ENHANCING FODDER PRODUCTION THROUGH TREE BASED AGROFORESTRY SYSTEMS AND OPTIMUM NITROGEN DOSES

A THESIS

BY

FARHANA AFROSE
Student ID: 1601057
Session: 2023-2024
Semester: January-June, 2025

MASTER OF SCIENCE

IN

AGROFORESTRY AND ENVIRONMENT

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENT
HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY
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JUNE, 2025

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Submitted to

Department of Agroforestry and Environment

Hajee Mohammad Danesh Science and Technology University, Dinajpur

In partial fulfillment of the requirements of degree of

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Dedicated

To My

Respectable Parents

ACKNOWLEDGEMENTS

First of all, I praise to Almighty Allah for completing this work successfully. I also praise to my respected parents, who help and inspiring me for my higher studies.

I express my heartiest respect, my deep sense of gratitude and sincere, profound appreciation to my Supervisor Prof. Dr. Md. Shafiqul Bari, Department of Agroforestry and Environment, Hajee Mohammad Danesh and Technology University (HSTU), Dinajpur for his sincere guidance, scholastic and continuous supervision, constructive suggestion and constant inspiration throughout the course and in preparation of the thesis.

I also express my heartiest respect and profound appreciation to my Co-supervisor to Israt Jahan Sarmin, Assistant Professor, HSTU, Dinajpur for his utmost cooperation and constructive suggestions to conduct the research work as well as preparation of this thesis.

It is my great pleasure and privilege to express Cordial thanks and honors to Prof. Dr. Md. Shoaibur Rahman, Chairman, Department of Agroforestry and Environment, HSTU, Dinajpur for providing the facilities to conduct the experiment and for their valuable advice, sympathetic co-operation and inspirations of this study.

I am pleased to all stuff and workers of Agroforestry and Environment Department, HSTU for their valuable and sincere help in carrying out the research work.

I would like to extend my special thanks to Mahmood Abubakar Bashir, a dedicated PhD student, for his valuable guidance, support, and encouragement throughout my thesis journey.

Finally, I like to thank to my friends for their help and encouragement in my research work. I profound gratitude and deepest appreciation to my parents, and my relatives for their never-ending prayer, encouragement, sacrifice and dedicated efforts to educate me to this level.

June, 2025 *The Author*

ABSTRACT

This study was done at the Research Field of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University (HSTU), Dinajpur to assess the effects of nitrogen fertilization and agroforestry systems on the growth, morphological traits and yield performance of Napier grass (Pennisetum purpureum). The experiment was laid out in a 2-factor randomized complete block design (RCBD) with three replications. Factor A consisted of four nitrogen levels, N_1 (0 kg/ha), N_2 (50 kg/ha), N_3 (100 kg/ha) and N_4 (150 kg/ha), whilst factor B had three production system, S_1 (Napier sole cropping), S_2 (Neem + Napier) and S_3 (Mahagoni + Napier). Results demonstrated that nitrogen fertilization and agroforestry systems had a significant effect on plant height, collar diameter, number of tillers, leaf traits (length, breadth and number of leaves), green forage yield and dry matter content. Nitrogen application had a significant positive effect on vegetative growth and forage yield, with 150 kgN/ha producing significantly more forage during the growing season. Napier grass grown as sole cropping produced greater than tree based systems due to low competition. Neem surprised by supporting moderate growth with additional soil benefits, while Mahagoni trees reduced Napier performance due to shading and resource competition. Interaction effects were not statistically different in most instances but indicated that in the production systems, tree-based systems (N_2S_3 and N_3S_2) potentially demonstrated considerable growth, tillering and leaves with intermediate N levels (50-100 kg/ha). The implications of this are that site-specific nutrient inputs and management should be taken into account. Dry matter was less susceptible to nitrogen, although DM did vary within systems with sole cropping producing the highest DM content. The study underscores the potential of integrating optimized nitrogen management with suitable agroforestry components to sustainably enhance Napier fodder production.

Keywords: Napier, fodder production, nitrogen fertilization, tree-based agroforestry systems

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CHAPTER I
INTRODUCTION

Livestock farming occupies a central position in Bangladesh's agriculture, which continues to be the backbone of the country's economy. It not only supplies food and cash income but also sustains the livelihood of millions of rural families. Of all livestock, cattle play a most vital role supplying the lion's share of the country's milk, meat, and hides. In fact, cattle contribute almost 98% of Bangladesh's total milk production (DLS, 2021). Despite such significance, the development of the livestock sub-sector has been severely hampered by an ongoing crisis the chronic lack of quality fodder. As per recent estimates, the country has over a 40% deficit in dry matter, a 65% gap in crude protein, and a 60% gap in metabolizable energy to feed its livestock (DLS, 2019; Roy *et al*., 2021). Green fodder whether from grazing or cut-and-carry systems hardly addresses the minimum daily need, with availability too often dipping below 2.5 kg of fresh grass per animal (DLS, 2019). This nutritional deficit shows up directly as lower milk and meat production, slower animal growth, and greater susceptibility to disease (Migwi, 1997; Uddin and Dhar, 2018). The issue is only worsening as the need for animal protein is rising fast in tandem with the increasing population of the country and the world. One of the underlying structural issues is how land is allocated. In Bangladesh, roughly 83% of arable land is allocated to food grain crops, yet a paltry 0.1% is allocated for fodder cultivation (BBS, 2015; Uddin and Dhar, 2018). Add to this the pressure from rapid urban expansion and industrial development and the result is a shrinking space for dedicated fodder production. Under these constraints, conventional solutions are no longer enough. There is an urgent need for alternative, land-efficient strategies to sustainably boost fodder output without compromising food crop production.

Agroforestry an integrated system that involves integrating trees with crops and/or livestock on the same land has proved to be a practical and ecologically viable answer to many of Bangladesh's agricultural questions. By marrying biodiversity with productivity, agroforestry not only maximizes land use but also improves soil health, buffers climate effects, and diversifies farm income (Nair, 1993; Rahman *et al.,* 2018). Unlike monoculture farming systems, agroforestry produces a diversity of outputs ranging from food and fodder to timber and environmental services rendering it highly resilient and adaptable (Jose, 2009). In Bangladesh, agroforestry is making inroads among farmers and policymakers alike. Research in places such as Dinajpur, Rajshahi, and Chapainawabgonj has established that rice-based agroforestry systems tend to outperform conventional cropping systems, not just in terms of profit but also land-use efficiency (Hossain *et al*., 2018). Trees such as mango, jackfruit, guava, litchi, and Indian jujube (*Ziziphus mauritiana*) have proved not only to have high commercial value but also robust ecological advantages, including carbon sequestration and soil enrichment (Talukder *et al*., 2021). What distinguishes agroforestry is its broad-spectrum value: it works for ecological sustainability while building economic resilience. Women, particularly, tend to find enlarged roles in these systems whether through managing fodder trees or marketing non-timber forest products rendering agroforestry a social inclusion tool as well (Alam *et al*., 2015; Hossain *et al*., 2018).

One of the most viable crops for application in the integration of fodder into agroforestry is Napier grass (*Pennisetum purpureum* Schumach), or elephant grass. Due to its rapid growth, high biomass yield, and ability to thrive under diverse conditions, Napier grass is appropriate to the climatic and soil conditions of Bangladesh. It also recuperates quickly after being cut and can be harvested between six or seven times a year making it an excellent crop for continuous fodder supply (Cook *et al*., 2005; Islam *et al*., 2021). Farmers in places such as Rangpur are already benefiting from high-yielding hybrid hybrids, and they are not only harvesting more but are enjoying improved profit margins too (BSS, 2025). But despite all its high production potential, Napier grass is generally poor in nutritional content as a whole and crude protein and energy content specifically unless properly managed with respect to soil fertility. Where agronomic means such as strategic fertilizer application come in. Literature suggests that by utilizing well-adjusted input strategies, the nutritional value of Napier grass can readily be enhanced so as to contribute much more meaningfully to animal productivity (Islam *et al*., 2021). In some cases, optimized management has been known to double useful forage per hectare.

The inclusion of tree species into Napier-based systems has yet another dimension of resilience and productivity. Many trees, especially the leguminous trees, can act as a supplementary source of fodder during dry spells, thereby stabilizing seasonal fluctuation in feed availability (Dawson *et al.,* 2014). Above all, the trees have the capacity to fix atmospheric nitrogen, thereby naturally feeding the plants and reducing chemical fertilizer application rates (Young, 1989; Gama-Rodrigues *et al.*, 2011). This. nitrification is not just valuable to the trees but also promotes growth and quality of Napier grass. n grown in the vicinity. Apart from nutritional input, fodder trees provide n. ecosystem services like shade provision, erosion prevention, habitat. provision of beneficial insects, and improved microclimates. They may also yield timber, fruit, or other valuable farm products based on the species to further increase farm revenue (Jose, 2009; Talukder *et al.*, 2021). Some of the tree species like *Ficus hispida*, *Artocarpus rigidus,* and *Ziziphus mauritiana* have shown potential as suitable counterparts in integrated fodder systems in Bangladesh. The choice of trees should be strategic and consider the prevailing environment in the area, compatibility with Napier grass, and ease of management.

Nitrogen is one of the most fundamental nutrients needed for plant growth, especially in high-demanding crops like Napier grass. Nitrogen directly influences biomass yield and protein content which are both vital during the manufacture of quality animal feed (Talukder *et al.,* 2021; Khalid *et al.,* 2003). But increasing nitrogen application is not a solution. Elevated application might lead to environmental problems such as nitrate leaching and greenhouse gas emissions. This compels one to establish the correct amount of nitrogen that would be capable of maximizing Napier's growth without compromising soil and environmental integrity. In agroforestry ecosystems, where legume trees are naturally nitrogen-fertilizing soils, things get more complicated. One needs to understand how such indigenous nitrogen inputs interact with fertilizers used to direct balanced and sustainable nutrient management strategies. Previous studies have shown that urea fertilization may enhance valuable growth characteristics such as plant height, leaf diameter, and overall yield in Napier grass (Talukder *et al.,* 2021). However, the response is varied with several local factors including the nature of soil fertility, climate, and Napier variety. Research that is tailored to Bangladeshi agro-ecological conditions is necessary to develop accurate, site-specific recommendations.

Bangladesh is working hard to strengthen its food system amid population growth, climate challenges, and limited arable land, the livestock sector is under mounting pressure. Meeting the rising demand for animal products will require innovative ways to increase fodder availability without expanding land use. Agroforestry systems especially those combining Napier grass with fodder-friendly trees present an attractive pathway toward sustainable intensification. Despite the growing popularity of Napier grass, there is still a lack of concrete, field-based data on how best to integrate it with tree species and manage nitrogen levels effectively. This study aims to fill that gap by exploring how different combinations of Napier, tree species, and nitrogen doses affect fodder yield, quality, and soil health in Bangladesh. The objectives of this research are;

1. To ascertain the optimal nitrogen doses required for the successful cultivation of Napier fodder within the plantation featuring Neem and Mahagoni trees.
2. To evaluate the advantages of this approach in terms of improved utilization of land space and other natural resources along with an increased return per unit, and
3. To evaluate the yield potential of Napier grass cultivation within the agroforestry system underpinned by Neem and Mahagoni trees.

CHAPTER II

REVIEW OF LITERATURE

The evaluation of optimum nitrogen dose for the production of Napier grass as fodder in forest tree-based agroforestry practices across the world including Bangladesh, very limited research works have been conducted. An attempt has been made to find out the optimum nitrogen dose for the production of Napier grass as fodder in forest tree-based agroforestry practices. To facilitate the research works different literatures have been reviewed in this chapter under the following headings.

2.1 Fodder Production in Bangladesh through the Integration of Napier Grass

Bangladesh continues to face a severe and growing deficit in livestock fodder. Recent data highlight the scale of this problem over 40% of the required dry matter, 65% of crude protein, and 60% of metabolizable energy are missing from the country's current feed supply for its livestock population (DLS, 2019; Roy *et al.*, 2021). The availability of fresh green grass either from natural grazing or through cut-and-carry systems remains well below recommended levels, often providing less than 2.5 kilograms per animal per day (DLS, 2019). The consequences are clear: underfed animals produce less milk and meat, grow more slowly, and are more susceptible to disease and stress (Migwi, 1997; Uddin and Dhar, 2018).

Adding to the urgency, the demand for animal protein is rapidly increasing, driven by Bangladesh's expanding population and the broader global trend, with projections showing the global population reaching 9 billion by 2050. This growing demand puts even more pressure on an already overstretched fodder system (DLS, 2019).

At the same time, land-use patterns in Bangladesh present another serious obstacle. About 83% of the country's cultivable land is used for growing cereals, while only a tiny fraction just 0.1% is designated for fodder cultivation (BBS, 2015; Uddin and Dhar, 2018). The rapid pace of urbanization and industrial expansion only adds to the competition for land. Under these conditions, expanding conventional fodder production becomes increasingly difficult, if not impossible. This makes it crucial to explore smarter, more integrated approaches to increase fodder availability without demanding more land. In this context, Napier grass (*Pennisetum purpureum* Schumach) has emerged as a strong candidate to help close the feed gap. This section explores how Napier grass can be utilized more effectively as a key part of sustainable fodder production strategies in Bangladesh especially when integrated into agroforestry systems and supported by proper nutrient management.

2.1.1 Napier Grass: A Game-Changer for Fodder Supply in Bangladesh

Napier grass, often referred to as elephant grass, has long been recognized across tropical and subtropical regions for its high yield potential and adaptability (Cook *et al*., 2005). In countries like Bangladesh, where arable land is limited and farming conditions are diverse, Napier offers several advantages: fast growth, the ability to regenerate quickly after cutting, drought tolerance, and strong performance across various soil types (Islam *et al*., 2021). Its high photosynthetic efficiency and ability to thrive even in suboptimal conditions further strengthen its case as a vital fodder resource.

Over the years, Bangladeshi farmers have gradually increased their reliance on Napier grass. Hybrid varieties have been introduced in districts like Rangpur, where many farmers now report high yields and good profits from its cultivation (BSS, 2025). One of Napier's biggest advantages is its capacity for multiple harvests in a year typically six to seven cuts ensuring a near-continuous supply of fresh fodder (BSS, 2025).

That said, high biomass alone isn't enough. Under traditional management conditions, Napier grass often falls short in terms of crude protein (CP) and metabolizable energy (ME), both essential for livestock nutrition (Cook *et al.,* 2005). This underscores the importance of good management particularly optimized fertilization and timely harvesting to enhance the grass's feed quality. With well-planned nutrient support and proper agronomic practices, researchers have shown that Napier's nutritional profile and overall productivity can be significantly improved (Islam *et al*., 2021). For Bangladesh, this opens the door to doubling usable forage output without needing additional land.

2.1.2 Cultivation and Management Practices for Optimizing Napier Grass Production

Napier grass adapts well to a wide range of soils from sandy loam to clay provided they are well-drained. For optimal performance, fertile loamy soils with a pH between 5.5 and 7.0 are considered ideal (Chaparro *et al*., 1995). In Bangladesh's varied agro-ecological zones, choosing fields with moderate to good organic matter or amending them with compost can give Napier a strong start. Proper land preparation, such as plowing and harrowing, is essential to create the fine seedbed needed for successful establishment.

Farmers in Bangladesh typically propagate Napier grass through stem cuttings or root splits. Stem cuttings, ideally 2–3 nodes long, are planted at an angle or laid flat, ensuring at least one node is in contact with the soil. Root splits, which include parts of the rhizome and root system, also work well and tend to establish quickly. Spacing is a key factor in achieving optimal yields common arrangements range from 50×50 cm to 100×50 cm depending on soil conditions, variety, and cutting frequency (Islam *et al.*, 2021). While tighter spacing can boost early yields, it may require more frequent harvesting to prevent lodging.

Nutrient management especially nitrogen application is critical. Napier is a nutrient-hungry crop, and nitrogen is the primary driver of its growth and protein content. Research from Bangladesh and similar climates consistently shows that nitrogen application improves plant height, leaf area, biomass, and crude protein content (Khalid *et al.*, 2003; Talukder *et al.*, 2021). General guidelines recommend annual nitrogen applications ranging from 150–300 kg per hectare, ideally split into multiple doses applied after each harvest. Phosphorus (40–60 kg/ha) and potassium (60–80 kg/ha) are also important, as is the use of organic manure (Miah *et al.*, 2020; Uddin *et al.*, 2010). Split applications reduce nutrient losses and improve efficiency, especially in rainfed systems.

Though it's relatively drought-tolerant, Napier requires consistent moisture for high yields, particularly during regrowth phases. Irrigating during dry spells especially after fertilizer application can significantly boost productivity. However, the grass does not tolerate waterlogging, so proper drainage is essential. Weed control is most important during the early establishment period. Regular hand-weeding or careful herbicide use can help Napier take off. Once established, its dense canopy generally keeps most weeds at bay. Cutting frequency also matters too early and it depletes reserves; too late and the feed quality drops due to fiber build-up. The ideal harvest time is when plants reach 1–1.5 meters in height, usually every 45 to 60 days. A stubble height of 10–15 cm promotes faster regrowth, and under good conditions, farmers can expect 6–7 harvests per year (Islam *et al.*, 2021).

2.1.3 Enhancing Napier Grass Production through Integration and Improved Practices

Integrating Napier with forage legumes or suitable trees can significantly enhance the quality and sustainability of fodder production. Leguminous species like cowpea, desmodium, or stylo fix atmospheric nitrogen and help improve soil fertility, all while boosting the protein content of the forage mix (Muir *et al.*, 2011). This is especially beneficial for smallholders, who often lack access to expensive fertilizers.

Adding nitrogen-fixing trees to Napier plots brings even more benefits. Species like *Leucaena leucocephala*, *Gliricidia sepium*, *Sesbania grandiflora*, *Moringa oleifera*, and native *Ficus* varieties commonly found in Bangladesh can provide high-protein browse especially useful during dry periods (Dawson *et al*., 2014). These trees enrich the soil, reduce the need for synthetic fertilizers, and improve the overall structure and health of the land (Gama-Rodrigues *et al*., 2011; Young, 1989).

Besides supplying fodder, trees also create microclimates that reduce heat stress for livestock and improve water-use efficiency in the grass layer below. Over time, such systems offer not only better feed security but also additional sources of income through timber, fruits, and other non-timber products (Jose, 2009; Talukder *et al*., 2021). The right combination of trees and grass will depend on local soil conditions, climate, and farmer goals.

Since Napier grass grows rapidly during the monsoon and slows down in the dry season, surplus fodder often goes to waste. Processing it into silage or hay can ensure a more balanced year-round supply. Silage produced by fermenting chopped Napier under anaerobic conditions preserves its nutritional quality and is especially suited for wet seasons. Hay involves drying the grass until moisture drops below 15%. Though Napier's thick stems make hay-making slightly more difficult, chopping or crushing before drying can help (Uddin and Dhar, 2018). These simple techniques can make a big difference for smallholders.

Local research institutions like BARI and BLRI are already working to develop and promote improved Napier varieties with higher protein content and resistance to pests and diseases (DLS, 2019). The success of hybrid Napier in several districts shows that the potential is real what's needed now is wider adoption and better management practices to match.

2.1.4 Challenges and Constraints in Napier Grass Cultivation in Bangladesh

Despite its potential, farmers still face several hurdles when it comes to cultivating Napier grass. One of the biggest challenges is the availability of clean, disease-free planting material. Informal sources often provide substandard cuttings or root splits, leading to poor crop establishment. Establishing community nurseries or encouraging commercial propagation units could help address this gap. Another major issue is land availability. With most cultivable land already devoted to food crops, allocating space for fodder is difficult. This makes integrated systems such as growing Napier along field bunds, in homestead gardens, or under tree plantations all the more important (Uddin and Dhar, 2018).

A lack of knowledge also limits productivity. Many farmers are unaware of the best practices for planting, fertilizing, harvesting, and preserving Napier grass (Uddin and Dhar, 2018). Strengthening extension services and offering hands-on training can make a huge difference here. Napier is generally resilient; it can be affected by stem borers and fungal diseases. Outbreaks, though localized, can be serious, so there is a need for pest-resistant varieties and better pest management practices. Even when fodder is abundant, post-harvest losses are common due to poor storage and low adoption of preservation techniques. Promoting silage and hay-making among farmers could drastically improve year-round availability. The initial costs planting material, fertilizers, labor can be a deterrent, especially for small-scale farmers. Demonstrating the financial benefits through model plots and offering early support could encourage wider adoption. Creating local fodder markets could also give farmers more incentive to grow Napier beyond subsistence levels.

Ultimately, improving fodder production with Napier grass directly enhances livestock performance better milk yields, faster weight gain, and improved reproductive outcomes. This translates into higher incomes and more resilient rural livelihoods (DLS, 2019). At the environmental level, cultivating Napier reduces the pressure on forest lands and supports more sustainable grazing practices. The plant's rapid growth also contributes to carbon sequestration. When grown alongside trees in agroforestry systems, this benefit is amplified supporting climate mitigation goals while boosting farm productivity (Rahman *et al*., 2019; Talukder *et al*., 2021).

2.2 The Role of Nitrogen in Napier Grass Production

Nitrogen is arguably the most essential nutrient when it comes to growing healthy, high-yielding crops. It plays a fundamental role in several plant processes from building chlorophyll, the molecule at the heart of photosynthesis, to forming the proteins, enzymes, and DNA that drive plant growth and development (Marschner, 2012). For forage crops like Napier grass, which are grown primarily for their lush, leafy biomass, nitrogen is especially important. Without enough of it, plants simply can't grow to their full potential, and the quality of the feed they provide also suffers.

2.2.1 Meeting the High Nitrogen Demand of Napier Grass

Napier grass, a robust C4 perennial, is known for its fast growth and large biomass output. Like other C4 species, it’s quite efficient in using water and nutrients but that efficiency doesn’t mean it has a low appetite. In fact, its rapid growth creates a steady, high demand for nutrients especially nitrogen. Without enough nitrogen in the soil, Napier struggles to reach its potential. Plants often show visible signs like yellowing leaves, reduced growth, and thinner canopies, which ultimately lead to lower yields and less nutritious fodder (Khalid *et al*., 2003; Talukder *et al*., 2021).

A growing body of research both in Bangladesh and similar agricultural settings has shown just how vital nitrogen is for maximizing Napier grass production. Numerous field trials have demonstrated that as nitrogen application increases, so do green biomass and dry matter yields (Islam *et al*., 2021; Uddin *et al*., 2010). For example, Islam and colleagues (2021) found that applying higher doses of nitrogen significantly boosted fodder yields, though the gains begin to level off after a certain point. Similar findings by Khalid *et al*. (2003) showed that urea application led to taller plants with broader leaves, and much higher biomass overall. The message is clear: nitrogen is often the main limiting factor when it comes to growing Napier grass effectively in Bangladesh.

But yield isn't the only concern quality matters too. Nitrogen plays a direct role in boosting the crude protein (CP) content of Napier grass, which is a critical factor for animal health, milk production, and growth. As a key element in amino acids and proteins, nitrogen helps plants synthesize the nutrients that livestock rely on. Several studies have found that applying nitrogen not only increases the overall biomass but also raises the crude protein levels significantly (Islam *et al*., 2021; Uddin *et al*., 2010). Higher protein content also tends to make the forage more palatable and digestible, which means animals are more likely to eat more and gain more from it. That said, it's worth noting that going overboard with nitrogen isn't always a good thing. Too much can sometimes lead to watery forage with lower dry matter content, although this usually only becomes a problem at very high application rates. For most practical purposes, the right nitrogen management can dramatically improve both the quantity and quality of Napier grass making it more valuable as animal feed.

2.2.2 Getting Nitrogen Management Right for Sustainable Yields

Given how fast Napier grass grows and the fact that it's often harvested several times a year applying nitrogen all at once is far from ideal. It leads to inefficient uptake, and a lot of the fertilizer can be lost through leaching or volatilization. Instead, most experts recommend split applications: dividing the total nitrogen dose across multiple intervals, typically after each cutting (Islam *et al*., 2021; Uddin *et al*., 2010). For instance, if you're planning to apply 200 kg of nitrogen per hectare over the year, you might break that into five or six doses of around 30–40 kg each.

This approach ensures that the plant always has enough nitrogen during its critical regrowth phases, without overwhelming the soil or the plant. It also makes better economic and environmental sense. While chemical fertilizers like urea are commonly used and effective, relying solely on them isn't always sustainable especially for smallholder farmers. A more balanced strategy, often referred to as Integrated Nutrient Management (INM), combines synthetic fertilizers with organic sources like cow dung, compost, or green manure. These organic materials not only supply nitrogen slowly and steadily but also improve soil texture, boost microbial activity, and help retain water (Miah *et al*., 2020).

Napier grass can also benefit from being grown alongside nitrogen-fixing plants. Intercropping with forage legumes or planting Napier under nitrogen-fixing trees, like *Leucaena leucocephala* or *Gliricidia sepium,* adds another layer of sustainability (Gama-Rodrigues *et al*., 2011; Young, 1989). These companion plants contribute biologically fixed nitrogen to the soil, reducing the need for chemical fertilizers. Over time, this helps build soil health and reduces input costs an especially important factor for farmers working on limited budgets.

That said, like any input, nitrogen needs to be managed carefully. Overuse can lead to serious environmental problems, such as nitrate leaching into groundwater or the release of nitrous oxide a greenhouse gas that's far more potent than carbon dioxide. So it's not just about adding more nitrogen, but about finding the right balance one that meets the plant's needs without harming the environment or wasting resources (Talukder *et al*., 2021).

2.3 Boosting Fodder Output by Integrating Napier Grass with Neem and Mahagoni Trees

Agroforestry holds enormous potential for improving fodder availability in land-limited countries like Bangladesh. Integrating Napier grass with multi-purpose trees such as Neem (*Azadirachta indica*) and Mahagoni (*Swietenia macrophylla* or *Swietenia mahagoni*) can lead to more productive and sustainable fodder systems. While these trees are not direct sources of livestock feed, their indirect contributions to soil fertility, microclimate regulation, pest control, and farm income can significantly enhance Napier grass production and overall farm resilience.

2.3.1 Neem (*Azadirachta indica*): More Than Just a Medicinal Tree

Neem is a familiar sight throughout Bangladesh grown along roadsides, in homestead gardens, and across rural landscapes. It’s known for its deep cultural value, medicinal uses, natural pest-repellent compounds like azadirachtin, and quality timber (Islam *et al*., 2011; Roy *et al*., 2007).

Although its leaves aren’t typically used as livestock feed due to their bitter taste and anti-nutritional properties (Akhtar *et al*., 2002), Neem still plays a helpful role in supporting fodder systems. For instance, Neem leaves and decaying litter improve the soil by adding organic matter, enhancing its structure and water-holding capacity (Khan *et al*., 2009). This enriched soil environment benefits Napier grass, which thrives in well-structured and nutrient-rich conditions.

Another key advantage of Neem is its ability to create a more favorable microclimate. Its shade reduces soil moisture loss and can help lower extreme ground temperatures—something that becomes especially valuable during the dry, hot months in Bangladesh (Rahman *et al*., 2018). Its bioactive compounds may also deter soil pests, creating a less hostile environment for Napier growth (Singh *et al*., 1999).

Beyond ecological benefits, Neem trees can also support farm income. Their seeds are used for oil extraction, their bark and leaves have medicinal uses, and the timber fetches a decent market price. This diversified income can indirectly help farmers invest in Napier cultivation for example, through buying improved planting materials or investing in irrigation during dry spells.

2.3.2 Mahagoni (*Swietenia macrophylla*): The Timber Tree with Hidden Benefits

Mahagoni is one of the most widely planted timber species in Bangladesh. It’s known for its high-quality, durable wood and is often planted along boundaries, in farm forests, or in homestead areas (Rahman *et al*., 2019; Talukder *et al*., 2021). While Mahagoni leaves are not fed to livestock, the tree brings other valuable contributions to an integrated fodder system.

Its deep root system plays an important ecological role: pulling nutrients up from the subsoil and depositing them on the surface through leaf fall and decomposition. This nutrient cycling enriches the topsoil, giving Napier grass access to more available nutrients without additional fertilizer input (Gama-Rodrigues *et al*., 2011).

Mahagoni trees also help regulate the environment. Their shade offers relief from extreme heat for both Napier grass and livestock. During the hottest months, this protection can reduce plant stress and help maintain fodder growth (Jose, 2009). On sloping lands or flood-prone areas, Mahagoni's extensive roots can stabilize the soil, prevent erosion and safeguard the land used for fodder cultivation (Young, 1989).

Importantly, the economic return from Mahagoni timber gives farmers a long-term asset. This financial security can be reinvested in short-term needs, such as purchasing quality fertilizers, investing in pest control, or expanding Napier cultivation. In this way, Mahagoni supports fodder production not by direct feeding but by strengthening the overall farming system.

2.3.3 Working Together: Neem, Mahagoni, and Napier in Synergy

When integrated thoughtfully, Neem and Mahagoni trees can work in harmony with Napier grass to create a productive, resilient, and sustainable fodder system. Leaf litter from both trees enriches the soil over time, reducing the dependence on synthetic fertilizers and lowering input costs (Miah *et al.*, 2020). While canopy shade from the trees could potentially reduce sunlight for Napier grass, this can be managed through smart spacing and regular pruning. In the context of Bangladesh's climate, some shade can actually be beneficial helping conserve moisture and shielding Napier grass from heat stress during dry periods (Rahman *et al.*, 2018).

Neem's natural pest-repellent properties may even offer a protective halo effect in the system discouraging pests from attacking Napier grass without the need for chemical pesticides. This could result in healthier plants and fewer crop losses. Another major benefit is system diversification. Farmers don't have to rely solely on fodder for income. Neem provides medicinal products and oil, Mahagoni offers valuable timber, and Napier delivers a steady supply of high-yield green forage. This mix of outputs increases economic resilience, especially in tough seasons, and helps ensure year-round fodder availability (Rahman *et al.*, 2018).

By combining the strengths of each species, integrated systems with Neem, Mahagoni, and Napier grass can meet both ecological and economic goals. They provide a path forward for improving livestock feed security in Bangladesh without requiring more land or heavier chemical inputs.

CHAPTER III

MATERIALS AND METHODS

An evaluation to determine the optimum nitrogen dose for the production of Napier grass as fodder in forest tree-based agroforestry practices across the world including Bangladesh. In this chapter, the materials used and methodology followed during the experimental period are described in details.

3.1 Experimental site

The experiment was conducted in the Research Field of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur.

3.2 Research duration

The experiment was conducted from January to December, 2024.

3.3 Climate

The geographical location of the site is between 25° 13' latitude and 88° 23' longitude and about 37.5m above the sea level. It is characterized by heavy rainfall from July to August and scanty rainfall in the rest period of the year. About 80 to 90% rainfall is received between June to September. The remaining 10 to 20% rainfall is received during November to April (Zeni *et al*., 2015), presented in Appendix I.

3.4 Planting materials

The experiment was setup at the existing three fruit tree orchards of the field laboratory of the department of agroforestry and environment, HSTU, Dinajpur. The structure of the orchards is:

a) Neem (*Azadirachta indica*)

- Spacings: 6 m × 6 m; i.e. 317 trees ha^{-1}
- Planting geometry: Row planting
- Planting direction: North-South
- Date of planting: August 2005

b) Mahagoni (*Swietenia macrophylla*)

- Spacings: 6 m × 6 m; i.e. 317 trees ha^{-1}
- Planting geometry: Row planting
- Planting direction: North-South
- Date of planting: August 2015

c) Napier fodder (ground layer) establishment: BLRI Napier-5 (*Penicitum peripurium* Var. 5) was cultivated as per standard protocol. 15 cuttings were used in each plot in each system (Open, Neem and Mahagoni), 180 total in each system.

3.5 Experimental treatments and design

It was two factors RCBD designed experiment. The two factors was:

Factor A: Production systems

1. N_1= 0 kg N per hectare
2. N_2= 50 kg N per hectare
3. N_3= 100 kg N per hectare
4. N_4= 150 kg N per hectare

Factor B: Nitrogen Fertilizations

1. S_1= Napier sole cropping
2. S_2= Neem + Napier fodder
3. S_3= Mahagoni + Napier fodder

3.6 Soil used for Experiment

The experimental field was prepared by ploughing and harrowing, later, plots are made according to number of treatments to accommodate all the three systems. The soil belongs to the Old Himalayan Piedmont Plain (AEZ 1). The soil samples used in the pots were dried, and mixed thoroughly. The soil samples were analyzed in the Soil Resource Development Institute (SRDI), Dinajpur. The result of soil analysis has been presented in Appendix II.

3.7 Fertilizer application

The application of fertilizer in the experimental plots was done after soil preparations and labelling. Organic matter was applied uniformly into the soil in all the 16 plots and later different doses of nitrogen fertilizer was applied at recommended treatments before planting. The fertilizers doses according the treatments are as follows:

Treatment	Nitrogen Doses (Kg ha^{-1})
N_1	0
N_2	50
N_3	100
N_4	150

3.8 Planting

Napier cutting was planted on the same day morning and afternoon in all the 36 plots. Fifteen cuttings (15) were planted per each plot with plant spacing of 60cm by 80cm distance.

3.9 Intercultural Operations

Weeding and irrigation: At some time of the growing period, weeds should be removed from the plots and in case of rainfall absence, irrigation should be done to maintain field capacity moisture content.

Gap filling and thinning: Gap filling was done for failed germinated plants in all the plots and thinning was maintain the required spacing of Napier within the plots

3.10 Harvesting and Cutting interval

Napier grass was harvested after every 3 months from the planting date within the maximum of 90 DAP. Cutting was at about 5cm from the base of the plant, in each case it should made into bunches, tied and tagged for further records purposes.

3.11 Data collection

In this experiment the following observations was considered in respect of plant growth and yield performance. However, the benefits cost ratio will also be calculating to identify the suitability of the systems.

3.11.1 Quantitative Parameters

Plant heights (cm): The plant height was measured at each cut by selecting ten plants randomly in each plot with the help of meter ruler from the base of a plant to its highest growing point.

Collar diameter (cm): Thickness of ten randomly selected tillers from each plot will be measured from the collar point with the help of Vernier caliper during harvesting time.

Number of Tiller: Tiller number was counted from each plot randomly at every cut, each till was bunched and tagged.

Number of leaves: The number of leaves was counted from five selected plant in each plot

Leave length (cm): Length of the leaf was measure from randomly selected plant in each plots using a meter ruler.

Leave breadth (cm): The breadth of the leaf was obtained with help of centimetre scale ruler in each plot.

Yield (t ha^{-1}): After harvest, all plant in a plot at appropriate stubble height and weight was determined using digital weighing balance. The total yield per plot was converted into tonnes per hectare (ha).

Dry Matter (DM): The sample is dried in an oven at 105°C until a constant weight is obtained. The difference in weight before and after drying is used to calculate the dry matter content. DM is important for comparing the nutrient content of feeds on a consistent basis. The formula below can be used to calculate the DM as a percentage of the original sample weight as recommended by Shreve *et al*. (2006).

$$\mathrm{DM}(\%) = \left(\frac{\text{Weight after drying}}{\text{Initial sample Weight}}\right) \times 100$$

3.12 Statistical Analysis

All data collected from various parameters under this experiment will statistically be analyzed using statistical software R studio to find out the significance of the treatment effects. The means for all the treatments was calculated and analysis of variance (ANOVA) for all the characters was performed by the F-test. The significance of difference between the pair of means and Correlation analysis was use considering Least Significant Difference (LSD) test at 5% level of significance to obtain the pair wise comparison of the means.

CHAPTER IV

RESULTS AND DISCUSSION

This chapter includes the results obtained from the experiment.

4.1 Plant heights (cm)

Effect of Nitrogen Fertilizer on Plant Height

As presented in Table 1, nitrogen application significantly affected Napier plant height, especially at 30 and 90 DAS, with increasing nitrogen rates resulting in increased growth. The highest plant height at 30 DAS (85.58 cm) and 90 DAS (223.11 cm) was observed under N_4 treatment (150 kg N/ha), while the control (N_1, 0 kg N/ha) showed the lowest heights. This aligns with previous studies that highlighted nitrogen as a vital macronutrient promoting vegetative growth, especially in grasses like Napier (Mpairwe *et al.*, 2003; Agyin-Birikorang *et al.*, 2020). Nitrogen enhances chlorophyll content, photosynthetic activity, and cell division, leading to increased biomass and plant height (Ramesh *et al.*, 2005). However, at 60 DAS, the trend was slightly inconsistent, where N_1 (162.73 cm) performed better than higher doses, possibly due to early-stage nutrient immobilization or soil nitrogen mineralization effects not captured in the immediate aftermath of fertilization. These results confirm findings by Ghosh *et al*. (2001), who reported that nitrogen fertilization positively correlates with biomass accumulation and tiller development in forage crops, particularly Napier grass, which has high nitrogen demand due to its rapid growth rate.

Table 01. Effect of nitrogen fertilizer on plant height of Napier

Fertilizer	**Plant heights (cm)**		
	30 DAS	**60 DAS**	**90 DAS**
N_1	63.83 c	162.73 a	180.01 c
N_2	65.35 c	154.91 ab	186.21 c
N_3	77.65 b	143.52 bc	205.78 b
N_4	85.58 a	139.21 c	223.11 a
LSD	6.80	12.14	16.98
CV (%)	7.15	6.22	6.57
LS	**	*	**

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare.

Effect of Agroforestry System on Plant Height

Table 2 presents the impact of different agroforestry systems on Napier height. At 60 and 90 DAS, the differences were statistically significant. Napier sole cropping (S_1) consistently resulted in the tallest plants, followed by Neem + Napier (S_2), and Mahagoni + Napier (S_3), which recorded the shortest heights. The reduced growth under tree-based systems (S_2 and S_3) may be attributed to shading effects, competition for light, nutrients, and water between trees and Napier grass (Nair, 1993). Mahagoni (*Swietenia mahagoni*) in particular, with its dense canopy, may create a more pronounced shading impact compared to Neem (*Azadirachta indica*), thereby limiting photosynthesis and plant elongation. These results are in line with findings by Singh *et al.* (2006), who observed that grass yields and heights were lower under dense tree canopies due to limited light penetration.

Table 02. Effect of agroforestry system on plant height of Napier

System	**Plant heights (cm)**		
	30 DAS	**60 DAS**	**90 DAS**
S_1	75.93 a	163.84 a	216.17 a
S_2	72.93 ab	149.02 b	195.75 b
S_3	70.45 b	137.42 c	184.42 b
LSD	5.33	9.51	13.32
CV (%)	7.15	6.22	6.57
LS	NS	**	**

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

Combined Effect of Fertilizer and Agroforestry System

The interaction effects illustrated in Table 3 suggest that the response of Napier to nitrogen fertilization varies with the agroforestry system in place. Although the statistical analysis indicates non-significance (NS) across all stages (30, 60, and 90 DAS), some trends are noteworthy. The highest plant height at 90 DAS (258.00 cm) was recorded under the combination of N_4S_1 (150 kg N/ha with Napier sole cropping), which contrasts the main effect trend where higher N levels gave higher growth. This anomalous result might be attributed to localized nutrient dynamics under tree cover or microclimatic modifications that improved nitrogen use efficiency at lower fertilizer rates. This observation warrants further investigation, especially considering nitrogen use efficiency under agroforestry conditions

(Palm *et al.*, 2001). Similarly, N_3S_2 (100 kg N/ha + Neem + Napier) and N_3S_3 (100 kg N/ha + Mahagoni + Napier) also showed relatively high growth, suggesting that intermediate nitrogen levels might be more effective under specific tree-based systems. These results resonate with studies by Mureithi *et al*. (1994), which noted that the effect of nitrogen on grass growth under trees is often influenced by the degree of canopy openness and root interactions.

Table 03. Combined effect of fertilizer and agroforestry system on plant height of Napier

Fertilizer×System	Plant heights (cm)		
	30 DAS	**60 DAS**	**90 DAS**
N_1S_1	64.53 cde	143.80 bcd	188.70 bc
N_1S_2	64.40 cde	136.33 cd	178.67 c
N_1S_3	62.56 de	137.50 cd	172.67 c
N_2S_1	69.03 bcde	157.89 abcd	199.30 bc
N_2S_2	64.92 cde	140.67 cd	186.00 bc
N_2S_3	62.10 e	132.00 d	173.33 c
N_3S_1	78.80 abc	169.83 ab	218.67 b
N_3S_2	77.60 abcd	157.57 abcd	207.67 bc
N_3S_3	76.55 abcde	137.33 cd	191.00 bc
N_4S_1	91.33 a	183.83 a	258.00 a
N_4S_2	84.80 a	161.53 abc	210.67 bc
N_4S_3	80.60 ab	142.83 bcd	200.67 bc
LSD	15.39	27.46	38.43
CV (%)	7.15	6.22	6.57
LS	NS	NS	NS

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare; S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

4.2 Collar diameter (cm)

Effect of Nitrogen Fertilizer on Collar Diameter

Table 4 reveals that collar diameter increased progressively with higher nitrogen doses at all three growth stages. At 30 DAS, the maximum collar diameter (5.86 cm) was observed in N_4 (150 kg N/ha), which was significantly higher than the control (N_1, 5.20 cm). Similar patterns were evident at 60 DAS and 90 DAS, where N_4 showed significant superiority (10.39 cm and 12.72 cm, respectively) over lower nitrogen levels. These findings align with those of Ghosh *et al*. (2001) and Zhou *et al*. (2020), who reported that nitrogen application stimulates vegetative growth, including stem thickening, due to enhanced protein synthesis, increased cell division, and elongation. The significantly larger collar diameter under N4 reflects enhanced physiological activity and nutrient assimilation, reinforcing nitrogen's role in structural growth. Collar diameter improvement across time suggests a cumulative effect of nitrogen in sustaining stem development as the plant matures, which is critical for lodging resistance and biomass support (Singh *et al*., 2010).

Table 04. Effect of nitrogen fertilizer on collar diameter of Napier

Fertilizer	**Collar diameter (cm)**		
	30 DAS	**60 DAS**	**90 DAS**
N_1	5.20 b	8.18 b	10.09 c
N_2	5.43 ab	8.90 b	10.62 c
N_3	5.59 ab	9.75 a	11.68 b
N_4	5.86 a	10.39 a	12.72 a
LSD	0.57	0.78	0.91
CV (%)	7.95	6.45	6.23
LS	*	**	**

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare.

Effect of Agroforestry System on Collar Diameter

Table 5 shows that the agroforestry system significantly affected collar diameter at all stages ($p < 0.01$). The sole cropping system (S_1) consistently exhibited the largest collar diameter at 30 (6.08 cm), 60 (10.58 cm), and 90 DAS (12.57 cm). In contrast, S_3 (Mahagoni + Napier) had the lowest collar diameter across all intervals. Tree-crop interactions, especially shading and belowground competition, significantly influence Napier's growth traits. Under S_3, the denser canopy and extensive root system of *Mahagoni* likely reduced light penetration and nutrient availability, leading to narrower collar diameter. This is supported by the findings of Nair (1993) and Singh *et al*. (2006), who reported that reduced light under tree canopies limits photosynthetic activity and results in thinner stems and reduced forage quality. Interestingly, S_2 (Neem + Napier) outperformed S_3 but was still inferior to sole cropping. Neem, with a comparatively lighter canopy and nitrogen-enhancing allelopathic properties, may have offered a more favorable microenvironment (Azad *et al*., 2015). Hence, Neem-based systems may present a better compromise between biodiversity and fodder productivity.

Table 05. Effect of agroforestry system on collar diameter of Napier

System	Collar diameter (cm)		
	30 DAS	**60 DAS**	**90 DAS**
S_1	6.08 a	10.58 a	12.57 a
S_2	5.48 b	9.08 b	11.32 b
S_3	4.99 c	8.25 c	9.94 c
LSD	0.45	0.61	0.72
CV (%)	7.95	6.45	6.23
LS	**	**	**

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

Combined Effect of Nitrogen and Agroforestry on Collar Diameter

In Table 6, the interaction effects of nitrogen and agroforestry system on collar diameter show non-significance at 30 DAS but become significant at 60 and 90 DAS. This suggests that interaction effects become more pronounced as plants mature, potentially due to cumulative effects of nitrogen uptake and interspecific competition. The maximum collar diameter at 90 DAS (15.18 cm) was recorded under N_4S_1 (150 kg N/ha with Napier sole cropping). These results are interesting because they contradict the individual trends observed in Tables 4 and 5. Specifically, while Mahagoni-based systems showed poor growth on average, N_4S_1 (150 kg N/ha with Napier sole cropping) resulted in a surprisingly high collar diameter. This anomaly may be attributed to localized microclimatic effects or adaptive stress responses under moderate nitrogen supplementation in shaded environments, where limited competition early in development followed by nitrogen-supported catch-up growth might result in thicker stems (Palm *et al*., 2001). Such interactions deserve further investigation, as they suggest opportunities to fine-tune nitrogen application under specific agroforestry setups to optimize structural growth. Another notable combination is N_3S_3 (100 kg N/ha + Mahagoni), which produced significant collar thickening at 90 DAS (12.33 cm), reinforcing that moderate to high nitrogen rates can somewhat compensate for the growth-limiting effects of tree competition. These findings echo those by Mureithi *et al*. (1994) and Baudron *et al*.

(2012), who emphasized the importance of resource management in mixed cropping systems for sustained productivity.

Table 06. Combined effect of fertilizer and agroforestry system on collar diameter of Napier

Fertilizer×System	Collar diameter (cm)		
	30 DAS	60 DAS	90 DAS
N_1S_1	5.42 b	8.72 cde	10.26 def
N_1S_2	5.27 b	8.29 cde	10.30 cdef
N_1S_3	4.91 b	7.53 e	9.71 ef
N_2S_1	5.86 ab	9.87 bc	11.65 bcde
N_2S_2	5.41 b	8.75 cde	10.67 cdef
N_2S_3	5.01 b	8.08 de	9.53 f
N_3S_1	6.17 ab	11.20 ab	13.20 ab
N_3S_2	5.58 b	9.34 cd	11.98 bcd
N_3S_3	5.02 b	8.71 cde	9.85 ef
N_4S_1	6.87 a	12.54 a	15.18 a
N_4S_2	5.67 ab	9.95 bc	12.33 bc
N_4S_3	5.03 b	8.68 cde	10.64 cdef
LSD	1.29	1.77	2.07
CV (%)	7.95	6.45	6.23
LS	NS	*	*

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare; S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

4.3 Number of Tiller

Effect of Nitrogen Fertilizer on Tiller Number

Table 7 indicates a significant and consistent increase in the number of tillers with increasing nitrogen rates across all growth stages. At 30 DAS, tiller numbers increased from 2.66 (N_1) to 3.29 (N_4), and the trend continued through 60 DAS (3.07 to 3.76) and 90 DAS (3.66 to 4.81). The LSD values confirm significant differences among treatments at the 5% probability level. This pattern aligns with established findings that nitrogen stimulates the production of lateral shoots (tillers) by enhancing cytokinin activity and improving carbohydrate partitioning to basal buds (Ramesh *et al*., 2005; Tessema *et al*., 2010). Higher nitrogen availability promotes cell division and vegetative growth, thus increasing the tiller count. The gradual increase in tiller numbers over time under higher nitrogen doses implies a sustained positive effect of nitrogen on plant vigor and productivity (Zhou *et al*., 2020). N_4 (150 kg N/ha) consistently outperformed lower doses, suggesting that this level may be optimal for maximum tiller proliferation under the study's conditions.

Table 07. Effect of nitrogen fertilizer on number of tillers of Napier

Fertilizer	Number of Tillers		
	30 DAS	60 DAS	90 DAS
N_1	2.66 b	3.07 b	3.66 b
N_2	2.93 ab	3.34 ab	4.19 ab
N_3	3.12 ab	3.54 a	4.26 ab
N_4	3.29 a	3.76 a	4.81 a
LSD	0.54	0.46	0.79
CV (%)	13.84	10.29	14.44
LS	*	*	*

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare.

Effect of Agroforestry System on Tiller Number

According to Table 8, agroforestry systems had a significant effect on tiller number at 60 and 90 DAS, though not at 30 DAS. This suggests that system-induced differences become more pronounced as the plant matures and competition with tree components intensifies. The sole cropping system (S_1) consistently supported the highest number of tillers, followed by S_2 (Neem + Napier) and S_3 (Mahagoni + Napier). At 90 DAS, S1 produced 4.62 tillers per plant, significantly more than S_3 (3.78). These results are consistent with earlier studies indicating that shading and root competition under trees especially those with dense canopies like Mahagoni can reduce light availability and limit vegetative propagation in forage crops (Singh *et al*., 2006; Nair, 1993). Neem, with its relatively open canopy and soil-improving properties, appears to provide a better environment for tiller development than Mahagoni. Neem has also been reported to have beneficial effects on soil nitrogen dynamics due to its allelopathic interactions and leaf litter quality (Azad *et al*., 2015), which may partly explain its intermediate performance.

Table 08. Effect of agroforestry system on number of tillers of Napier

System	Number of Tillers		
	30 DAS	60 DAS	90 DAS
S_1	2.99 a	3.62 a	4.62 a
S_2	3.12 a	3.48 ab	4.28 ab
S_3	2.89 a	3.19 b	3.78 b
LSD	0.42	0.36	0.62
CV (%)	13.84	10.29	14.44
LS	NS	*	*

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

Combined Effect of Nitrogen and Agroforestry System on Tiller Number

In Table 9, although the interaction effect of nitrogen × agroforestry system was statistically non-significant at all three growth stages, the treatment means reveal notable biological trends. The highest number of tillers at 90 DAS (5.83) was observed in N_4S_1 (150 kg N/ha with Napier sole cropping), which surprisingly outperformed even sole cropping with high nitrogen. This may be due to a synergistic response to moderate nitrogen under mild stress, prompting adaptive growth and tillering as a compensatory mechanism. Such phenomena have been observed in shaded conditions where moderate nutrient stress can stimulate lateral growth as a survival strategy (Palm *et al*., 2001). Other high-performing combinations included N_3S_2 (4.50 tillers), N_4S_2 (4.67), and N_2S_1 (4.47). These results underscore the value of optimizing nitrogen use in agroforestry contexts. For instance, Neem-based systems combined with 100–150 kg N/ha produced tillering nearly on par with sole cropping, reinforcing Neem's compatibility with Napier fodder systems. N_3S_1 and N_2S_1 underperformed despite being part of sole cropping. These anomalies might reflect variability in initial soil conditions, root competition, or micro environmental effects not directly measured in this study. These trends echo findings by Baudron *et al*. (2012) and Mureithi *et al*. (1994), who emphasized site-specific adaptation of integrated systems to maximize biomass while preserving ecological function.

Table 09. Effect of nitrogen fertilizer and agroforestry system on number of tillers of Napier

Fertilizer×System	Number of Tillers		
	30 DAS	60 DAS	90 DAS
N_1S_1	2.47 a	3.07 b	3.80 b
N_1S_2	2.90 a	3.17 ab	3.77 b
N_1S_3	2.60 a	2.97 b	3.40 b
N_2S_1	2.80 a	3.40 ab	4.47 ab
N_2S_2	3.20 a	3.50 ab	4.20 ab
N_2S_3	2.80 a	3.13 b	3.90 b
N_3S_1	3.17 a	3.80 ab	4.37 ab
N_3S_2	3.13 a	3.60 ab	4.50 ab
N_3S_3	3.07 a	3.23 ab	3.90 b
N_4S_1	3.53 a	4.20 a	5.83 a
N_4S_2	3.23 a	3.63 ab	4.67 ab
N_4S_3	3.10 a	3.43 ab	3.93 b
LSD	1.22	1.04	1.80
CV (%)	13.84	10.29	14.44
LS	NS	NS	NS

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare; S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

4.4 Number of leaves

Effect of Nitrogen Fertilizer on Number of Leaves

Nitrogen application had a significant positive effect on leaf production at all three growth stages (30, 60, and 90 DAS). The number of leaves increased progressively with increasing nitrogen rates. At 90 DAS, Napier treated with N_4 (150 kg N/ha) produced the highest number of leaves (61.06), significantly more than the control (N_1: 40.13). The trend was similar at 30 DAS (13.44 in N_1 and 21.16 in N_4) and 60 DAS. These results align with earlier studies indicating that nitrogen stimulates leaf initiation and expansion by promoting cell division, protein synthesis, and chlorophyll production (Ghosh *et al*., 2001; Ramesh *et al*., 2005). Nitrogen is also associated with enhanced tillering, which indirectly increases the number of leaves per unit area (Zhou *et al*., 2020). The leaf proliferation observed here contributes directly to higher photosynthetic capacity and forage yield. The highest nitrogen dose (N_4) resulted in significantly higher leaf numbers compared to N_2 and N_3, indicating that 150 kg N/ha may be optimal under the experimental conditions for maximizing leaf area in Napier grass.

Table 10. Effect of nitrogen fertilizer on number of leaves of Napier

Fertilizer	Number of leaves		
	30 DAS	**60 DAS**	**90 DAS**
N_1	13.44 c	29.86 b	40.13 b
N_2	15.86 bc	33.16 ab	42.48 b
N_3	18.96 ab	35.56 ab	50.06 ab
N_4	21.16 a	40.37 a	61.06 a
LSD	3.98	9.41	11.33
CV (%)	17.64	20.83	17.98
LS	*	*	*

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare.

Effect of Agroforestry System on Number of Leaves

Table 11 reveals that agroforestry system significantly influenced leaf number at 30 and 90 DAS, but not at 60 DAS. Napier under sole cropping (S_1) produced the highest leaf numbers across the stages, followed by Neem + Napier (S_2) and then Mahagoni + Napier (S_3). At 90 DAS, S_1 produced 55.69 leaves per plant, while S3 lagged behind with only 41.98. This reduction in leaf number under tree-based systems can be attributed to competition for light, water, and nutrients, especially under Mahagoni, which casts a denser shade and has an extensive root system. Shading can inhibit photosynthetic activity, reduce leaf expansion, and delay leaf emergence (Nair, 1993; Singh *et al*., 2006). In contrast, Neem's relatively open canopy allows more light to reach the understorey crops, resulting in better growth performance than Mahagoni. These observations are consistent with findings from Azad *et al.* (2015), who reported that Neem-based agroforestry systems enhance microclimatic conditions and may improve nitrogen cycling, contributing to better vegetative performance than more competitive tree species.

Table 11. Effect of agroforestry system on number of leaves of Napier

System	Number of leaves		
	30 DAS	60 DAS	90 DAS
S_1	19.47 a	38.21 a	55.69 a
S_2	17.71 ab	34.13 a	47.62 ab
S_3	14.90 b	31.86 a	41.98 b
LSD	3.12	7.38	8.88
CV (%)	17.64	20.83	17.98
LS	*	NS	*

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

Combined Effect of Nitrogen and Agroforestry System on Leaf Number

In Table 12, the combined effect of nitrogen and agroforestry system on the number of leaves was not statistically significant at any stage. However, biological trends observed in the means indicate interesting interactions. At 90 DAS, the highest number of leaves (75.83) was recorded in N_4S_1 (150 kg N/ha with Napier sole cropping), followed by N_4S_2 (60.67) and N_3S_1 (60.00). Surprisingly, Mahagoni-based systems (S_3), which generally showed reduced growth in the main effect, performed better under moderate nitrogen application in this interaction. This may reflect a compensatory growth response under suboptimal conditions, where plants adapt by producing more foliage in response to mild nutrient stress and moderate shade (Palm *et al.*, 2001). N_2S_1 (45.27 leaves) and N_4S_3 (46.67 leaves) did not match the performance of N_4S_1 (150 kg N/ha with Napier sole cropping), suggesting that moderate nitrogen levels may be more effective in some agroforestry contexts, especially when excessive nitrogen could lead to luxury consumption or imbalanced growth under shaded environments (Rao *et al.*, 2015).

Table 12. Effect of fertilizer and agroforestry system on number of leaves of Napier

Fertilizer×System	Number of leaves		
	30 DAS	60 DAS	90 DAS
N_1S_1	15.00 abc	33.07 a	41.67 b
N_1S_2	15.33 abc	29.50 a	40.40 b
N_1S_3	10.00 c	27.00 a	38.33 b
N_2S_1	18.93 abc	34.93 a	45.27 b
N_2S_2	15.17 abc	33.37 a	42.17 b
N_2S_3	13.49 bc	31.17 a	40.00 b
N_3S_1	21.19 ab	37.33 a	60.00 ab
N_3S_2	18.92 abc	35.67 a	47.23 b
N_3S_3	16.77 abc	33.67 a	42.93 b
N_4S_1	22.74 a	47.50 a	75.83 a
N_4S_2	21.40 ab	38.00 a	60.67 ab
N_4S_3	19.33 ab	35.60 a	46.67 b
LSD	9.01	21.30	25.63
CV (%)	17.64	20.83	17.98
LS	NS	NS	NS

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare; S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

4.5 Leave length (cm)

Effect of Nitrogen Fertilizer on Leaf Length

Figure 1 demonstrates that increasing nitrogen levels significantly enhanced leaf length at all growth stages (30, 60, and 90 DAS) with $p < 0.01$. The leaf length increased from 34.93 cm at 30 DAS under N_1 (0 kg N/ha) to 48.90 cm under N_4 (150 kg N/ha). Similarly, at 90 DAS, leaf length ranged from 66.45 cm (N_1) to 86.27 cm (N_4), reflecting a substantial 29.8% increase due to nitrogen application. These results are consistent with studies by Zhou *et al.* (2020) and Ramesh *et al*. (2005), who noted that nitrogen stimulates vegetative growth, especially leaf elongation, by promoting cell division and expansion. Nitrogen is also critical for chlorophyll production, which indirectly supports photosynthetic efficiency and prolongs the growth period of leaves (Ghosh *et al.*, 2001). The consistent increases across all stages indicate a cumulative benefit of nitrogen over time, with 150 kg N/ha emerging as the most effective rate under the given conditions.

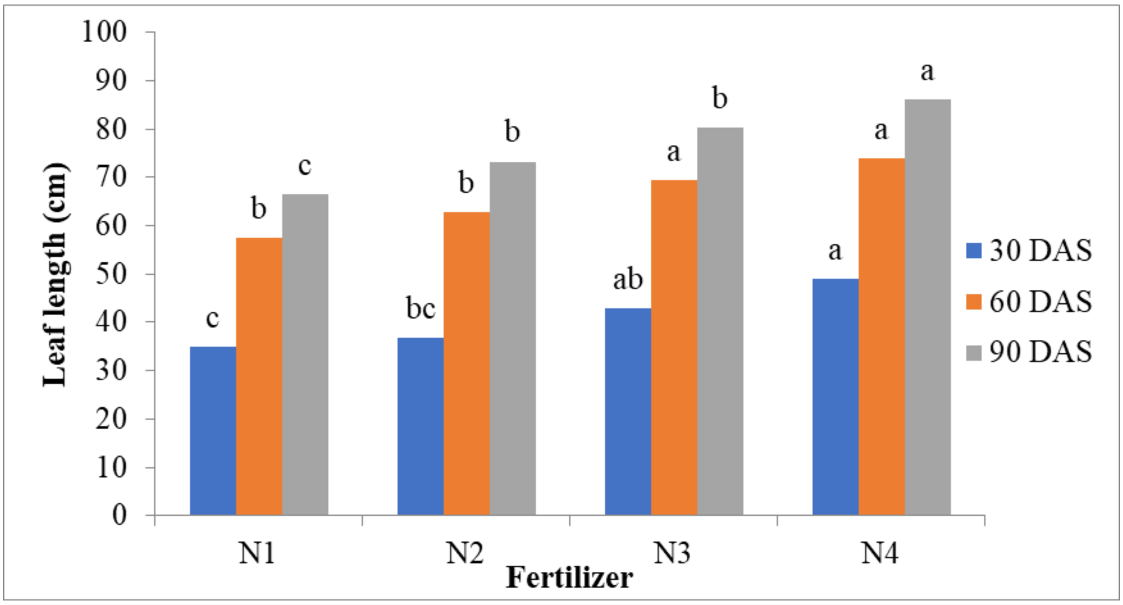

Figure 1. Effect of nitrogen fertilizer on leave length of Napier

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare.

Effect of Agroforestry System on Leaf Length

According to figure 2, the agroforestry system significantly influenced leaf length at all three time points ($p < 0.05$). The highest leaf lengths were recorded in sole cropping (S_1) at all stages (e.g., 80.63 cm at 90 DAS), followed by S_2 (Neem + Napier), while the shortest leaves were found in S_3 (Mahagoni + Napier). This trend reflects the inhibitory effect of shading and competition under tree-based systems, especially Mahagoni. Dense tree canopies reduce light interception at the lower crop canopy level, limiting photosynthesis and, thus, leaf expansion (Nair, 1993; Singh *et al.*, 2006). Conversely, Neem, which provides a more open canopy and improves soil fertility through leaf litter and nitrogen cycling (Azad *et al.*, 2015), supports better growth than Mahagoni, though still inferior to sole cropping. The superiority of S1 indicates that light availability and reduced competition are major drivers of leaf elongation in Napier grass. This supports findings by Baudron *et al*. (2012), who emphasized the role of microclimate management in integrated farming systems.

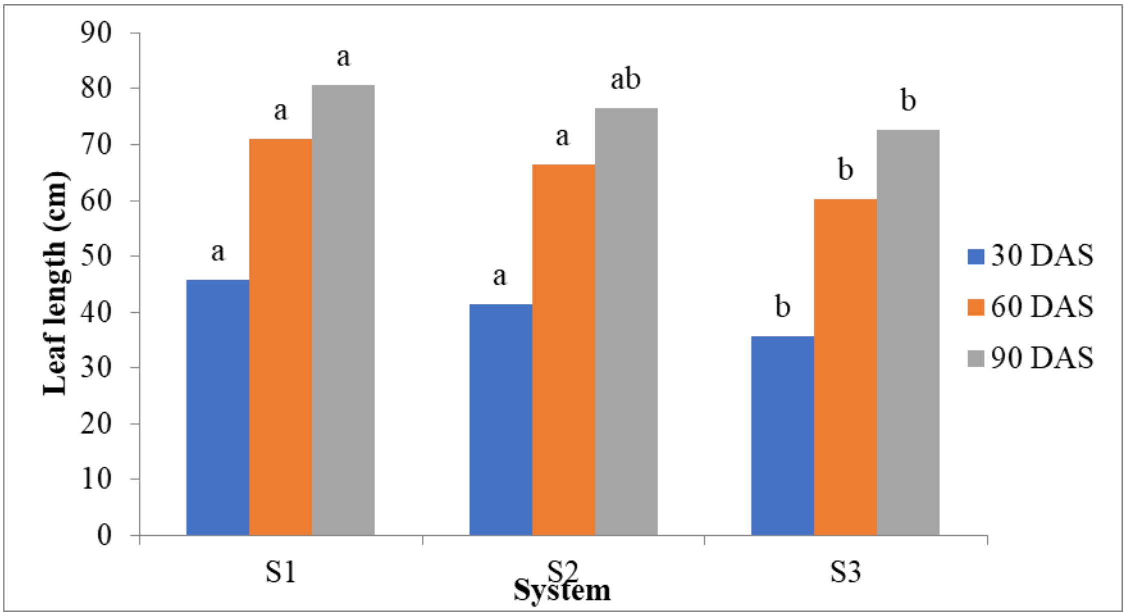

Figure 2. Effect of agroforestry system on leave length of Napier

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

Combined Effect of Fertilizer and Agroforestry System on Leaf Length

Table 13 shows that the interaction of nitrogen and agroforestry system on leaf length was not statistically significant (NS) at any stage, but several biologically important patterns are observable. At 90 DAS, the maximum leaf length (90.84 cm) was recorded in N_4S_1 (150 kg N/ha with Napier sole cropping). Surprisingly, the Mahagoni-based system (S_3), which generally suppressed leaf growth when analyzed independently, showed the best performance under moderate nitrogen (N_2 and N_3) in combination. This suggests a stress-compensatory effect, where moderate shade and competition, combined with adequate nitrogen availability, may enhance leaf elongation as an adaptive strategy (Palm *et al.*, 2001). Shading can sometimes reduce evaporative stress and extend leaf longevity, particularly when nutrient conditions are favorable. N_1S_1 and N_2S_1, both under sole cropping, showed lower leaf lengths than expected, indicating that beyond a certain nitrogen threshold, other factors (e.g., moisture, genetic potential) may limit further elongation, or that luxury nitrogen consumption does not always lead to proportional growth benefits (Rao *et al.*, 2015). Combinations such as N_4S_2 and N_4S_3 yielded comparable leaf lengths (around 79–80 cm) to those under sole cropping, reinforcing that Neem-based systems with higher nitrogen levels can perform nearly on par with monoculture under optimal management.

Table 13. Effect of fertilizer and agroforestry system on leave length of Napier

Fertilizer×System	Leave length (cm)		
	30 DAS	**60 DAS**	**90 DAS**
N_1S_1	37.53 bc	62.56 bcde	68.77 def
N_1S_2	35.22 c	57.53 de	66.22 ef
N_1S_3	32.05 c	52.56 e	64.38 f
N_2S_1	40.41 abc	66.79 abcde	77.83 abcdef
N_2S_2	38.29 bc	62.15 cde	72.72 cdef
N_2S_3	31.90 c	59.20 de	69.33 def
N_3S_1	51.63 ab	76.74 ab	85.07 abc
N_3S_2	40.16 abc	70.39 abcd	79.45 abcde
N_3S_3	37.10 bc	61.03 de	76.35 bcdef
N_4S_1	53.41 a	77.71 a	90.84 a
N_4S_2	51.96 ab	75.41 abc	87.50 ab
N_4S_3	41.34 abc	68.50 abcd	80.48 abcd
LSD	15.05	14.26	13.91
CV (%)	12.50	7.35	6.17
LS	NS	NS	NS

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare; S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

4.6 Leaf breadth (cm)

Effect of Nitrogen Fertilizer on Leaf Breadth

Nitrogen application significantly influenced leaf breadth at 30 and 60 DAS, but not at 90 DAS, suggesting a diminishing response as plants mature. At 30 DAS, leaf breadth increased from 1.01 cm (N_1) to 1.97 cm (N_4), with a statistically significant difference ($p < 0.01$). A similar trend was observed at 60 DAS, where N_4 had the highest breadth (2.92 cm) compared to N_1 (2.22 cm, $p < 0.05$). This response aligns with prior research indicating that nitrogen positively affects cell expansion and tissue development in leaves, especially during early vegetative stages (Ramesh *et al.*, 2005; Ghosh *et al.*, 2001). Nitrogen promotes chlorophyll synthesis, protein formation, and turgor-driven expansion, all of which enhance leaf area parameters, including width (Zhou *et al.*, 2020). The non-significant difference at 90 DAS suggests that by the late vegetative stage, genetic potential and environmental constraints may override the effects of nitrogen alone, or that leaf width stabilizes across treatments due to structural maturity of the plant (Tessema *et al*., 2010).

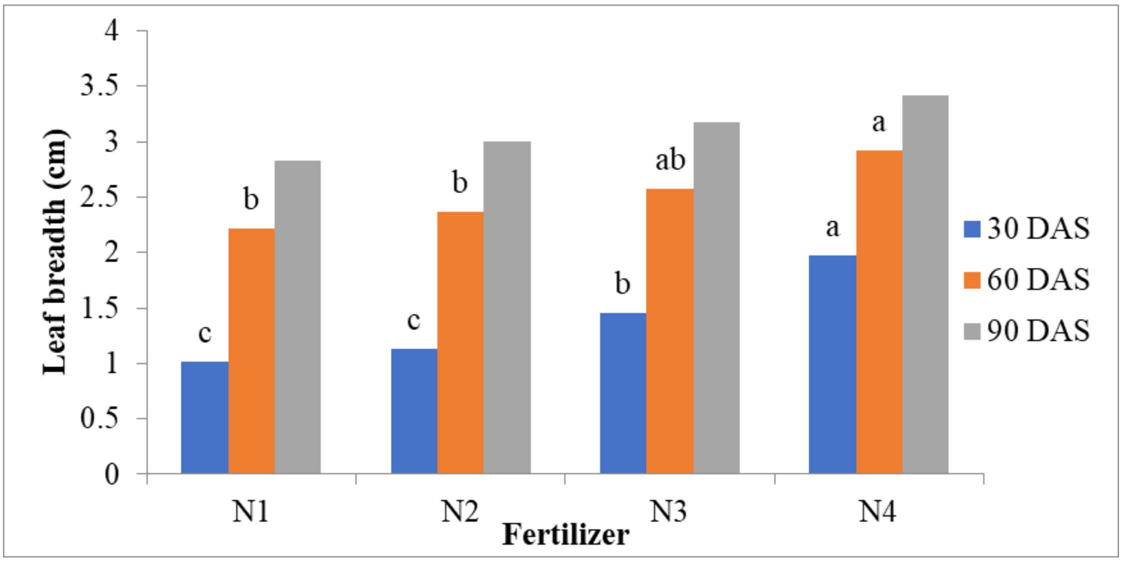

Figure 3. Effect of nitrogen fertilizer on leave breadth of Napier

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare.

Effect of Agroforestry System on Leaf Breadth

Figure 4 shows that the agroforestry system had a significant effect only at 30 DAS ($p < 0.01$), where sole cropping (S_1) produced the broadest leaves (1.66 cm), significantly outperforming both Neem (S_2) and Mahagoni (S_3) systems. By 60 and 90 DAS, differences were statistically non-significant, though numerically, S_1 consistently maintained slightly higher breadth values. The early advantage in S_1 may be attributed to better light penetration and unhindered resource availability in monoculture systems. In contrast, tree-based systems, particularly Mahagoni, can impose shading and root competition, which limits early vegetative expansion (Nair, 1993; Singh *et al*., 2006). While light limitation can reduce both length and breadth of leaves, moderate shade can sometimes delay maturity, leading to prolonged but slower growth (Palm *et al*., 2001). The reduced influence of the system at later stages may result from plant adaptation to shaded environments, such as increased chlorophyll content or modified leaf anatomy, as observed in other tropical forages under agroforestry conditions (Mpairwe *et al*., 2003).

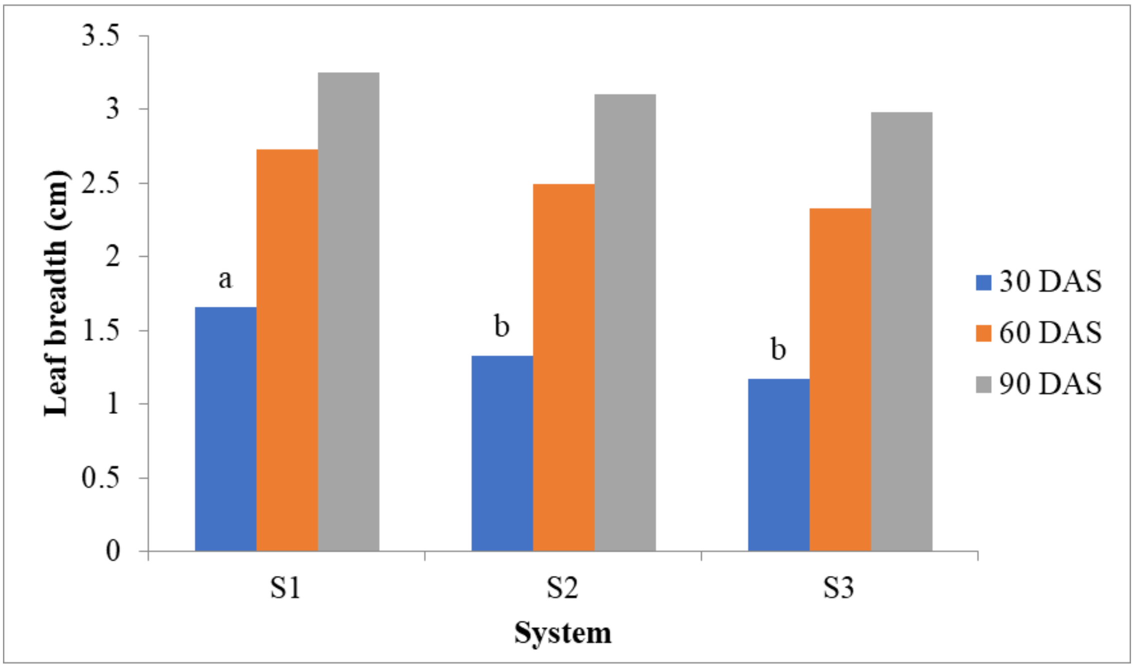

Figure 4. Effect of agroforestry system on leave breadth of Napier

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

Combined Effect of Nitrogen and Agroforestry System on Leaf Breadth

Table 14 presents the interaction between nitrogen levels and agroforestry systems on leaf breadth. While the interaction effect was only significant at 30 DAS ($p < 0.05$), several noteworthy trends can be observed. The highest leaf breadth at 30 DAS (2.59 cm) was recorded in N_2S_3 (50 kg N/ha + Mahagoni), which is an interesting and somewhat unexpected result, given that Mahagoni generally showed lower performance in the main effects. This suggests a potential synergistic effect between moderate nitrogen application and shaded conditions, possibly stimulating leaf expansion as an adaptive response (Palm *et al*., 2001). N_4S_1 (150 kg N/ha with Napier sole cropping) produced relatively broad leaves, indicating that intermediate to high nitrogen levels can offset some negative effects of tree competition. Conversely, sole cropping combinations (e.g., N_3S_1, N_2S_1) had narrower leaves at 30 DAS, which could be due to accelerated vertical growth and reduced lateral expansion under open light conditions (Zhou *et al*., 2020). At 60 and 90 DAS, although the statistical differences were non-significant, numerical values remained consistent with the trends observed earlier. Leaf breadth stabilized across treatments, and high variability (CV values >16%) may have masked potential differences.

Table 14. Effect of fertilizer and agroforestry system on leave breadth of Napier

Fertilizer×System	Leaf breadth (cm)		
	30 DAS	**60 DAS**	**90 DAS**
N_1S_1	1.08 c	2.33 ab	2.97 a
N_1S_2	1.00 c	2.27 ab	2.80 a
N_1S_3	0.97 c	2.07 b	2.73 a
N_2S_1	1.24 bc	2.44 ab	3.07 a
N_2S_2	1.10 c	2.34 ab	3.00 a
N_2S_3	1.03 c	2.30 ab	2.93 a
N_3S_1	1.74 b	2.80 ab	3.30 a
N_3S_2	1.46 bc	2.53 ab	3.17 a
N_3S_3	1.14 c	2.37 ab	3.03 a
N_4S_1	2.59 a	3.37 a	3.65 a
N_4S_2	1.77 b	2.82 ab	3.42 a
N_4S_3	1.54 bc	2.58 ab	3.20 a
LSD	0.58	1.20	1.67
CV (%)	14.12	16.13	18.31
LS	*	NS	NS

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare; S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

4.7 Yield (t ha^{-1})

In figure 5, yield increased significantly ($p < 0.01$) with rising nitrogen levels. The lowest yield (4.40 t/ha) was recorded in N_1 (0 kg N/ha), whereas the highest yield (17.58 t/ha) was observed under N_4 (150 kg N/ha), indicating a nearly fourfold increase. This pattern is consistent with numerous studies reporting that nitrogen is the most limiting nutrient for Napier productivity, stimulating tiller growth, leaf expansion, and overall biomass accumulation (Ramesh *et al.*, 2005; Rao *et al.*, 2015). Nitrogen enhances cell division and elongation, directly contributing to shoot mass and canopy development, which results in higher yield.

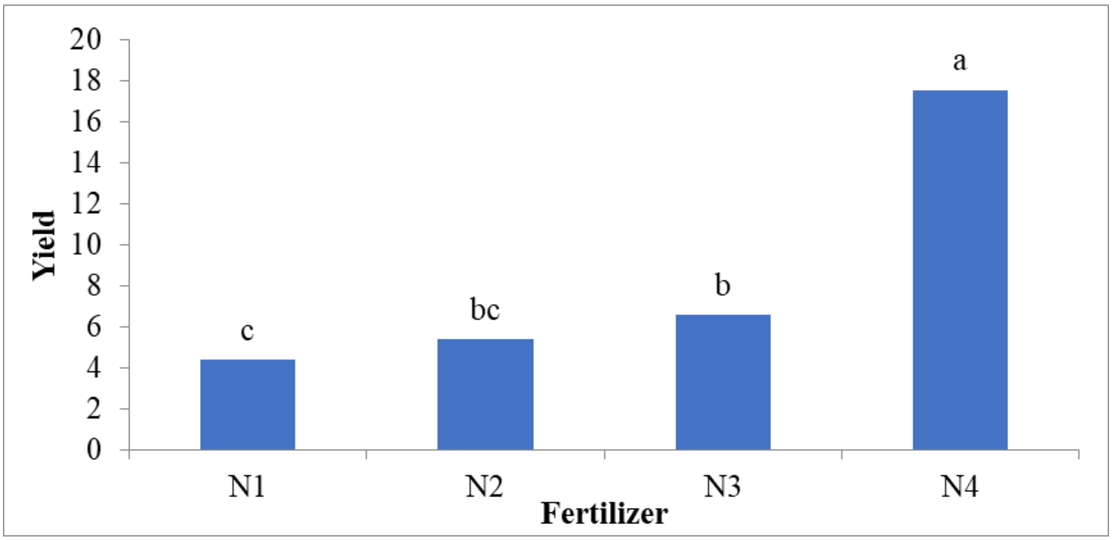

Figure 5. Effect of nitrogen fertilizer on yield and dry matter of Napier

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare.

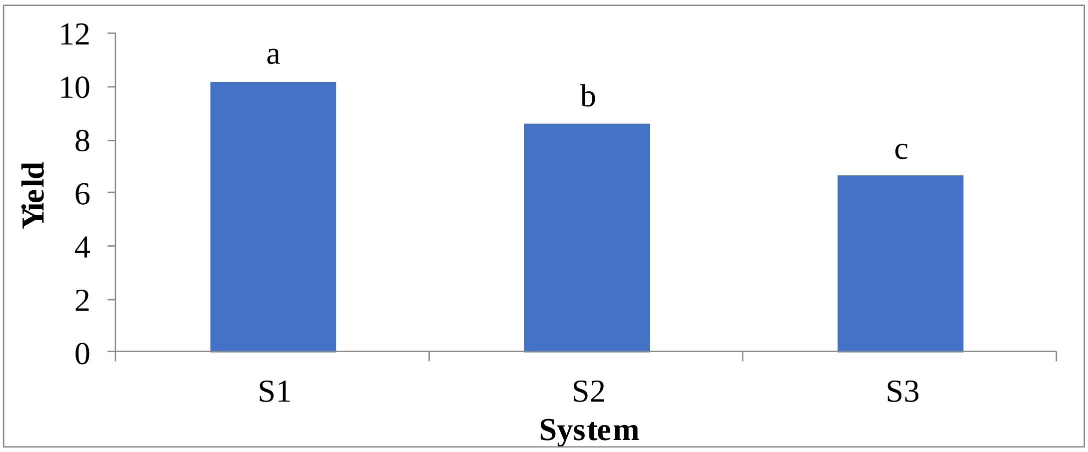

Figure 6. Effect of agroforestry system on yield and dry matter of Napier

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

Figure 6 shows that the agroforestry system significantly affected yield ($p < 0.01$), with sole cropping (S_1) producing 10.22 t/ha, significantly higher than Neem + Napier (S_2: 8.62 t/ha) and Mahagoni + Napier (S_3: 6.65 t/ha). This reduction in yield under tree-based systems is likely due to interference from tree canopy shading and root competition, which limits light, water, and nutrient availability to the Napier grass. These findings align with the work of Nair (1993) and Singh *et al*. (2006), who noted that dense tree canopies and aggressive root systems can suppress intercrop productivity in agroforestry setups.

In Table 15, the interaction between fertilizer and agroforestry system also showed significant effects ($p < 0.01$) on yield. The highest yield (21.92 t/ha) was observed under N_4S_1 (150 kg N/ha with Napier sole cropping), followed by N_4S_2 (18.40 t/ha). This is somewhat as expected, as Mahagoni typically reduced yield in the main effect. Optimal forage yield appears to occur with moderate to high nitrogen doses (N_3 or N_4) under sole or Neem-based systems, balancing resource use and minimizing tree competition.

4.8 Dry Matter (DM)

Dry matter content (DM) showed non-significant variation with nitrogen levels (figure 7). The DM percentage ranged narrowly from 18.54% to 19.21%, indicating that nitrogen primarily influenced the quantity of biomass, but not its dry matter proportion. This finding is consistent with previous reports by Ghosh *et al.* (2001) and Zhou *et al.* (2020), who observed that while nitrogen boosts biomass production, its impact on DM is often limited or inconsistent due to compensatory changes in moisture retention and tissue density.

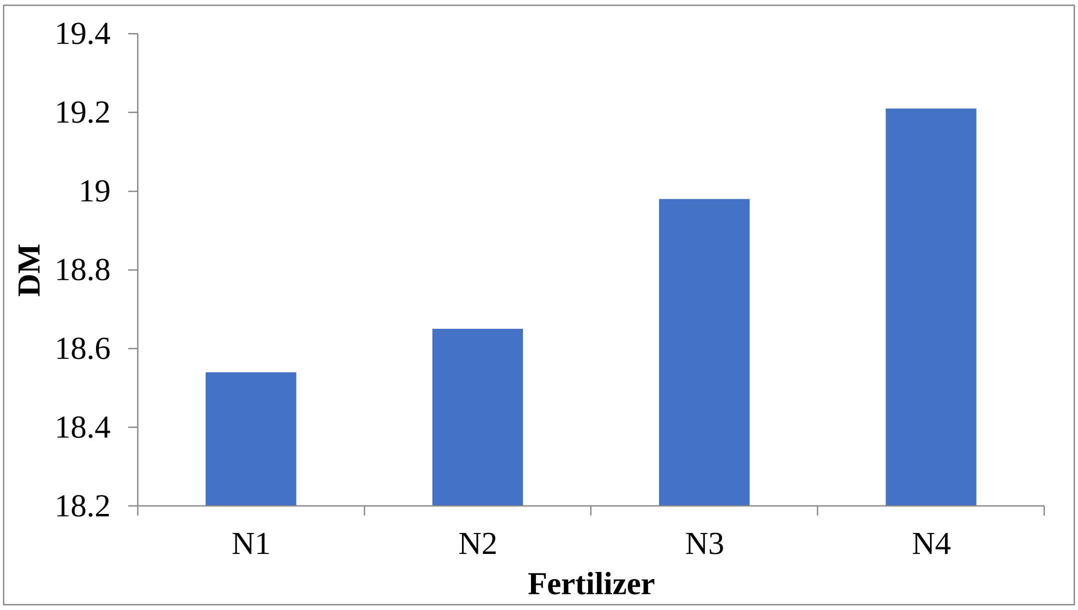

Figure 7. Effect of nitrogen fertilizer on yield and dry matter of Napier

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare.

In figure 8, the agroforestry system had a significant effect on DM content ($p < 0.01$). The highest DM was recorded under sole cropping (S_1: 21.21%), followed by Neem + Napier (S_2: 19.93%), while the lowest was observed under Mahagoni + Napier (S_3: 15.39%). The reduced DM under Mahagoni likely results from prolonged shading and delayed tissue lignification, which slows down physiological maturity (Azad *et al*., 2015). Shaded environments often induce softer, more succulent growth with higher water content and lower fiber concentration, thereby reducing dry matter concentration.

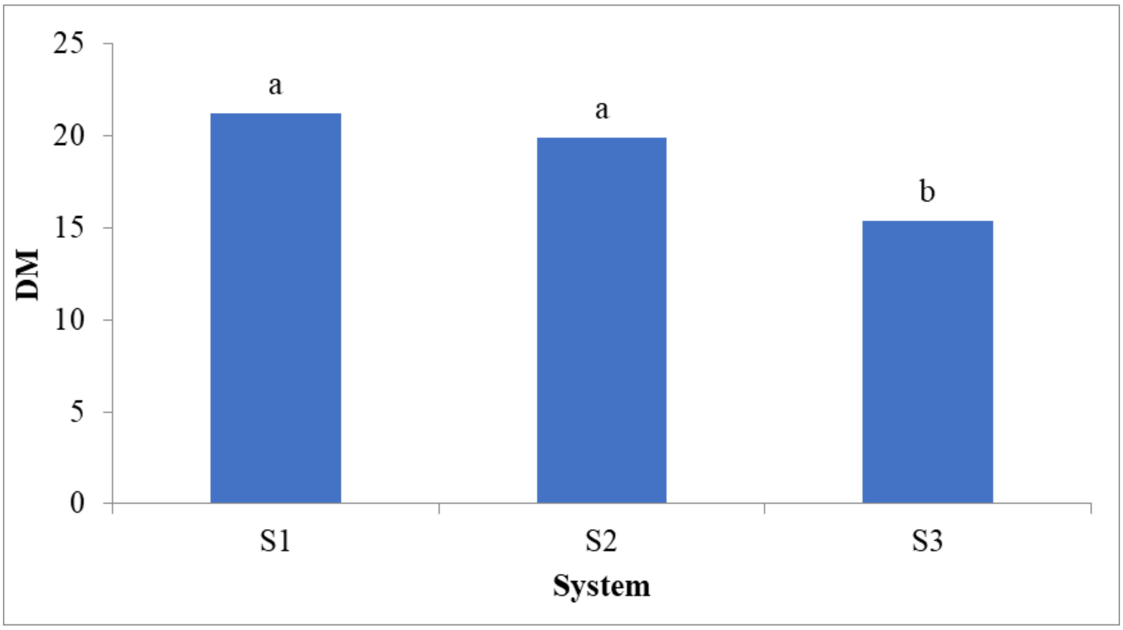

Figure 8. Effect of agroforestry system on yield and dry matter of Napier

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

In Table 15, the interaction effect was statistically non-significant, though some combinations showed biologically meaningful variation. For example, N_3S_1 (100 kg N/ha with Napier sole cropping) and N_4S_1 (150 kg N/ha with Napier sole cropping) produced the highest DM values (22.58% and 22.01%, respectively), whereas N_4S_3 (150 kg N/ha + Mahagoni) had the lowest (14.63%). These results suggest that tree species and nitrogen levels jointly influence water content and dry matter partitioning. Neem-based systems, offering partial shade and improved soil microflora, may favor balanced growth and higher tissue density.

Table 15. Effect of fertilizer and agroforestry system on yield and dry matter of Napier

Fertilizer×System	Yield	DM
N_1S_1	5.06 de	20.11 abc
N_1S_2	4.28 e	19.44 abcd
N_1S_3	3.87 e	16.08 bcd
N_2S_1	6.03 de	20.15 abc
N_2S_2	5.55 de	20.19 abc
N_2S_3	4.62 e	15.61 bcd
N_3S_1	7.87 d	22.58 a
N_3S_2	6.25 de	19.10 abcd
N_3S_3	5.68 de	15.25 cd
N_4S_1	21.92 a	22.01 a
N_4S_2	18.40 b	20.98 ab
N_4S_3	12.41 c	14.63 d
LSD	2.88	5.39
CV (%)	11.50	9.73
LS	**	NS

LSD=Least of significant difference, CV=Coefficient of variance, LS=Level of significant, * = Significant at 0.05% probability, ** = Significant at 0.01% probability. N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare; S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder.

CHAPTER V
SUMMARY AND CONCLUSION

The experiment was conducted at the conducted in the Research Field of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur. The experiment was setup at the existing three fruit tree orchards of the field laboratory of the department of agroforestry and environment, HSTU, Dinajpur. It was two factor RCBD designed experiment. The two factors was; factor A: production systems, N_1= 0 kg N per hectare, N_2= 50 kg N per hectare, N_3= 100 kg N per hectare and N_4= 150 kg N per hectare; factor B: Nitrogen fertilizations, S_1= Napier sole cropping, S_2= Neem + Napier fodder and S_3= Mahagoni + Napier fodder. Napier cutting was planted on the same day morning and afternoon in all the 36 plots.

Both nitrogen fertilizer and agroforestry systems independently affect the growth of Napier grass. Optimal nitrogen levels (especially 150 kg/ha) substantially enhance plant height, though benefits may vary based on the growth stage and associated cropping system. Sole cropping ensures the maximum expression of growth potential, while tree-based systems like Neem + Napier can still maintain respectable growth with ecological benefits. Both nitrogen application and agroforestry system significantly influence the collar diameter of Napier grass, a trait vital for plant strength and yield potential. Sole cropping systems and higher nitrogen levels (150 kg N/ha) provide the most favorable conditions for robust stem development. However, interaction effects reveal that even under resource-competitive systems like Mahagoni + Napier, optimal nitrogen levels (especially 50–100 kg N/ha) can still support structural vigor. Tiller development in Napier grass is significantly influenced by both nitrogen fertilization and agroforestry system. Nitrogen rates up to 150 kg/ha significantly increase tiller numbers, confirming nitrogen’s role in promoting vegetative propagation. Agroforestry systems, particularly Mahagoni-based ones, may suppress tiller formation due to shading and competition, though these effects can be partially mitigated by optimal nitrogen application.

N_2S_3 and N_3S_2 demonstrate that moderate nitrogen in tree-based systems can still support high tillering, highlighting the importance of adaptive nutrient management strategies in agroforestry. The number of leaves in Napier grass is significantly enhanced by nitrogen fertilization and is also affected by the cropping system. Higher nitrogen levels, particularly 150 kg N/ha, resulted in the maximum number of leaves, confirming nitrogen's crucial role in vegetative growth. Sole cropping provides the best environment for leaf development due to the absence of shading and competition. However, Neem-based systems offer a viable alternative with moderate leaf production and ecological benefits. While interaction effects were not statistically significant, combinations such as N_2S_3 and N_3S_2 showed promising results, suggesting that intermediate nitrogen levels may optimize growth in tree-integrated systems.

Leaf length in Napier grass is significantly enhanced by nitrogen fertilization and affected by the cropping system, particularly in the context of agroforestry. Nitrogen application up to 150 kg/ha consistently increased leaf elongation, which is vital for maximizing photosynthetic area and fodder yield. Sole cropping resulted in the longest leaves due to optimal light conditions, while Mahagoni-based systems suppressed leaf growth due to shading and resource competition. The interaction of nitrogen and tree system, although statistically non-significant, revealed that intermediate nitrogen levels (50–100 kg/ha) under Mahagoni and Neem can support substantial leaf elongation sometimes exceeding that of sole cropping. This highlights the potential for optimized nitrogen use to mitigate the competitive effects of agroforestry components.

The leaf breadth of Napier grass leaves is positively influenced by nitrogen application, especially during early vegetative growth. The greatest response was observed at 30 DAS, with 150 kg N/ha (N_4) producing the widest leaves. However, as the crop matures, the differences in leaf breadth diminish, suggesting a temporal limitation to nitrogen's effect on this trait. The agroforestry system significantly influenced leaf breadth only during early stages, with sole cropping showing the best results due to favorable microclimate and absence of competition. Mahagoni-based systems consistently exhibited lower values, although under certain nitrogen levels, such as N_2, they surprisingly supported wider leaves.

The study reveals that nitrogen fertilization significantly increases the green forage yield of Napier, with 150 kg N/ha (N_4) emerging as the most effective rate. Yield is also significantly influenced by the agroforestry system, where sole cropping is superior due to the absence of competition. However, Neem-based systems show promising intermediate performance, offering a sustainable compromise between productivity and ecological benefits. In contrast, dry matter content is less responsive to nitrogen but significantly affected by the agroforestry system. Sole cropping produces the highest DM, while Mahagoni-based systems result in the lowest, possibly due to excessive shading and delayed tissue hardening. Although the interaction effects were not statistically significant for DM, combinations like N_2S_2 and N_1S_3 suggest that tree selection and moderate nitrogen can favor higher forage quality.

Conclusions:

Based on the findings from the study on the influence of nitrogen fertilization and agroforestry systems on Napier grass growth and productivity, the following conclusions can be drawn;

1. Nitrogen serves as an important driver of growth and yield traits of Napier grass with significant increases noted in leaf length and width of leaf on a particular sampling date in nutrient–poor (low nitrogen) system to zero allowance of inter-specific competition in a sole cropping system. A high nitrogen rate (150 kg N/ha) had the best effect on plant height, tiller number, leaf explansion, and green forage yield, which indicated nitrogen was a critical input to promote vigorous vegetative growth.
2. Agroforestry systems placed some constraints on Napier grass performance, and the sole cropping (S_1) cropping system allowed for greatest expression of growth potential due to zero inter-specific competition. The neem-based cropping systems (S_2) offered a compromise of ideal growing conditions and ecological impacts on the surrounding environment. On the one hand, the neem systems gained the environmental sustainability benefits of being intercropped with trees, but were still quite sustainable due to moderate growth levels of Napier grass.
3. Collar diameter (size) and structural development of Napier grass were optimized within the high nitrogen allowance (150 kg N/ha) and the sole cropping systems. There was some reasonable structural vigour maintained when growing Napier grass herbs under resource competition in a Mahagoni + Napier system in the treatment combinations with intermediate levels of nitrogen (50 – 100 kg/ha).
4. All vegetative plant dimensions (number of leaves, leaves length, and leaf breadth) performed well with nitrogen fertilization, particularly in the early growth stage, while the agroforestry systems (particularly Mahagoni) may have reduced the leaf development because of shading and competition for light. Nevertheless, from N_2S_2 and N_3S_2 it appears that at least some nitrogen modest alleviated the shading and light competition to get leaf development.
5. The forage yield of Napier grass was proliferated and impacted by fertilization rates and cropping systems, while the nutritive value or nutritional quality of the material for dry matter decline was primarily affected by the agroforestry system and had little

impact from the nitrogen levels. The sole cropping system produced the greatest DM values, with Mahagoni system produced the lowest DM yield values (800 g DM/ha) and most likely why it did not produce better yields was related to the time until tissue hardening occurred as a late effect of the shading.

Recommendations:

Here are some recommendations based on the following study and its findings:

1. Applying 150 kg N/ha showed the best results for Napier grass height, tillers, leaf development and green forage yield. Farmers should use this rate if they want maximum growth, specially in open field without trees.

2. Growing Napier without trees (sole cropping) helped the grass grow better since there's no competition for light and space. It might not be as eco-friendly as tree-based systems, but it gives better yield and stronger plants.

3. Neem-based agroforestry gave okay results compared to Mahagoni. It's may considered as a good middle choice for farmers who want to protect the environment but still get moderate Napier growth and yield.

4. In tree-based systems like Mahagoni + Napier, using 50–100 kg N/ha still helped the grass grow decently. So when trees are already there, farmers don't always need to go for the highest nitrogen level, a moderate dose may work just fine.

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APPENDICES

Appendix I: Monthly recorded of air temperature, rainfall, relative humidity and sunshine at the experimental site

Months	Temperature		Relative humidity (%)	Rainfall (mm) Total)	Sunshine (hr) (Total)
	Maximum	Minimum			
November 2019	28.89	13.53	70.56	3.45	4.52
December 2019	20.11	10.58	61.78	1.140	5.23
January 2020	18.42	8.12	63.56	0.0	6.12
February 2020	27.21	14.17	65.52	1.75	5.12
March 2020	30.12	189.54	75.25	10.52	5.01

Source: Bangladesh Meteorological Department (Weather Research Station) Rajbati, Dinajpur

Appendix II. Physical and chemical properties of soil used in experiment

Characteristics	Value	Critical value	Analytical methods
Sand (%)	50.8	-	Sedimentation and Decantation method
Silt (%)	32.4	-	
Clay (%)	16.8	-	
Textural class	Loam	-	Hydrometer method
pH	6.13	-	Glass-electrode pH meter
EC (dS/m)	7.90-15.69	-	EC meter
Organic carbon (%)	0.479	-	Wet oxidation method
Organic matter (%)	0.825	-	Wet oxidation method
Total N (%)	0.06	0.10	Micro Kjeldhal method
Available P (ppm)	12.11	10.00	Borax method
Exchangeable K (me 100^{-1} g soil)	0.32	0.12	Using an Atomic Absorption Spectrophotometer
Available S (ppm)	14.21	10.00	Turbidity method using BaCl2

Source: Soil Resources Development Institute (SRDI) Noshipur, Dinajpur.

PLATES

Plate 01. Land preparation

Plate 02. Napier in field condition

Plate 03. Field visit by supervisor

Plate 04. Data collection

Plate 05. Harvesting