri	21	1.42
	Batadella	62	5.43
	Beru	21	1.68
	Gini thana	28	3.24
	Iluk	27	2.47
	Thunhiriya	7	0.38
Poly bag (550 mm)	Wel maruk	15	0.96
	Ali maana	4	0.17
Bamboo device (550 mm) - Submerged	Bajiri	15	0.89
	Batadella	9	0.41
	Beru	6	0.29
	Gini thana	16	1.70
	Iluk	5	0.25
	Thunhiriya	5	0.27
	Wel maruk	6	0.25

Appendix- K: Variation of the No. of tillers/pot across the treatment.

Treatment	Plant Name	Tillers/pot (Mean)	Std. Error
Control	Ali maana	0	0.18
	Bajiri	2	0.28
	Batadella	5	0.85
	Beru	1	0.15
	Gini thana	4	0.68
	Iluk	1	0.30
	Thunhiriya	0	0.00
Bamboo device (550 mm) - on surface	Wel maruk	3	0.46
	Ali maana	0	0.15
	Bajiri	2	0.36
	Batadella	6	0.77
	Beru	3	0.27
	Gini thana	5	0.42
	Iluk	3	0.31
	Thunhiriya	1	0.14
Standard black polybag	Wel maruk	2	0.42
	Ali maana	1	0.18
	Bajiri	2	0.21
	Batadella	4	0.58
	Beru	3	0.33
	Gini thana	4	0.48
	Iluk	2	0.33
	Thunhiriya	0	0.00
Poly bag (550 mm)	Wel maruk	3	0.37
	Ali maana	0	0.00
Bamboo device (550 mm) - Submerged	Bajiri	1	0.23
	Batadella	2	0.27
	Beru	0	0.00
	Gini thana	3	0.33
	Iluk	0	0.00
	Thunhiriya	0	0.00
	Wel maruk	0	0.00

Appendix- L: No. of days taken to reach flowering stage across the treatment.

Treatment	Plant Name	Days (Mean)	Std. Error
Control	Ali maana	40	1.45
	Bajiri	12	0.82
	Batadella	13	0.75
	Beru	20	1.50
	Gini thana	42	1.23
	Iluk	20	0.65
	Wel maruk	14	0.88
Bamboo device (550 mm) - on surface	Ali maana	14	0.88
	Bajiri	42	1.18
	Batadella	12	0.96
	Beru	10	0.82
	Gini thana	21	0.75
	Iluk	44	1.19
	Thunhiriya	20	0.85
	Wel maruk	43	1.45
Standard black polybag	Ali maana	13	1.33
	Bajiri	42	1.67
	Batadella	11	0.58
	Beru	9	0.48
	Gini thana	22	1.19
	Iluk	43	1.44
	Thunhiriya	19	0.75
	Wel maruk	41	0.67
Poly bag (550 mm)	Bajiri	18	1.75
	Gini thana	49	1.49
Bamboo device (550 mm) - Submerged	Ali maana	41	1.44
	Bajiri	13	0.58
	Batadella	12	0.65
	Beru	20	0.71
	Gini thana	44	2.18
	Iluk	20	0.63
	Thunhiriya	42	1.78
	Wel maruk	12	0.96
	Total	26	2.51

Appendix- M: Multiple Comparisons (LSD) of Plant height across the treatment.

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.
Control	Bamboo device (550 mm) on surface	-3.61	3.90	0.36
	Standard black polybag	-4.16	3.91	0.29
	Polybag (550 mm)	8.80	4.66	0.06
	Bamboo device (550 mm) submerged	-7.13	3.90	0.07
Bamboo device (550 mm) on surface	Control	3.61	3.90	0.36
	Standard black polybag	-0.55	3.84	0.89
	Polybag (550 mm)	12.41*	4.60	0.01
	Bamboo device (550 mm) submerged	-3.53	3.82	0.36
Standard black polybag	Control	4.16	3.91	0.29
	Bamboo device (550 mm) on surface	0.55	3.84	0.89
	Polybag (550 mm)	12.95*	4.61	0.01
	Bamboo device (550 mm) submerged	-2.98	3.84	0.44
Polybag (550 mm)	Control	-8.80	4.66	0.06
	Bamboo device (550 mm) on surface	-12.41	4.60	0.01
	Standard black polybag	-12.95*	4.61	0.01
	Bamboo device (550 mm) submerged	-15.93*	4.60	0.00
Bamboo device (550 mm) submerged	Control	7.13	3.90	0.07
	Bamboo device (550 mm) on surface	3.53	3.82	0.36
	Standard black polybag	2.98	3.84	0.44
	Polybag (550 mm)	15.93*	4.60	0.00

(* Denotes that the mean difference is significant at $p \leq 0.05$ level).

Appendix- N: Multiple Comparisons (LSD) of the No. of leaves /pot across the treatment.

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.
Control	Bamboo device (550 mm) on surface	-0.6	1.31	0.65
	Standard black polybag	-1.29	1.32	0.33
	Polybag (550 mm)	12.33*	1.61	0.00
	Bamboo device (550 mm) submerged	0.1	1.31	0.94
Bamboo device (550 mm) on surface	Control	0.6	1.31	0.65
	Standard black polybag	-0.69	1.29	0.60
	Polybag (550 mm)	12.93*	1.59	0.00
	Bamboo device (550 mm) submerged	0.7	1.29	0.59
Standard black polybag	Control	1.29	1.32	0.33
	Bamboo device (550 mm) on surface	0.69	1.29	0.60
	Polybag (550 mm)	13.62*	1.59	0.00
	Bamboo device (550 mm) submerged	1.38	1.29	0.28
Polybag (550 mm)	Control	-12.33*	1.61	0.00
	Bamboo device (550 mm) on surface	-12.93*	1.59	0.00
	Standard black polybag	-13.62*	1.59	0.00
	Bamboo device (550 mm) submerged	-12.24*	1.59	0.00
Bamboo device (550 mm) submerged	Control	-0.1	1.31	0.94
	Bamboo device (550 mm) on surface	-0.7	1.29	0.59
	Standard black polybag	-1.38	1.29	0.28
	Polybag (550 mm)	12.24*	1.59	0.00

(* Denotes the mean difference is significant at $p \leq 0.05$ level).

Appendix- O: Multiple Comparisons (LSD) Of the No. of leaves /pot across the treatment.

(I) Treatment	(J) Treatment	Mean Difference (I-J)	Std. Error	Sig.
Control	Bamboo device (550 mm) on surface	-0.58*	0.19	0.00
	Standard black polybag	-0.39*	0.19	0.04
	Polybag (550 mm)	0.82*	0.22	0.00
	Bamboo device (550 mm) submerged	-0.52*	0.19	0.01
Bamboo device (550 mm) on surface	Control	0.58*	0.19	0.00
	Standard black polybag	0.20	0.19	0.30
	Polybag (550 mm)	1.41*	0.21	0.00
	Bamboo device (550 mm) submerged	0.06	0.19	0.74
Standard black polybag	Control	0.39*	0.19	0.04
	Bamboo device (550 mm) on surface	-0.20	0.19	0.30
	Polybag (550 mm)	1.21*	0.21	0.00
	Bamboo device (550 mm) submerged	-0.13	0.19	0.48
Polybag (550 mm)	Control	-0.82*	0.22	0.00
	Bamboo device (550 mm) on surface	-1.41*	0.21	0.00
	Standard black polybag	-1.21*	0.21	0.00
	Bamboo device (550 mm) submerged	-1.34*	0.21	0.00
Bamboo device (550 mm) submerged	Control	0.52*	0.19	0.01
	Bamboo device (550 mm) on surface	-0.06	0.19	0.74
	Standard black polybag	0.13	0.19	0.48
	Polybag (550 mm)	1.34*	0.21	0.00

(* Denotes that the mean difference is significant at $p \leq 0.05$ level).