DETERMINATION OF COMPARATIVE BIOMASS YIELD, NUTRITIONAL QUALITY AND PRODUCTION COST OF FIVE DIFFERENT HYDROPONIC FODDER SPECIES

A THESIS

BY

MD. MUSTAJABUR RAHMAN

STUDENT ID NO.: MS- 230830

AGROTECHNOLOGY DISCIPLINE

KHULNA UNIVERSITY

KHULNA-9208

JUNE, 2024

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ABSTRACT

Hydroponics technology is the practice where plants are cultivated without using the soil. It has emerged as a promising method for green fodder production. This technology can be utilized to avoid shortage of animal feed caused by limited arable land. The study aims to compare biomass production, analyze nutritional content, and assess the production costs of five hydroponically grown fodder species- maize (*Zea mays*), wheat (*Triticum aestivum*), oat (*Avena sativa*), sorghum (*Sorghum bicolor*), and cowpeas (*Vigna unguiculata*). The experiment was conducted at Khulna University. The research was conducted using completely randomized design (CRD) and experimental setup involved collection of seed, preparation of seeds, preparation of growing area. Seeds were selected for quality, soaked, and sprouted before being distributed on trays. Cultivated hydroponic fodders were harvested on 11th day. Key parameters such as production of biomass, the height of the plant, the length of the primary roots, and chlorophyll content were recorded. A cost analysis for production of fodders using hydroponic technology was also performed. Nutritional composition of hydroponic fodders was also analyzed. On day 11, oat had the highest biomass yield (1254.22g ± 249.98), followed by cowpea (1045.22g ± 71.57) from 250 g seeds. In terms of plant height, oat (19.81 cm ± 1.34) and maize (19.04 cm ± 1.40) were highest. Maize showed the longest root length (28.59 cm ± 0.12), while cowpea had the highest chlorophyll index (39.17 ± 0.69). Cost analysis revealed sorghum (51.16 BDT/kg ± 3.90) and cowpea (50.52 BDT/kg ± 3.99) had the highest production costs, whereas wheat had the lowest (21.12 BDT/kg ± 1.17). Proximate analysis showed that wheat had the highest dry matter content (26.62% ± 2.91) and cowpea the highest crude protein content (25.80% ± 0.48). This study highlights the potential of hydroponic technology to address fodder shortages by providing a sustainable and efficient alternative to conventional cultivation. The findings suggest that adopting hydroponics for fodder production could significantly enhance livestock nutrition and productivity in regions with limited arable land. Future research is needed for better utilization of hydroponic technology to increase disease resistance during cultivation and to increase productivity. Scalability of this technology and its long-term economic impacts on the livestock industry is also need to be evaluated.

Keywords: Hydroponics, Fodder production, Livestock nutrition, Nutritive value, Production cost, Sustainable agriculture.

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CHAPTER 1

INTRODUCTION

1.1 Background of the study

The population of the world is predicted to grow to 9.7 billion by 2050. It is also anticipated that half of the arable land of the world will become unfit for agriculture at the same time (UN DESA, 2017). Despite representing only 3% of the total land area on the planet, cities are responsible for 60–80% of energy usage and contribute to 75% of carbon emissions (United Nations, 2023). Urban population growth is primarily driven by several factors, including natural increase, the migration of residents from rural areas to cities, and reclassification, which refers to the annexation and expansion of urban regions at the expense of surrounding rural areas (United Nations, 2018). Migration and reclassification put agriculture in competition with thriving urban areas for soil, water, and labor, requiring it to fight climate change on all fronts—maintaining biodiversity, preserving habitats, and producing more food with fewer workers and less land. It appears that agriculture, being the hub of the food chain, faces a significant challenge. However, despite the thousands of acres treated with chemical pesticides and fertilizers that are no longer suitable for farming because of soil degradation, water scarcity, and climate change, open-field agriculture is still widely practiced worldwide (Zárate, 2014).

The majority of today's farming practices rely on soil and water, making them very susceptible to disasters. Therefore, it is vital that current farming systems' economic policies be changed (Gashgari et al., 2018). Severe climate change, declining soil fertility and water availability, and competition between cereal crops and fodder have made this situation even worse (El-Morsy et al., 2013). Researchers have focused their emphasis on investigating more effective alternative methods of producing fodder in considering the limitations associated with the traditional method and the substantial gap between the availability and demand for green fodder (Girma & Gebremariam, 2018; Naik et al., 2015b).

The efficiency with which animals reproduce and productive is negatively impacted by the lack of high-quality green feed. The main obstacles faced by livestock farmers for the growing of green fodder include limited land availability, increased labor costs associated with farming (sowing, earthning, weeding, harvesting, etc.), longer workdays for harvesting, non-year-round availability of the same quality, requirements for manure and fertilizer, rainfall uncertainty, water scarcity, and natural disasters brought on by climate change (Naik et al., 2016; Reddy et al., 1988).

Hydroponics is one of the soilless culture methods. The Greek terms "hydro" (meaning water) and "ponos" (meaning work) are the origin of the term "hydroponics" (Ani & Gopalakirishnan, 2020). Other names for hydroponic feed crops are sprouting grain, hydroponic forage, and hydroponic feed (Dung et al., 2010). In a greenhouse with regulated conditions, it grows and develops quickly (Sneath & McIntosh, 2003). Hydroponic forage is grown without the need of soil and with water. Nutrient-rich liquids can be used in greenhouses for brief periods of time. The feed, which consists of roots, seeds, and plants, resembles a mat and is likely 20 to 30 cm tall. Animals find it to be extremely tasty, easily digested, and nutrient-dense. When hydroponic fodder is used, milk production increases by 8–13%. In places where the availability of conventional green fodder is restricted, this method serves as an optimal alternative, utilizing cost-effective resources for dairy livestock (Naik et al., 2015b).

A viable substitute technique for sustainable livestock farming is hydroponic fodder production (Girma & Gebremariam, 2019). In comparison to field conditions, hydroponic forage production necessitates only 3–5% of the water to yield an equivalent amount of forage (Al-Karaki & Al-Hashimi, 2012). The application of hydroponic technology supports the growth of a variety of fodder crops, including barley, oats, wheat, sorghum, alfalfa, cowpea, and maize (Al-Karaki & Al-Hashimi, 2012; Brown et al., 2018; Farghaly et al., 2019; Guerrero-Cervantes et al., 2016; Kide et al., 2015; Snow et al., 2008). Cereal green fodder is cultivated hydroponically over a period of 7-9 days (Ajmi et al., 2009; Farghaly et al., 2019; Fazaeli et al., 2011; Gebremedhin, 2015; Wang et al., 2019). The selection of hydroponic fodder varieties is contingent upon the specific geographic and agroclimatic circumstances, as well as the accessibility of seeds. Hydroponic fodder production can also be economically facilitated by the use of wheat (*Triticum aestivum L.*) (Guerrero-Cervantes et al., 2016; Tayade & Chavan, 2018). A variety of six hydroponic systems (HS) are employed for the growth of plants through hydroponic technology (HT), with the choice depending on the approach to nutrient solution delivery. These systems consist of ebb and flow HS, nutrient film technique (NFT), aeroponics, deep water culture HS, wick HS, and drip-irrigation HS. No matter which way the plants are fed, they all share the same parts (pump, frame, and pipe). The development of suitable pumps, time clocks, plastic piping, solenoid valves, and other equipment has made it possible to automate the hydroponic system as a whole, resulting in a reduction of the original investment and continuous operational costs (Tayade & Chavan, 2018).

Hydroponic fodder production has become popular for its advantages in enhancing livestock well-being. Hydroponics fodder is known for its added palatability, digestibility and valuable nutritional value, which contributes to the well-being of livestock (Naik et al., 2015b).

Hydroponic growing systems can achieve a larger harvest of livestock feed, all the while utilizing substantially less space when compared with traditional methods (Schoenian, 2013). The weight of the hydroponically grown maize feed is observed to be 5.5 times more than the weight of the fresh seed.

In comparison to conventional CO-3 green fodder (Napier bajra hybrid) and hydroponically grown barley, the hydroponic fodder of maize had a slightly greater DM content. The crude protein, ether extract, and nitrogen free content of hydroponic maize fodder were lower than those of Napier bajra hybrid (CO-3) green fodder, but the levels of crude fiber, total ash, and acid insoluble ash were higher. The digestibility of crude protein and crude fiber increased ($P<0.05$) in the cows when they were fed hydroponically grown maize fodder (Naik et al., 2014).

There are some limitations of hydroponic fodder. The strong possibility of mold growth is one of the main disadvantages of feed systems. Almost all of the examined studies cited mold growth as a problem with fodder systems. Regrettably, the warm temperatures and high moisture content that are ideal for sprouting grain growth are also ideal for the growth of mold. Many articles noted or advised having backup plans for a feed replacement and in case of a mold epidemic because moldy fodder can result in a loss of feed, sick animals, or even dead animals (Kerr, 2014; Sneath & McIntosh, 2003; Willsey, 2014).

1.2 Justification of the study

Use of hydroponic technology allows for the growth of various crops such as maize, cowpea, barley and chickpea which can be cultivated to yield fodder in a shorter duration of time (Akkenapally & Lekkala, 2021). Hydroponic fodder production offers advantages in efficiently as it converts grain into vibrant green sprouts. For instance, completely independent of soil hydroponic system can be utilized to yield 6 to 10kg of fodder from one kg of grain (Sneath & McIntosh, 2003). Fodder seeds are grown using tap water or nutrient-enriched solutions without soil which makes hydroponic fodder a feasible alternative for fresh feed (Bakshi et al., 2017).

Studies have indicated that sprouting grains has the added benefit of boosting digestibility and producing more enzymes and vitamins A, E, C, and B complex (Finney, 1983; Naik et al., 2015a). The process of sprouting releases enzymes that convert the starches in the grain to sugar, improving the feed's digestibility. But acidosis can result from consuming too much sugar (from excessive amounts of fodder or from feeding too rapidly) (Hafla et al., 2014). In general, producing fodder is expensive per pound of dry matter, and the initial capital cost of these systems—especially pre-fabricated systems that are purchased—can be prohibitive. Good quality hay costs $0.11 per pound of dry matter to produce, but the cost of producing fodder is $0.40, according to an economic analysis (Tranel, 2013).

The nutritional composition of hydroponically grown fodder made from cereal grains varies (Fazaeli et al., 2011). The starch content was inversely correlated with the dry matter and organic matter contents. The plant's metabolic conversion of starch to soluble sugar is known as sprouting. Nevertheless, the ether extract of hydroponic feed rises as a result of the plant's increased production of structural lipids and chlorophyll. With sprouting, the concentration of linoleic acid also increases. The production of structural carbohydrates results in a decrease in nitrogen free extract but an increase in crude, acid, and neutral detergent fibers. The process of sprouting leads to an increase in total ash content and a decrease in organic matter. Beginning on day four, the sprout's mineral content increases due to root growth that increases mineral intake. When more nutritional solution is utilized than water, the ash content rises higher (Dung et al., 2010). In terms of ether extract, nitrogen-free extracts, organic content, and crude protein, hydroponic fodder performs better than conventional non-leguminous fodder. However, the total digestible nutrient content, metabolizable energy, and gross energy all decrease during sprouting. This results from the plant's energy intake during respiration (Ajmi et al., 2009; Fazaeli et al., 2011). Hydroponic fodders are more nutrient-dense than conventional fodders. A nutritional departure occurs during sprouting, leading to an increase in crude protein, ether extract, and nitrogen free extract and a decrease in crude fiber, total ash, and insoluble ash. Plants grown hydroponically that are high in enzymes are called fodder sprouts. The highest level of enzyme activity is seen in the sprouts during the seven days following germination. They contain a lot of antioxidants, including β-carotene (Shipard, 2005; Sneath & McIntosh, 2003).

1.3 Research gap

a. Limited information available on comparative biomass yield of five hydroponic fodder species.

b. Inadequate data of the nutritional composition of different fodders grown hydroponically.

c. Insufficient understanding of production cost analysis for different hydroponic fodder.

d. A lack of understanding regarding the economic feasibility of determining which type of hydroponically grown fodder is most effective.

1.4 Objective(s)

1.4.1 Research Goal

Estimation of comparative biomass production, nutritional value and production cost of five different hydroponic fodders.

1.4.2 Specific Objectives

a. Comparative study on biomass yield of five hydroponically grown fodder.
b. To evaluate the nutritional value of five different hydroponically grown fodders.
c. To assess the production cost of hydroponic fodders.

CHAPTER 2

LITERATURE REVIEW

2.1 Hydroponic system and its types

Hydroponics is a term that finds its roots in the Greek language, where "hydro" signifies water and "ponics" refers to work. This approach allows for the cultivation of plants without relying on soil (Dung et al., 2010). It grows and develops quickly in a greenhouse under regulated conditions (Sneath & McIntosh, 2003).

Six hydroponic systems are widely utilized, including the wick system, drip system, ebb and flow system, water culture system, nutrient film technique, and the recently introduced aeroponic system, along with the window farm model (Akkenapally & Lekkala, 2021; Lee & Lee, 2015). The customizable nature of hydroponic systems has resulted in the development of numerous modified iterations designed to optimize the growing conditions for certain plant varieties (Jensen, 1999). Six basic hydroponic system is discussed below and shown in Figure 1.

2.1.1 Wick system

The wick system or passive system stands out as a very good choice for cultivation of indoor plants. It is a self-sustainable model and water pump is not required (Shrestha & Dunn, 2010). Root area receives a supply of water or nutrient solution from a reservoir through the use of a wick or fibrous materials such as nylon. These materials can absorb and transport water through capillary action. It is usually not used commercially. Process of using this system is very simple and it is used in small scale gardens such as in home or office. This system can resist diseases which are common due to overwatering. This system is not suitable for large plants or long-term use as wick system cannot supply enough water that is required by the plant (Harris, 1988).

2.1.2 Drip system

When nutrient solution is pumped through a tube which is positioned above the plants where solution can dip down onto the plants and roots is called drip system. It is very good for monitoring drip amount closely (Akkenapally & Lekkala, 2021). It is also called drip irrigation system (Reed, 1996). This strategy is most effective for crops like tomatoes and peppers (Velazquez-Gonzalez et al., 2022). This is a common technique used both commercially and home (Rouphael & Colla, 2005). Drip models can be categorized into two types based on the processing of nutrient solutions or recycled water: the circulating system and the non-circulating system. In a system that circulates, the solution is directed back to the reservoir; conversely, in a non-circulating system, the nutrient solution is not reusable and is limited to a single use (Akkenapally & Lekkala, 2021; Santamaria et al., 2003; Schoenian, 2013). Variety of crops can be grown in a systematic manner while preserving water. It is designed to endure brief power outages or equipment malfunctions. This system is also known for its superior water conservation capabilities compared to alternative systems. Setting up this system can be a challenging and costly due to the timed supply of the solution (George & George, 2016; Sharma et al., 2018).

2.1.3 Ebb and flow system

It stands as one of the pioneering systems employed in a commercial context. An automatic flood and drain irrigation system is utilized, which periodically and temporarily submerges the plants in water (Buwalda et al., 1994). Consequently, this system is commonly referred to as a

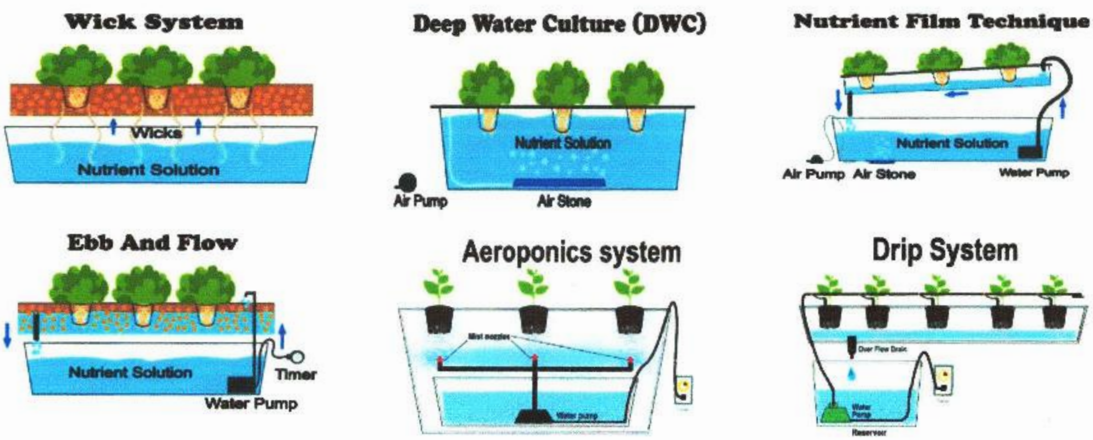

Figure 2.1 Types of hydroponics (Source: www.modernfarmer.sg)

flood and drain system. This hydroponics system, operating on the flood and drain principle is the first of its kind to be introduced in the commercial market. This system has gained popularity due to its low maintenance cost and budget-friendly setup. Root rot, algae and mold is common occurrence in this system that is why which highlights the need for a filtration unit to be integrated into this system (George & George, 2016; Sharma et al., 2018). The nutrient solution is pumped from the reservoir to the top tray, which is then saturated with the nutrient-rich solution for the plants. After a while, the nutrient solution is drained back into the lower reservoir. This approach provides an ample supply of nutrients initially, followed by a subsequent dry phase. During this dry phase, the roots of the plants will expand in their quest for additional nutrients, leading to increased growth rates (Akkenapally & Lekkala, 2021; Nielsen et al., 2006).

2.1.4 Deep water culture (DWC) system

It is also called water culture system. Many of the modified system that are used in hydroponics were originated from this method (Harris, 1988). This is one of the most basic and easiest technique that is used for plant cultivation in hydroponic technique (Akkenapally & Lekkala, 2021). The deep water culture system was designed to support plant growth by keeping roots consistently suspended in water. Progress in aeration technologies plays a crucial role in sustaining adequate levels of dissolved oxygen. The plant system is anchored by a floating platform, ensuring that the roots are always in contact with water or a nutrient solution. An air pump provides oxygen, operating on a periodic basis (Saaid et al., 2013).

2.1.5 Aeroponic system

In 1973-1974 Cabot Foundation Laboratories created a hydroponic system called aeroponics system. This system is intended to promote plant development by allowing the roots to interact with a nutrient mist (Zobel et al., 2013). The origin of the word aeroponic can be traced back to two Latin words where "aero" refers to air and "ponic" refers to work (Lakkireddy et al., 2012). This method is particularly suitable for growing low leafy vegetables like lettuce and spinach (Khan, 2018). Within this arrangement, the plants depend on periodic spraying from a system of sprinklers to absorb nutrients (Velazquez-Gonzalez et al., 2022). This system is not widely adopted in commercial settings, largely because of the significant installation expenses and maintenance demands, which include routine cleaning to mitigate plant diseases and to avoid the clogging of spray heads (Lee & Lee, 2015). Aeroponic farming excels over traditional propagation methods in various aspects, such as aeration, efficient use of water, time and space requirements, independence from seasonal variations, the ability to propagate disease-free plants, and the potential for large-scale production. he adoption of aeroponic techniques has yielded significant commercial success in areas including propagation, seed germination, seed potato production, tomato production, leafy crops, and micro-greens. This system has been instrumental in the commercial cultivation of numerous vegetable crops, such as potatoes, yams, tomatoes, lettuce, and various leafy vegetables (Kumari & Kumar Bhardwaj, 2019).

2.1.6 Nutrient film technique (NFT)

To address the constraints of the ebb and flow system, the nutrient film technique (NFT) was established in the 1960s (Jones Jr., 2004). This technique presents beneficial choice to increase oxygen levels and lower water usage. The main difference with this system is utilization of a row of plants, suspended at a slight tilt. This tilt facilitates the movement of water through the root tips by gravitational force (Akkenapally & Lekkala, 2021). The reservoir contains water or nutrient solution that circulates throughout the system, entering the growth tray through a water pump that functions without time control, thus maintaining a steady flow around the roots (Domingues et al., 2012). This system facilitates the collection and reuse of the solution, while the water level is managed through the inclination of the tray and the capacity of the water pump. However, the roots are at risk of fungal infections as they are kept submerged in water or nutrient solution (Thinggaard & Middelboe, 1989). This technique is analogous to the Deep Water Culture (DWC) system; however, the roots of the plants do not remain entirely submerged in the nutrient solution (Velazquez-Gonzalez et al., 2022). In a conducted experiment, flow rates of 10, 20, and 30 L/h were allocated. The results demonstrated that the growth of lettuce was improved when the flow rate was set at 20 L/h, in comparison to both 10 L/h and 30 L/h (Al-Tawaha et al., 2018). In another study it was revealed that, vegetable plant sample displayed robust growth during cultivation with superior quality yield of crops when harvested in around 3.5 weeks (Kuncoro et al., 2021).

2.2 Watering techniques utilized in six basic hydroponic system with their advantages and disadvantages

According to Ahamed et al. (2023) watering technique with their advantages and disadvantages is shown in Table 2.1.

Table 2.1 Watering techniques with their advantages and disadvantages of six basic hydroponic system (Ahamed et al., 2023)

Name of the hydroponic system	Watering technique	Advantage	Disadvantage
Wick system	Plants are set in porous growing media which is submerged in a liquid by capillary action	-Low cost of maintenance -Small plants are ideal -Simple, cost-effective, and easy	-Vulnerable to algae growth -Oxygen excess is limited -Recirculation facility is absent

Drip system	Nutrient solution is supplied to each plant root through a dripping mechanism	-Recirculation is possible -Enough oxygen flows -Nutrient absorption is maximum	-Regular cleaning is required -Occurrence of clogging in holes -Vulnerable to algae growth
Ebb and flow system	Nutrient solution is periodically flooded into the plant roots in the growing channel	-Uniform germination of seeds -Maintenance cost is low -Recirculation is possible	-Vulnerable to algae growth -Occurrence of clogging in recirculation valve -Technical problem can result in loss of crop yield
Deep water culture (DWC) system	Plant roots are suspended in a nutrient solution and oxygen is provided by air stone	-Biomass yield is high -Nutrient pump is not required -Cost effective and reliable	-Occurrence of various common root diseases -Growth rate is slow -Reservoir need to be refilled on regular basis
Aeroponic system	Plants are held in mid-air with their roots exposed to a fine spray of nutrient-rich solution	-Very good oxygen flow -Growth of plant is fast -Nutrient absorption is maximum	-Nozzles often get clogged -Not very suitable fort thick organic based nutrients -Production cost is high

Nutrient film technique (NFT)	Plants are positioned within a tilted growing channel with a continuous flow of nutrient solution constantly bathing their roots.	-Water requirement is low -Absence of clogging -Enough Oxygen flow	-Flowrate is low due to poor supply of nutrient solution -Technical problem will cause loss in yield of crops

By combining any of the basic six methods mentioned above hybrid systems can also be developed (Akkenapally & Lekkala, 2021). Moreover, According to Goddek et al. (2019) hydroponic system can be classified according to different aspect which is shown in Table 2.2 as categorization of the different soilless systems is essential due to the multitude of systems that can be employed.

Table 2.2 Classification of hydroponic system according to different aspects (Goddek et al., 2019)

Characteristics	Category	Examples
Water supply	Continuous	-Deep Flow Technique (DFT) -Nutrient Film Technique (NFT)
	Periodical	-Ebb and flow system -Aeroponics -Deep irrigation
Open/closed systems	Closed or recirculation system	-Closed loop system
	Open or run to waste system	-Open cycle system
Soilless system	With substrate	-Organic substrate (Coconut fiber, wood fiber, peat etc.) -Inorganic substrate (Stone wool, sand, expanded clay, perlite, vermiculite etc.)
	No substrate	-Deep Flow Technique (DFT) -Nutrient Film Technique (NFT) -Aeroponics

2.3 Substrates

Substrate works as structural foundation of plants that holds them upright and creates optimal conditions for growth through the supply of a sterile, well-oxygenated environment and a steady supply of nutrients (Gruda et al., 2017). Table 2.3 provides an overview of commonly used substrates in some hydroponic system with their advantages and disadvantages. Certain important factors to consider when deciding on a substrate includes chemical inertness, biological inertness, porosity, oxygenation and c capillarity which are shortly described under the following section (Malik et al., 2014; Olle et al., 2012; Vinci & Rapa, 2019).

- Chemical inertness: It is imperative that the substrate is composed of materials that do not interact with the chemicals present in the nutrient solution. Any reaction will cause changes in its composition of the nutrients.
- Biological inertness: Diseases can easily spread among plants that have a high root density caused by circulation of the nutrient solution. Immediate corrective actions are necessary to prevent the transmission of diseases. It is essential that the substrate does not encourage biological activities as microorganisms can harm plants by causing diseases, malnutrition and other adverse outcomes.
- Porosity: The performance of plants in various metabolic functions, including respiration, transpiration, and photosynthesis, is reliant on the availability of nutrients, which is directly correlated with the porosity of the soil.
- Oxygenation: Substrate needs to be constructed in such a way that allows the roots to intake oxygen when it is in contact with the nutrient solution.
- Capillarity: Nutrients are absorbed by the substrate through capillarity and then nutrients are transported to the root of the plant for distribution.

Table 2.3 Commonly used substrates in some hydroponic system

Material	Advantage	Disadvantage	Source
Coconut coir	Decent water holding capacity and air content, pH ranges from 5-8, Low density (approx. 60kg/m3)	Salt content is high, energy consumption occurs during transport	(Savvas & Gruda, 2018)
Sand	Cost effective, decent porosity and decent plant support	Low water retention, salt accumulation occurs, high density (appox. 1500kg/m3)	(Olle et al., 2012)
Rockwool	Easy to handle, completely inert, low density (approx.80kg/m3)	Reusing causes negative impact on health	(Gruda, 2019; Othman et al., 2019, p. 20)
Vermiculite	Adequate nutrient holding capacity, decent water holding capacity, low density (Approx. 80kg/m3)	Consumes energy, expensive	(Malik et al., 2014)
Peat/Peat moss	Inert material, water holding capacity is high, leaching of nutrients is preventable	Negative impacts on environment like loss of organic carbon from soil, comparatively expensive	(Othman et al., 2019)
Perlite	Biologically inert material, pH is neutral, low density (Approx. 90kg/m3)	Water holding capacity is low, expensive	(Vinci & Rapa, 2019)
Pumice	Cost-effective and long lasting, density is low, chemically inert	Growth and yield of crops is affected by hydraulic properties and particle size	(Gizas & Savvas, 2007)

2.4 Nutrient solution

In a hydroponic system, plants are provided with all required nutrients via a nutrient solution, while carbon, hydrogen, and oxygen are acquired from the surrounding air. The provision of nutrient sources is predominantly achieved through the use of inorganic fertilizers, with iron being an exception as it is supplied in chelated form to improve its accessibility for plants. Many of the fertilizers utilized in hydroponic systems for nutrient solution preparation consist of highly soluble inorganic salts, and certain inorganic acids are also integrated into the mix (Gianquinto et al., 2013). According to Gianquinto et al. (2013), The chemical makeup of the nutrient solution is influenced by the specific type of crop and the growth stage of the plant. Few fertilizers which are soluble in solution used in hydroponic system are shown in Table 2.4. The primary plant organ responsible for absorbing nutrients is its active roots. Protons (H^+) or hydroxyls (OH^-) are forced out of the plant by anions and cations upon absorption from the nutrient solution, preserving the equilibrium of electric charges (Haynes, 1990).

Table 2.4 Commonly used soluble fertilizer in hydroponics (Gianquinto et al., 2013)

Fertilizer	Chemical formula	Percentage in nutrient	Molecular weight (g)	Solubility (kg liter^{-1}, 0°C)
Ammonium heptamolybdate	$(NH_4)6Mo_7O_{24}$	Mo: 58	1163.3	0.43
Ammonium nitrate	NH_4NO_3	N: 35	80.0	1.18
Borax	$Na_2B_4O_7.10H_2O$	B: 11	381.2	0.016
Boric acid	H_3BO_3	B: 17.5	61.8	0.050
Calcium nitrate	$5[Ca(NO_3)_2.2H_2O]$ NH_4NO_3	N: 15.5, Ca: 19	1080.5	1.02
Copper sulfate	$CuSO_4.5H_2O$	Cu: 25	249.7	0.32
Iron chelates	Various types	Fe: 6–13	-	-
Magnesium nitrate	$Mg (NO_3)_2.6H_2O$	N: 11, Mg: 9	256.3	2.79 (at 20°C)
Magnesium sulfate	$MgSO_4.7H_2O$	Mg: 9.7, S: 13	246.3	0.26
Manganese sulfate	$MnSO_4.H_2O$	Mn: 32	169.0	1.05
Monoammonium phosphate	$NH_4H_2PO_4$	N: 12, P: 27	115.0	0.23
Monopotassium phosphate	KH_2PO_4	P: 23, K: 28	136.1	1.67
Nitric acid	HNO_3	N: 22	63.0	-
Phosphoric acid	H_3PO_4	P: 32	98.0	-
Potassium bicarbonate	$KHCO_3$	K: 39	100.1	1.12
Potassium nitrate	KNO_3	N: 13, K: 38	101.1	0.13
Potassium sulfate	K_2SO_4	K: 45, S: 18	174.3	0.12
Sodium molybdate	$Na_2MoO_4.2H_2O$	Mo: 40	241.9	0.56
Sodium octaborate	$Na_2B_8O_{13}.4H_2O$	B: 20.5	412.4	0.045
Zinc sulfate	$ZnSO_4.7H_2O$	Zn: 23	287.5	0.62

2.5 Ideal crops for hydroponics

Several crops that are hydroponically appropriate are listed in Table 2.5. (Zárate, 2014)

Table 2.5 Crops suitable for hydroponic system

Type	Common Name	Scientific Name	Cultivation Technique
Bulb Vegetables	Garlic	*Allium sativum*	Drip system
	Leek	*Allium porrum*	NFT, Drip system
	Onion	*Allium cepa*	NFT, Drip system
Fruit Vegetables	Chile	*Capsicum annuum*	Drip system
	Eggplant	*Solanum melongena*	Drip system
	Green bean	*Phaseolus vulgaris*	Drip system
	Pea	*Pisum sativum*	Drip system
	Squash	*Sechium edule*	Drip system
	Tomatillo	*Physalis ixocarpa*	Drip system, NFT
	Tomato	*Solanum licopersicum*	Drip system, NFT
Inflorescent Vegetables	Broccoli	*Brassica oleracea var. Italica*	Drip system, NFT
	Cantaloupe	*Cucumis melo*	Drip system, NFT
	Cauliflower	*Brassica oleracea var. botrytis*	Drip system, NFT
	Cucumber	*Cucumis sativus*	Drip system, NFT
	Huauzontle	*Chenopodium sp.*	NFT, DWC
	Watermelon	*Citrullus vulgaris*	Drip system
	Zucchini	*Cucurbita pepo*	Drip system, NFT
Leafy Vegetables	Brussels sprouts	*Brassica oleracea var. gemmifera*	NFT, DWC
	Cabbage	*Brassica oleracea var. capitata*	NFT, DWC
	Celery	*Apium graveolens*	NFT, DWC
	Chard	*Beta vulgaris var. cicla*	NFT, DWC

	Coriander	*Coriandrum sativum*	NFT, DWC, Drip system
	Lettuce	*Lactuca sativa*	NFT, DWC
	Mustard	*Brassica nigra*	NFT, DWC
	Parsley	*Petroselinum crispum*	NFT, DWC
	Purslane	*Portulaca oleracea*	NFT, DWC
	Spinach	*Spinacia oleracea*	NFT, DWC
	Watercress	*Nasturtium officinale*	NFT, DWC
Pulse Vegetables	Bean	*Vicia faba*	Drip system
	Sweet Corn	*Zea mays*	Drip irrigation
Root Vegetables	Beetroot	*Beta vulgaris*	Drip system, aeroponics
	Carrot	*Daucus carota*	Drip system, aeroponics
	Jicama	*Pachyrrhizus erosus*	Drip system
	Radish	*Raphanus sativus*	Drip system, aeroponics
	Turnip	*Brassica rapa*	NFT
	Yucca	*Manihot esculenta*	NFT, Drip system
Stem Vegetables	Artichoke	*Cynara scolymus*	Drip system
	Asparagus	*Asparagus officinalis*	NFT, DWC
	Swede	*Brassica oleracea var. gongyloides*	Drip system
Tuber Vegetables	Potato	*Solanum tuberosum*	Drip system
	Sweet potato	*Ipomoea batatas*	Drip system

2.6 Implementation of hydroponic technology for fodder production

Hydroponic feed crops are alternatively referred to as hydroponic forage. Other names include sprouted feed, or sprouted grain (Dung et al., 2010). Hydroponic technology is applicable for the cultivation of various feed crops, including barley, oats, wheat, sorghum, alfalfa, cowpea, and maize (Al-Karaki & Al-Hashimi, 2012; Brown et al., 2018; Farghaly et al., 2019; Guerrero-Cervantes et al., 2016; Kide et al., 2015; Snow et al., 2008). The cost of the seeds accounts for 85–90% of the total production costs in the hydroponic fodder production method (Naik, 2014; Jemimah et al., 2015).

In a greenhouse, grain sprouting takes place in just seven days or less (Sneath & McIntosh, 2003). An inflated or framed structure covered in a transparent or translucent material is called a greenhouse. It is large enough to allow someone to work within it and cultivate crops under conditions that are at least partially controlled (Chandra & Gupta, 2003). Hydroponic fodder is grown without soil but with the help of water. It is possible to employ nutrient-rich liquids in greenhouses for brief periods of time. However, tap water can be used instead of this fertilizer solution. The feed is made up of roots, seeds, and plants and resembles a mat that is about 20 to 30 centimeters tall. It is considered to be very tasty, easily digested, and nutrient-rich for animals. Utilizing hydroponic feed results in an enhancement of milk production by 8 to 13%. In areas where conventional green fodder is in short supply, this method is the most practical alternative for dairy livestock, relying on cost-efficient resources (Naik et al., 2015b).

The efficiency with which animals reproduce and are productive is negatively impacted by the lack of high-quality green feed. The main obstacles faced by livestock farmers for the production of green fodder include limited land availability, increased labor costs associated with farming (sowing, earthning, weeding, harvesting, etc.), longer workdays for harvesting, non-year-round availability of the same quality, requirements for manure and fertilizer, rainfall uncertainty, water scarcity, and natural disasters brought on by climate change (Naik et al., 2014; Reddy et al., 1988).

2.7 Commonly used method of hydroponic technology for fodder production

It entails obtaining high-quality, viable, sound, intact, and untreated seeds and grains (Naik et al., 2015a; Sneath & McIntosh, 2003). Before seed washing, seeds are directly dried in the sun for one day. After properly washing the seeds with tap water for five minutes, all dirt and subpar seeds are eliminated. The seeds of several fodder species are subjected to a stimulant solution, which consists of either 0.1–1.5% sodium hypochlorite or 1-2% hydrogen peroxide, with soaking durations of 20 hours for maize, 12 hours for jowar, 10 hours for barley, 6 hours for wheat, and 15 hours for bajra (Jemimah et al., 2015).

For 30–60 minutes, the seeds should be cleansed in a solution of 1-2% hydrogen peroxide or 0.1–1.5% bleach (sodium hypochlorite) (Jeton, 2016; Jemimah et al., 2015). Once the cleaning solution has been drained, the seeds undergo a washing process with tap water. For twelve hours, seeds were soaked in fresh water. After that, all of the water was drained out, and the grains were let to hang in a perforated bucket for a full hour to get completely dry on the outside (Bari et al., 2022). But soaking time can vary depending on the species of the seeds used. Duration time can be 4 hours (Naik et al., 2014), 12–16 hours or whole night (Al-Karaki & Al-Momani, 2011; El-Deeba et al., 2009). Speed at which seeds germinate is influenced by the temperature of the soaking solution, which varies according to the hardness of the seed coat. Average 23°C is a suitable temperature for soaking (Sneath & McIntosh, 2003). Seeds were placed into a gunny bag and covered with a cotton cloth for germination after soaking; in less than 24 hours, about 85% of the grains germinated and after germination both non-germinated and germinated seeds were sprayed and transplanted onto aluminum trays that had been sanitized. (Bari et al., 2022).

In some cases, following soaking, the seeds are spread out in plastic or lightweight metallic trays up to one centimeter deep. The trays incorporate holes that serve to drain wastewater and nutrient solutions, allowing for the accumulation of waste in a tank that can be recycled. The output of fodder is also determined by the seed rate, defined as the number of seeds planted per unit area, which differs based on the seed variety. For the hydroponic production of barley, wheat, or sorghum feed, a seeding rate of 4 to 6 kg/m² is advised (Al-Karaki & Al-Momani, 2011) and between 6.4 and 7.6 kg/m² for maize (Naik et al., 2014, 2017). Water or nutrient solution was supplied in usually manually by hand sprinklers (Akinmutimi et al., 2022; Bari et al., 2022; Kide et al., 2015).

2.8 Environment for fodder production

2.8.1 Temperature and relative humidity

A study found that barley fodder was produced for feedlot calves in a controlled environment hydroponic system with a temperature control of between 18 and 21°C and a relative humidity of 70%. The growth trays measured 70 centimeters in length, 30 centimeters in width, and 5 centimeters in height, and the harvesting period was six days. According to the study's findings, fresh barley yielded 21.9 kg/m² of fodder, in contrast to the 4.3 kg/m² yield from dry barley (Fayed, 2011). A further examination demonstrated the yield of barley fodder, achieved by sustaining a temperature of 24°C along with a relative humidity of 50% to 73%. Growing trays measuring 45 cm x 25 cm x 8 cm and requiring nine days for harvesting were employed by the authors. In fresh weight, barley fodder yielded 25.0 kg/m^2; in dry weight, it was 4.1 kg/m^2 (Al-Karaki, 2011). The productivity and nutritional advantages of hydroponically produced barley and maize were tested as goat fodder (Konkan Kanyal goat). The conditions were regulated to maintain a temperature range of 22 to 27 degrees Celsius and a relative humidity level of 70 to 80 percent. The growth tray measured 55 cm in length, 31 cm in width, and 5 cm in height, with a harvesting period of 8 days. The fresh yield for barley was recorded at 52.9 kg/m^2, while maize yielded 47.1 kg/m^2 (Gebremedhin, 2015). Ideal temperature and relative humidity might be between 16 and 27 degrees Celsius and 70 and 80%, respectively, to get an effective biomass output (Bakshi et al., 2017; Merino, 2011).

2.8.2 Water consumption

The water intake for berseem, lucerne, oat, sorghum, and cowpea were reported by the authors to be 454.5, 713.3, 312.5, 267.0, and 555.0 liters per kilogram, respectively. With a water requirement of only 2-3 liters to produce 1.0 kg of green fodder, hydroponic fodder cultivation is gaining recognition for its ability to conserve water (Indira et al., 2020; Ramteke et al., 2019; Suma et al., 2020). An experiment was conducted utilizing five different hydroponically cultivated fodder crops: wheat, alfalfa, barley, cowpea, and sorghum, to assess their water consumption and efficiency in water usage. Each growing tray underwent two manual rinses daily, maintaining a consistent flow rate of 0.6 liters. The results indicated that cowpea (1.58 L kg^{-1}) and barley (1.55 L kg^{-1}) exhibited lower water usage compared to sorghum (1.71 L kg^{-1}), wheat (1.80 L kg^{-1}), and alfalfa (1.92 L kg^{-1}). The fresh yield measurements for wheat (552 kg m^{-3}), alfalfa (521 kg m^{-3}), barley (645 kg m^{-3}), and cowpea (633 kg m^{-3}) were utilized to evaluate water use efficiency (Al-Karaki & Al-Hashimi, 2012). A separate study investigated the water consumption associated with maize cultivated through hydroponic methods. Drip system was used to irrigate the growing trays, and the water consumption ranged from 1.65 to 2.0 L kg^{-1} (Kide et al., 2015). In a research, the ideal pH range for the water was 6.3, and its temperature should be between 15 and 25 °C (Merino, 2011).

2.8.3 Artificial lighting

In low sunshine situations, artificial or additional lighting is employed to make up for the lack of light required for photosynthesis. Plant productivity has increased substantially because to the supplementary lighting (Hao et al., 2018; Rahman et al., 2021). Red and blue LED lights together have been shown to be the most essential for photosynthesis. The primary photosynthetic pigments effectively absorb the wavelengths produced by the mixture of red and blue light (Hao et al., 2018). The yield of wheat fodder grown hydroponically was assessed in a study that compared the effects of red, blue, and a combination of red and blue LED lights against the yield produced under natural sunlight. When comparing the yields, the combination of red and blue LED lights achieved the highest wheat fodder yield of 15.5 kg m^{-2}, exceeding the yields from red LED (14.3 kg m^{-2}), blue LED (13.9 kg m^{-2}), and sunlight (14.5 kg m^{-2}), while also delivering significant nutritional advantages. Additionally, the author conducted an economic study that resulted in a cost-benefit ratio of 1.63. (Bhat et al., 2021). Another study looked at the impact of fluorescent lighting on wheat fodder yield. The intensity of the fluorescent lighting was measured at 4.01 μmol m^{-2} s^{-1}, and it incorporated red and blue light wavelengths of 617-627 nm and 449-459 nm, achieving a total light intensity of 245 μmol m^{-2} s^{-1}. Throughout a seven-day growth period, every lighting source operated for 12 hours each day. According to the findings, fluorescent lighting produced the highest yield of wheat fodder (Grigas et al., 2020). An investigation examined the effects of several light sources, including LED, compact fluorescent, fluorescent, and natural light, on the yield of barley feed. For all of the chosen light sources, the daily light exposure time ranged from 6.0 to 24 hours. The writers came to the conclusion that LED lighting throughout the 12- to 18-hour photoperiod produced the highest yield of barley fodder (Mosallam et al., 2016). A separate experiment explores the effects of natural light, absent of extra lighting, as well as red and blue LED light in a 3:1 ratio for a 16-hour photoperiod, with an emphasis on the height of the plants. Compared to natural light, the authors found that LED light produced higher plant height growth. The findings from the extensive literature suggest that the use of both red and blue LED lights substantially supports the growth, development, and photosynthesis of plants in controlled environment facilities (Pennisi et al., 2019a; Pennisi et al., 2019b).

2.9 Nutrient data of hydroponic fodder

The nutritional qualities of the hydroponically produced fodder differ from those of the conventional fodder crops (Fazaeli et al., 2011). Grain sprouting causes a rise in the overall ash content, which is correlated with a fall in organic matter (El-Morsy et al., 2013). Several research efforts have revealed that there is no evident rise in dry matter (DM), and throughout eight to ten cycles of sprouting, the changes in dry matter ranged from a 10% decrease to a 15% increase (Shit, 2019). The absorption of energy and carbohydrates by the seed's metabolic processes during germination may be the cause of the loss of dry matter (Kaouche-Adjlanea et al., 2016). Yield, dry matter and crude fiber of various hydroponic fodder species at 8th day harvesting of the crop is shown in Table 2.6.

Table 2.6 Yield, dry matter and crude fiber of various hydroponic fodder species (Jolad et al., 2018)

Crop	**Green Fodder Yield (kg kg^{-1} of seed)**	**Dry Matter Yield (g kg^{-1} of seed)**	**Crude Fiber (%)**
Bajra fodder	2.73	304.61	4.60
Barley	3.19	382.05	6.17
Cowpea fodder	4.20	502.28	6.92
Grain bajra	2.69	300.05	4.25
Grain cowpea	5.29	692.53	7.16
Grain maize	5.37	704.96	7.17
Horse gram	5.24	689.80	7.18
Maize fodder	5.48	720.77	7.23
Oat	3.12	368.88	6.08
Soybean	0.00	0.00	0.00
Wheat	3.14	372.68	6.12

Experiments are undertaken to determine the proximate/chemical analysis of different hydroponic which are shown in Table 2.7 and Table 2.8.

Table 2.7 Cultivation details and nutritive value of different hydroponic fodder species with all proximate components

Fodder species	**Maize (*Zea mays L.*)**	**Wheat (*Triticum aestivum*)**	**White sorghum (*Sorghum bicolor*)**	**Red sorghum (*Sorghum bicolor*)**	**Cowpea (*Vigna unguiculata*)**
Day of harvest	8th	8th	7th	7th	7th
Seed weight per tray	500g	450g	500g	500g	490g
Seed treatment before soaking	None	None	Hydrogen peroxide	Hydrogen peroxide	30 min. in 20% sodium

			solution with about 1 liter of water for 20 minutes	solution with about 1 liter of water for 20 minutes	hypochlorite solution
Soaking duration	12 hours	12 hours	24 hours	24 hours	6-7hours
Germination time	24-36 hours	24 hours	24 hours	24 hours	Unspecified
Tray dimension (Length x width x height)	1.8 x 1 x 0.15 ft^3	30 x 12 x 1.5 $inch^3$	Unspecified	Unspecified	1.6 x 1 x 0.15 ft^3
Biomass yield (kg)	8.00 ± 0.36	6.27 ± 0.15	950 ± 53.24	900 ± 53.24	Unspecified
Dry matter (%)	18.25 ± 0.12	14.19 ± 0.84	87.51 ± 0.09	88.09 ± 0.09	17.97 ± 0.40
Crude Protein (%)	14.56 ± 0.29	19.83 ± 0.35	13.73 ± 0.37	15.33 ± 0.37	13.51 ± 0.24
Ether Extract (%)	4.67 ± 0.19	2.70 ± 0.03	2.90 ± 0.07	3.36 ± 0.07	3.23 ± 0.05
Crude Fiber (%)	10.00 ± 0.17	4.68 ± 0.03	10.64 ± 0.32	11.55 ± 0.32	14.04 ± 0.12
Total Ash (%)	2.83 ± 0.03	2.96 ±0.01	5.38 ± 0.10	4.81 ± 0.10	3.80 ± 0.01
Nitrogen Free Extract (%)	68.47 ± 1.63	69.82 ±0.33	54.88 ± 0.68	53.05 ± 0.68	65.06± 0.019
Irrigation system	Semi-automated drip irrigation	Hand sprinklers and tap water	Manual irrigation	Manual irrigation	Manual irrigation
Nutrient solution	Tap water	Tap water	D.I.-grow® growth booster	D.I.-grow® growth booster	Tap water
Source	(Kide et al., 2015)	(Bari et al., 2022)	(Akinmutimi et al., 2022)	(Akinmutimi et al., 2022)	(Mahale et al., 2021)

Table 2.8 Cultivation details and nutritional analysis of different hydroponic fodder species (Upreti et al., 2022)

Parameters	**Maize (*Zea mays*)**	**Oat (*Avena sativa*)**	**Wheat (*Triticum aestivum*)**
Day of harvest	11^{th}	11^{th}	11^{th}
Seed weight	1kg	1kg	1kg
Seed treatment before soaking	None	None	None
Soaking duration	Overnight	Overnight	Overnight
Germination time	48hours	48hours	48hours
Tray size	0.75 m long and 0.37 m width	0.75 m long and 0.37 m width	0.75 m long and 0.37 m width
Biomass yield (kg)	5.32 ± 0.05	7.96 ± 0.05	6.76 ± 0.05
Dry matter (%)	12.55 ± 2.05	14.13 ± 0.71	14.49 ± 1.18
Crude protein (%)	12.51 ± 0.83	13.96 ± 2.08	16.16 ± 1.59
Neutral detergent fiber (%)	37.49 ± 3.68	60.22 ± 2.86	62.72 ± 6.68
Acid detergent fiber (%)	12.58 ± 1.83	32.63 ± 2.03	29.63 ± 2.37
Acid detergent lignin (%)	3.78 ± 0.96	7.72 ± 0.62	8.17 ± 0.82
Irrigation system	Automatic fogger	Automatic fogger	Automatic fogger
Nutrient solution	Tap water	Tap water	Tap water

CHAPTER 3

MATERIALS AND METHOD

3.1 Site selection

The research activities were carried out at the Dr. Purnendu Gain Field Laboratory and the Animal Husbandry Laboratory, which are associated with the Agrotechnology Discipline at Khulna University. The research unit is situated on 22°80' N and 89°53' E latitude and longitude. Duration of the study was 9 months.

3.2 Design of the study

The research was conducted using a completely randomized design (CRD) to ensure unbiasedness and reliability of the results. The species under investigation comprised maize (*Zea mays*), wheat (*Triticum aestivum*), oat (*Avena sativa*), sorghum (*Sorghum bicolor*), and cowpeas (*Vigna unguiculata*). Each species represented as a treatment group. No control group was considered as the research focus on comparative analysis among the treatments.

3.3 Collection of seeds

The study under consideration assessed five different species of fodder crops, which include maize (*Zea mays*), wheat (*Triticum aestivum*), oat (*Avena sativa*), sorghum (*Sorghum bicolor*), and cowpea (*Vigna unguiculata*). Fodder seeds were collected from local markets.

3.4 Seed selection

To ensure high-quality hydroponic fodder production, good quality seeds free from damage and disease were carefully selected.

3.5 Preparation of growing area

The growing area and trays were thoroughly cleaned and disinfected by clean water, detergent powder solution and Salvon solution (0.3% Chlorhexidine Gluconate + 3% Cetrimide) to establish an antiseptic environment. This proactive measure effectively prevented the proliferation of disease-causing organisms. Also, proper drainage system was ensured to avoid the issue of waterlogging.

3.6 Preparation of seeds

The seeds were rinsed under running water to remove impurities and debris. After thorough rinsing, the seeds were soaked in water for 12 hours to initiate germination. After draining the water, the seeds were kept in a gunny bag for 24 hours until they sprouted. Average 250g of seed were taken for each species and each replication. The seeds were evenly spread on the trays of 20x16 sq. inches after they sprouted.

3.7 Uniformity of the environment

Mitigation of potential biasness was implemented and the randomization of the experimental setup was ensured by a systematic shuffling of the trays containing each species throughout the duration of the study. By periodically rearranging the trays, variations in factors such as light exposure, temperature, humidity, and other microclimate were evenly distributed across all treatment groups (species). Artificial lighting during day time was also provided to ensure uniformity in term of lighting.

3.8 Supplementation of water

Seeds were watered regularly 3-4 times daily manually. Care was taken to maintain proper moisture levels without waterlogging into the seed trays. Only tap water was used from the same source.

3.9 Harvesting

The hydroponic fodder was harvested at 11th day after germination.

3.10 Cleaning and repeating

The growing area and trays were cleaned thoroughly to eliminate any residue. The process was repeated by soaking and preparing new seeds then again spreading them evenly on the trays to initiate a new cycle of hydroponic fodder production.

3.11 Biomass yield

Biomass yield of different hydroponic green fodder was measured using a weighing balance. The quantification and record keeping of biomass production took place everyday morning before watering.

3.12 Plant height

Three plants were randomly chosen from each tray for measurement of height. Every plant was measured for height from the tray floor to the top leaf, and the average height of the plants was noted.

3.13 Primary root length

Three plants were selected at random from every tray to measure the height of their primary roots. Root length of various hydroponic fodder species was measured between day 4 and day 11.

3.14 Chlorophyll index

The chlorophyll levels of various hydroponic fodder species were assessed using an SPAD meter from day 7 to day 11.

3.15 Determination and comparison of production cost

The production costs associated with each hydroponic fodder species were analyzed and determined. The hydroponic fodder species with the highest economic feasibility and profitability were determined, considering both biomass yield and production costs based on per kg seed for comparison.

3.16 Proximate analysis

The evaluation of the chemical composition of dried fodder samples was carried out in accordance with the AOAC (1990) standard method at the Animal Husbandry Laboratory, Agrotechnology Discipline, Khulna University, Khulna.

3.16.1 Dry Matter analysis

The initial step involved weighing the tray using a weighing machine (W1). Subsequently, the grounded samples were carefully distributed onto each tray, and the combined weight of the sample and tray was recorded as W2. These trays with samples were then placed into a preheated oven set at 60°C, where they were dried for a duration of 24 hours. Following this initial drying period, the samples underwent an additional 24 hours drying at 105°C. Once the drying process was completed, the trays containing the dried samples were removed from the oven. The weight of each tray, now containing the dried sample was measured (W3). The determination of dry matter (DM) was conducted in accordance with the procedures outlined in the AOAC (1990) guidelines. The dry matter was determined using the following formula:

$$\% \text{ DM} = \frac{(W3 - W1)}{(W2 - W1)} \times 100$$

Where,

W1 = Weight of empty tray in grams

W2 = Weight of sample with tray in grams

W3 = Dry weight of sample with tray in grams

3.16.2 Crude Protein Analysis

VELP SCIENTIFICA DK 8 Heating Digester was used to finish the digestion process. Initially, 1g sample was weighted. Two catalyst tablets and 20ml of sulfuric acid were added to each sample before it was put into the digesting block. The sample was heated up to 60 minutes while the digesting block's temperature was kept at 420°C. The samples were subsequently cooled to between 50 and 60°C.

The UDK 129 Distillation Unit VELP SCIENTIFICA was used to carry out the distillation procedure. The sample was cooled and then combined with 50ml of distilled water. Then tube is inserted in the machine. A conical flask separately was prepared where 4% boric acid solution of 30ml was mixed with 2-3 drops of indicator. Then the conical flash was also inserted in the machine to its designated point. The machine's delay was set to zero, and the distillation process for each sample was carried out with a consistent NaOH level of 50ml, taking approximately 5 minutes per sample. Subsequently, washing was performed using a NaOH level of 0 in the machine for a duration of 3 minutes. Distillation was carried out up till the indicator combination solution's color did not change to green.

The conical flask is then removed for titration. It was tritiated against 0.1% hydrochloric acid solution. The titration process continued until the content of the conical flash become colorless. Overdose of the 0.1% hydrochloric acid solution to the conical flash would made the contents purple color. Amount of hydrochloric acid required for titration is recorded for the samples of five species and one for the blank sample. According to AOAC (1990) guidelines, nitrogen (%) was calculated by the following formula:

$$\frac{(\text{ml HCl required for sample} - \text{ml HCl required for blank}) \times 14.007 \times 100}{\text{Wight of sample} \times 1000}$$

Crude Protein (%) = Nitrogen (%) × 6.25

Where, 6.25 is the conversion factor.

3.16.3 Crude fiber analysis

An investigation of crude fiber was carried out utilizing the VELP SCIENTIFICA FIWE Raw Fibre Extractor. A 1g sample was placed in crucibles that had channels fixed to them. Three to five drops of n-octanol were added to 150 ml of 1.25% sulfuric acid in the analyzer flask as an anti-foam agent. The fiber analyzer's switch was switched onand boiled for precisely thirty minutes. Filtering of the residual agent was done thirty minutes later. The crucible was washed three times, adding 30 ml of hot deionized water to the top each time, and using compressed air to mix the contents of the crucible. One hundred and fifty (150) ml of 1.25% KOH and three to five drops of the anti-foam agent were added after the final wash was drained. Once more, after 30 minutes of boiling and three washings, one final washing was completed. Following that, the crucibles were dried in an oven at 105° C for an hour, and they were cooled in a desiccator to determine their dry weight (W1). After cooling in a desiccator (W2), the crucibles were put into a muffle and heated to 550° C for three hours to reweight. According to AOAC (1990) guidelines crude fiber was calculated by following formula:

Crude Fiber (%) = $\frac{(W1 - W2)}{W}$ x 100

Where,

W = Weight of sample in gram

W1= Weight of oven dried sample in gram

W2= Weight of ash containing crucible in gram

3.16.4 Ether Extract analysis

The VELP SCIENTIFICA SER 148 Solvent Extractor was used to analyze ether extract. A sample extraction process was conducted using 3 grams (W1) of homogenized and ground material. The procedure involved placing the samples directly into a cellulose thimble, which was then inserted into the extraction set. The vessel designated for collecting the extract was weighed (W2), and subsequently, 70 milliliters of acetone was added to it. The extraction vessel, containing the solvent, was then introduced into the extraction equipment. The equipment was activated by means of a general switch on the control panel, with the temperature set at 110°C for acetone. The process involved initiating the flow of cooling water and heating until the solvent reached boiling point. At this stage, the thimble was submerged by positioning the slider into an "immersion" configuration. After 60 minutes, the thimble was extracted from the solvent by moving the slider to the "washing" position. Following an additional 60 minutes of reflux washing, the slider was shifted to the "recovery" position. Subsequently, after a 30-minute recovery period, the stopcock beneath the water-cooled condenser was closed, allowing the solvent to evaporate completely from the extraction vessel. The vessel designated for collecting the extract, along with boiling stones, was then subjected to drying in an oven for 30 minutes, at a temperature sufficient to ensure complete evaporation of any solvent residues. Upon cooling, the extract collecting vessel was reweighed (W3). The determination of ether extract (EE) was carried out in accordance with the AOAC (1990) guidelines. According to AOAC (1990) guidelines, the following formula was used for Ether Extract (%) determination:

Ether Extract (%) $= \frac{(W3 - W2)}{W1} \times 100$

Where,

W1 = Initial weight of sample in grams

W2 = Initial weight of vessel in grams

W3 = Weight of vessel and Lipid residue in grams

3.16.5 Total Ash analysis

The initial step involved in the procedure was the weighing of the empty crucible (W1). Subsequently, 3 grams of the sample were accurately measured and placed into the crucible (W2). The crucibles, now containing the samples, underwent a preheating process facilitated by a coil heater for a duration of 20 minutes. Following this preheating, the crucibles were positioned within a muffle furnace set at 450°C for a period of 6 hours. Upon completion of the 6-hour heating period, the crucibles were allowed to gradually cool within the furnace for 24 hours. Subsequently, the cooled crucibles were transferred to a desiccator for further cooling to room temperature. Once cooled, the crucibles were reweighed (W3). The determination of ash content followed the guidelines outlined in the AOAC (1990) standards. Total Ash (%) contents was determined by following formula:

Ash (%) $= \frac{(W3 - W1)}{W2} \times 100$

Where,

W1 = Weight of empty crucible in grams

W2 = Weight of sample in grams

W3 = Weight of crucible and ash in grams

3.17 Data analyses

The data collected from this experiment were entered into a Microsoft Excel worksheet. For analysis, a one-way ANOVA was employed. Descriptive statistical tools, including the calculation of averages and standard errors were applied using the tabular technique. The analysis was conducted utilizing SPSS software (version 26.0) and R software.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Biomass yield

Biomass yields of different hydroponic fodder species measured over 11 days are shown in Table 4.1.

Germination weights from 250g seed showed that cowpea (514.72g ± 4.95) and oat (399.89g ± 5.38) had the highest values, followed by wheat (363.81g ± 1.62) where the mean difference was significant ($p<0.001$). Maize (337.28g ± 3.34) and sorghum (332.20g ± 4.12) had the lowest weights at germination. Cowpea had a significantly higher germination weight compared to all other species. Oat's germination weight was significantly different than sorghum, maize and wheat. Germination weight of wheat was significantly different from sorghum and maize. Oats (360.40g ± 64.10) and cowpea (344.15g ± 38.15) had the highest biomass yields on day 2 followed by wheat (277.95g ± 13.48) and sorghum (272.47g ± 15.73) while maize (229.03g ± 24.08) had the lowest biomass. Oats and cowpea had significantly higher biomass yields compared to maize. Sorghum and wheat did not significantly differ from each other or from oat, cowpea and maize. The highest biomass yield was observed on day 3 in cowpea (472.63g ± 54.01), followed by oat (433.81g ± 63.81), sorghum (347.54g ± 21.49), wheat (323.21g ± 14.36), and the lowest in maize (290.89g ± 27.42). Cowpea had a significantly higher biomass yield than maize. Oats had a significantly higher yield than maize but did not differ significantly from sorghum and wheat. Sorghum and wheat did not significantly differ from each other. Oats (558.69g ± 89.65) and cowpea (548.25g ± 68.83) exhibited the highest yields on day 4 followed by wheat (405.88g ± 24.07). Sorghum (370.13g ± 22.75) and maize (348.79g ± 29.75) showed the lowest biomass on day 4.

Oats and cowpea had significantly higher biomass yields compared to sorghum and maize at day 5. Wheat's biomass did not significantly differ from any of the other species. Oats (602.57g ± 55.09) had the highest biomass yield on day 5, followed by cowpea (562.86g ± 61.86), wheat (446.93g ± 21.78), maize (397.21g ± 25.34) while sorghum (384.77g ± 21.65) had the lowest biomass yield. Oats had a significantly higher yield than sorghum and maize at the same day. Biomass of cowpea was significantly higher than sorghum and maize but did not significantly differ from wheat. Wheat was not significantly different from maize at day 5.

The highest biomass yield was recorded on day 6 for oat (816.84g ± 144.87), with cowpea (605.85g ± 63.68) and wheat (513.97g ± 33.29) following. Maize (459.83g ± 31.04) and sorghum (424.74g ± 24.56) had the lowest yields. Oats had a significantly higher yield than cowpea, wheat, sorghum, and maize. Cowpea did not show a significant difference from wheat and maize but was significantly different from sorghum for biomass production. Mean biomass of wheat was significantly different from that of sorghum.

Oats (942.29g ± 162.69) produced the highest yield on day 7, with cowpea (676.91g ± 75.10), wheat (567.15g ± 34.85), and maize (523.50g ± 34.78) was followed. Sorghum (465.06g ± 27.44) had the lowest yield. Oats had a significantly higher yield compared to sorghum, maize, and wheat. Cowpea was significantly higher than sorghum but did not show a significant difference from wheat and maize at day 7. Wheat did not show a significant difference from maize.

The highest yield was observed on day 8 in oat (1099.35g ± 214.29), followed by while the other species cowpea (733.86g ± 83.53), wheat (630.47g ± 39.76), and maize (584.62g ± 40.36), and sorghum (531.96g ± 32.62) exhibited lowest yield. Oats (1168.87g ± 224.25) had the highest yield on day 9, followed by cowpea (773.59g ± 91.13), wheat (679.10g ± 42.07), maize (637.89g ± 46.30), and sorghum (595.79g ± 38.36) with the lowest yield.

Oats (1240.89g ± 281.56) continued to show the highest yield on day 10, with cowpea (800.93g ± 86.65), wheat (704.54g ± 45.99), maize (694.18g ± 61.96) was followed and sorghum (664.02g ± 42.68) showed lowest yield. Oats had a significantly higher yield compared to all other species during day 8 to 10. Cowpea, wheat, maize, and sorghum during this time did not show a significant difference from each other for biomass yield.

Oats (1254.22g ± 249.98) and cowpea (1045.22g ± 71.57) had the highest biomass yields at day 11. Wheat (732.85g ± 46.78), sorghum (720.44g ± 53.58) was followed and maize (707.79g ± 56.81) had the lowest yields. Oats and cowpea had significantly higher yields compared to wheat, sorghum, and maize, which did not show a significant difference from each other. Biomass weight over time is showed in Figure 4.1.

In an experiment it was noticed that biomass yield of red sorghum 900kg ± 53.24 harvested at 7th day which is higher than our current findings (Akinmutimi et al., 2022). In case of wheat, it was noticed from an experiment that biomass yield was 6.27kg ± 0.15 from 450g of seed harvested on day 8 which is higher than our current findings (Bari et al., 2022). In another separate experiment it was revealed that 3.5kg of wheat fodder can be hydroponically grown from 1kg of seed when harvested at 8th day which is higher than current study (Rahman et al., 2020). A study found biomass yield of maize hydroponic fodder at 8th day was 8.00kg ± 0.36 from 500g seed which does not correspond to the present study and present study showed lower biomass yield in maize hydroponic fodder (Kide et al., 2015). Maize production in hydroponic technology was found lower in the current investigation than some other studies (Jemimah et al., 2020; Jolad et al., 2018; Lamnganbi & Surve, 2017; Ningoji et al., 2020; Rahman et al., 2020; Shanmugam et al., 2018; Upreti et al., 2022). It was observed from a study that from 100g of oat seed 550g of oat hydroponic fodder can be produced when harvested at 6th day which is higher than present study (Hillier & Perry, 1969). When 1kg oat seeds were used it was found that it produced 7.96kg of hydroponically grown oat fodder at 11th day which is higher than present findings (Upreti et al., 2022). In another different investigation oat was found to produce 3.02kg to 3.35kg of hydroponically grown fodder from 1 kg of seed at 8th day which is higher than the current study. Cowpea fodder found to 4.12kg to 4.29kg of hydroponically grown fodder at 8th day which is also higher present finding (Jolad et al., 2018). In a separate investigation, researchers maintained a temperature of 24°C and a relative humidity of 50-73% to examine the output of barley fodder. They utilized growing trays measuring 45 cm x 25 cm x 8 cm and hydroponic fodder was harvested 9th day. The yield of barley fodder was determined to be 25.0 kg/m^2 in terms of fresh weight and 4.1 kg/m^2 in dry weight (Al-Karaki, 2011). An additional investigation was conducted to uphold a temperature range of 22 to 27 degrees Celsius and a relative humidity level of 70 to 80 percent. The growth tray dimensions were 55 cm × 31 cm × 5 cm, and the harvesting time was established at 8 days. The fresh yield figures for barley and maize were 52.9 kg/m^2 and 47.1 kg/m^2, respectively (Gebremedhin, 2015). Different hydroponic fodder production methods may result in variations in biomass yield of hydroponically grown fodder. Some factors such as design of hydroponic trays and the types of nutrient solutions used can affect growth and yield of the fodder. The yield of biomass in hydroponic fodder is subject to the effects of environmental variables, including humidity, temperature, and light intensity (Shit, 2019). Seed rate can also affect the biomass yield (Assefa et al., 2020). In environments with reduced sunlight, artificial or supplementary lighting serves to offset the lack of light essential for photosynthesis. The use of additional lighting has significantly increased plant productivity (Hao et al., 2018; Rahman et al., 2021).

Table 4.1 Biomass yields (g) of different species of hydroponic fodders from 250g of seeds

Day	Sorghum (*Sorghum bicolor*)	Cowpea (*Vigna unguiculata*)	Wheat (*Triticum aestivum*)	Maize (*Zea mays*)	Oat (*Avena sativa*)	F-value	Level of significance
Germination weight	$332.20^{d} \pm 4.12$	$514.72^{a} \pm 4.95$	$363.81^{c} \pm 1.62$	$337.28^{d} \pm 3.34$	$399.89^{b} \pm 5.38$	410.319	***
Biomass at day 2	$272.47^{ab} \pm 15.73$	$344.15^{a} \pm 38.15$	$277.95^{ab} \pm 13.48$	$229.03^{b} \pm 24.08$	$360.40^{a} \pm 64.10$	2.942	**
Biomass at day 3	$347.54^{abc} \pm 21.49$	$472.63^{a} \pm 54.01$	$323.21^{bc} \pm 14.36$	$290.89^{c} \pm 27.42$	$433.81^{ab} \pm 63.81$	4.239	**
Biomass at day 4	$370.13^{b} \pm 22.75$	$548.25^{a} \pm 68.83$	$405.88^{ab} \pm 24.07$	$348.79^{b} \pm 29.75$	$558.69^{a} \pm 89.65$	3.828	*
Biomass at day 5	$384.77^{c} \pm 21.65$	$562.86^{ab} \pm 61.86$	$446.93^{bc} \pm 21.78$	$397.21^{c} \pm 25.34$	$602.57^{a} \pm 55.09$	4.402	**
Biomass at day 6	$424.74^{c} \pm 24.56$	$605.85^{b} \pm 63.68$	$513.97^{bc} \pm 33.29$	$459.83^{bc} \pm 31.04$	$816.84^{a} \pm 144.87$	5.487	***
Biomass at day 7	$465.06^{c} \pm 27.44$	$676.91^{b} \pm 75.10$	$567.15^{bc} \pm 34.85$	$523.50^{bc} \pm 34.78$	$942.29^{a} \pm 162.69$	5.890	***
Biomass at day 8	$531.96^{b} \pm 32.62$	$733.86^{b} \pm 83.53$	$630.47^{b} \pm 39.76$	$584.62^{b} \pm 40.36$	$1099.35^{a} \pm 214.29$	5.778	***
Biomass at day 9	$595.79^{b} \pm 38.36$	$773.59^{b} \pm 91.13$	$679.10^{b} \pm 42.07$	$637.89^{b} \pm 46.30$	$1168.87^{a} \pm 224.25$	4.877	**
Biomass at day 10	$664.02^{b} \pm 42.68$	$800.93^{b} \pm 86.65$	$704.54^{b} \pm 45.99$	$694.18^{b} \pm 61.96$	$1240.89^{a} \pm 281.56$	4.298	**
Biomass at day 11	$720.44^{b} \pm 53.58$	$1045.22^{a} \pm 71.57$	$732.85^{b} \pm 46.78$	$707.79^{b} \pm 56.81$	$1254.22^{a} \pm 249.98$	8.078	***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$; Means with uncommon superscripts in a row differed significantly ($p<0.05$).

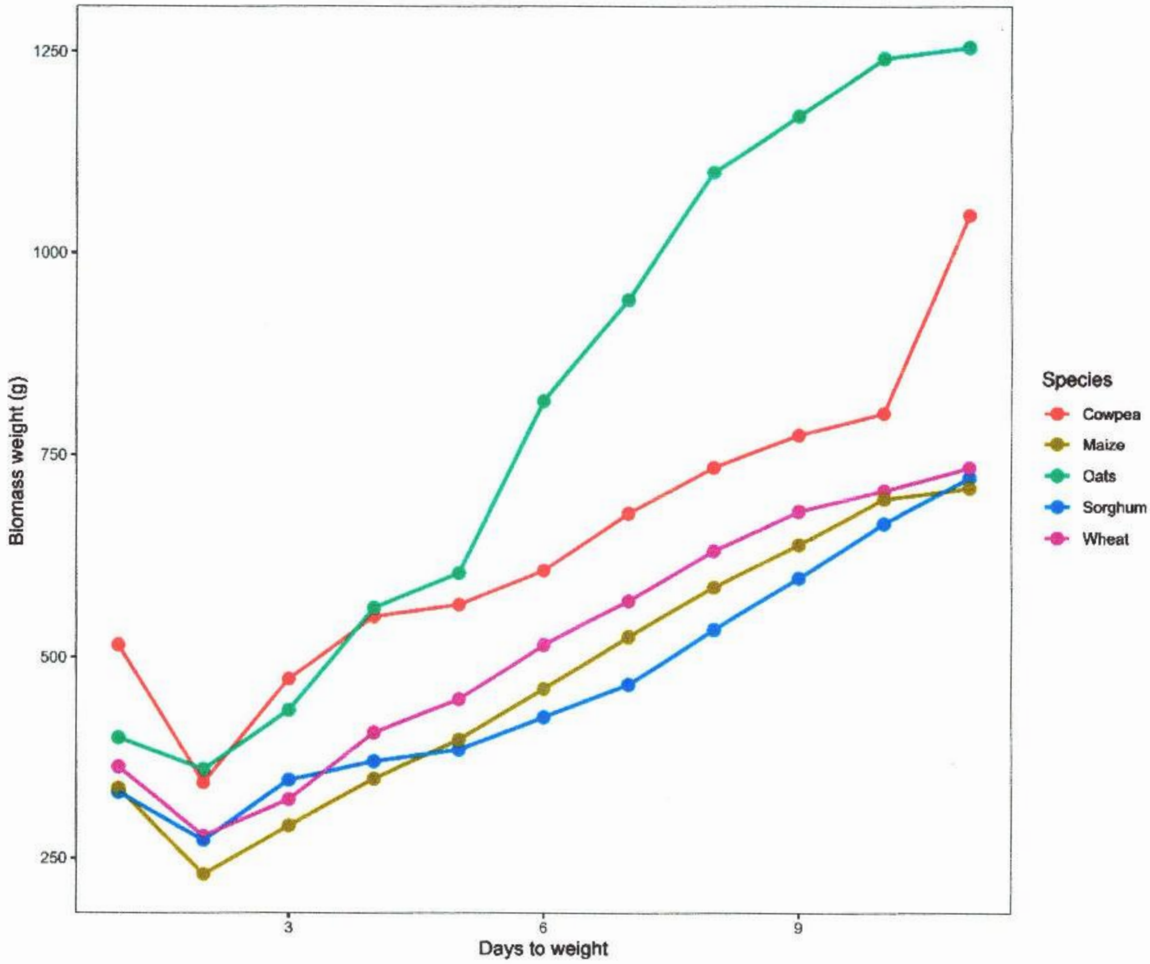

Figure 4.1 Biomass weight (g) of different hydroponic fodder species over time (days)

4.2 Plant height

Height of different hydroponic fodder species was measured during day 4 to day 11 and are shown in Table 4.2, with their growth progression illustrated in Figure 4.2. On day 4, wheat (3.23 cm ± 0.62) had the highest height, followed by maize (2.51 cm ± 0.27), oat (3.23 cm ± 1.22), cowpea (2.23 cm ± 0.23), while sorghum (1.40 cm ± 0.15) showed lowest height. Wheat significantly differed from sorghum, while the heights of maize, oat, and cowpea were not significantly different.

During day 5, oat had the highest height (6.06 cm ± 2), followed by cowpea (3.37 cm ± 0.39), maize (4.91 cm ± 0.50) and wheat (5.23 cm ± 0.87) while again sorghum (2.26 cm ± 0.33) showed lowest height. Oats significantly differed from sorghum and cowpea, while the heights of wheat and maize were not significantly different from sorghum and cowpea. During day 6, oat (10.17 cm ± 1.17) remained the tallest, followed by cowpea (6.59 cm ± 0.71), maize (6.96 cm ± 0.43), wheat (7.10 cm ± 0.83), and sorghum (4.68 cm ± 0.48). Height of oat was significantly differed from sorghum, cowpea, wheat and maize. By day 7, oat (12.32 cm ± 0.65) again showed to be the tallest, followed by cowpea (8.54 cm ± 0.75), maize (8.99 cm ± 0.44), wheat (8.62 cm ± 0.81), and sorghum (6.01 cm ± 0.55). Oats significantly differed from sorghum, cowpea, and wheat, while the height of cowpea, wheat, maze was not significantly different with each other.

On day 8, oat (13.67 cm ± 0.35) maintained the highest height, followed by cowpea (10.78 cm ± 0.78), maize (12.30 cm ± 0.68), wheat (10.47 cm ± 0.66), and sorghum (8.37 cm ± 0.31). Oats significantly differed from maize, sorghum, cowpea, and wheat, while the height of wheat, maize, cowpea was not significantly different with each other. On day 9, oat (16.32 cm ± 1.43) kept showing to be the tallest, followed by cowpea (12.07 cm ± 0.74), maize (14.26 cm ± 0.68), wheat (12.12 cm ± 0.67), and sorghum (10.51 cm ± 0.50). Oats showed significantly difference from sorghum, cowpea, and wheat, while the height of oat, maize and wheat, cowpea was not significantly different with each other. During day 10, oat (18.06 cm ± 1.38) continued to be highest in height, followed by cowpea (13.56 cm ± 0.68), maize (17.31 cm ± 1.17), wheat (13.22 cm ± 0.75), and sorghum (11.96 cm ± 0.34). Height of oats was significantly differed from sorghum, cowpea, and wheat, while the height of maize was not significantly different from oat.

On day 11, oat (19.81 cm ± 1.34) consistently remained the tallest, followed by cowpea (16.02 cm ± 0.69), maize (19.04 cm ± 1.40) and wheat (13.97 cm ± 0.81). Sorghum (13.74 cm ± 0.54) showed the lowest height. Oats significantly differed from sorghum, cowpea, and wheat, while the height of maize was not significantly different with oat similar to day 10.

Throughout the observation period it was notices that oat consistently stood out in terms of height. Statistical evaluation has shown a significant difference in height between the various species, with different levels of significance identified across several days (***$p < 0.001$, **$p < 0.01$, *$p < 0.05$). A study found plant height of maize, oat and wheat were 27.77cm, 27.11cm and 25.03cm respectively which is higher than our findings (Upreti et al., 2022). In another investigation it was revealed that at 5th day height of maize, sorghum and cowpea were 18.1cm, 10.8cm and 25.33cm respectively which is significantly higher than the current findings (Murthy et al., 2017). In a separate investigation it was shown that height of wheat hydroponic fodder at 11th day was 14.10cm ± 0.51 which is higher than present investigation (Bari et al., 2022). Growth of plants can be affected by the production methods employed in hydroponic systems and based on the use of nutrient solutions. The substitution of tap water with a nutrient solution as a nutrient source can markedly promote the growth in height of plants (Dung et al., 2010).

Table 4.2 Heights (cm) of different species of hydroponic fodders at different stage of growth (d)

Day	Sorghum (*Sorghum bicolor*)	Cowpea (*Vigna unguiculata*)	Wheat (*Triticum aestivum*)	Maize (*Zea mays*)	Oat (*Avena sativa*)	F-value	Level of significance
4th	$1.40^{b} \pm 0.15$	$2.23^{ab} \pm 0.23$	$3.23^{a} \pm 0.62$	$2.51^{ab} \pm 0.27$	$3.23^{a} \pm 1.22$	3.271	**
5th	$2.26^{c} \pm 0.33$	$3.37^{bc} \pm 0.39$	$5.23^{ab} \pm 0.87$	$4.91^{ab} \pm 0.50$	$6.06^{a} \pm 2$	4.819	**
6th	$4.68^{b} \pm 0.48$	$6.59^{b} \pm 0.71$	$7.10^{b} \pm 0.83$	$6.96^{b} \pm 0.43$	$10.17^{a} \pm 1.17$	4.654	**
7th	$6.01^{c} \pm 0.55$	$8.54^{b} \pm 0.75$	$8.62^{b} \pm 0.81$	$8.99^{b} \pm 0.44$	$12.32^{a} \pm 0.65$	6.146	***
8th	$8.37^{c} \pm 0.31$	$10.78^{b} \pm 0.78$	$10.47^{bc} \pm 0.66$	$12.30^{ab} \pm 0.68$	$13.67^{a} \pm 0.35$	6.614	***
9th	$10.51^{c} \pm 0.50$	$12.07^{bc} \pm 0.74$	$12.12^{bc} \pm 0.67$	$14.26^{ab} \pm 0.68$	$16.32^{a} \pm 1.43$	6.347	***
10th	$11.96^{b} \pm 0.34$	$13.56^{b} \pm 0.68$	$13.22^{b} \pm 0.75$	$17.31^{a} \pm 1.17$	$18.06^{a} \pm 1.38$	8.635	***
11th	$13.74^{b} \pm 0.54$	$16.02^{b} \pm 0.69$	$13.97^{b} \pm 0.81$	$19.04^{a} \pm 1.40$	$19.81^{a} \pm 1.34$	7.459	***

*** $p < 0.001$, ** $p < 0.01$,; Means with uncommon superscripts in a row differed significantly ($p<0.05$).

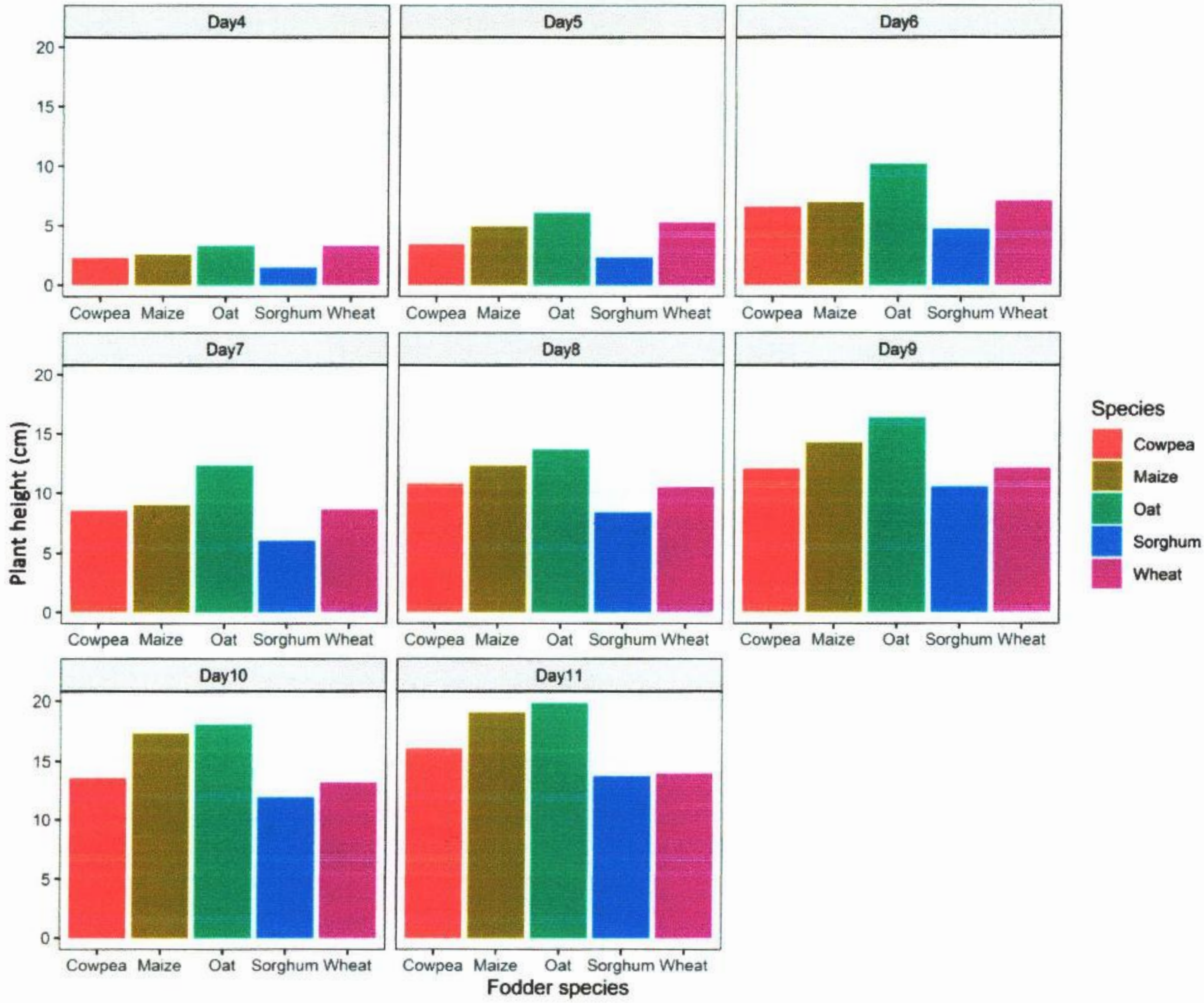

Figure 4.2 Height (cm) of different hydroponic fodder species at different days

4.3 Root length

Root length of different hydroponic fodder species was measured during day 4 to day 11 and are shown in Table 4.3. Maize (7.90 cm ± 0.12) had the longest root on day 6, followed by oat (3.99 cm ± 0.11), cowpea (3.61 cm ± 0.05), sorghum (2.74 cm ± 0.09), and wheat (2.59 cm ± 0.05). Root length of maize was significantly differed from all other species, while sorghum and wheat were not found to be significantly different with each other on this day but they were significantly different from cowpea, maize and oat. During day 7, maize (8.40 cm ± 0.11) again had the longest root length, followed by oat (5.82 cm ± 0.10), sorghum (4.47 cm ± 0.12), cowpea (4.30 cm ± 0.06), while wheat (3.34 cm ± 0.04) had the shortest root length. Significant difference was not found between sorghum and cowpea but they were significantly different from wheat, maize and oat. Maize (10.10 cm ± 0.10) continued to have the longest root length during day 8, followed by oat (7.26 cm ± 0.03), sorghum (5.54 cm ± 0.12), cowpea (4.94 cm ± 0.06), and wheat (4.29 cm ± 0.12). On this day, each of the species showed significant difference from each other.

On day 9, maize (19.25 cm ± 0.09) had the longest root length, followed by oat (9.61 cm ± 0.06), sorghum (5.81 cm ± 0.13) and wheat (5.27 cm ± 0.11), while cowpea (5.25 cm ± 0.09) had the shortest root length. Root length of cowpea and wheat were not found significantly different from each other on this day but they showed significant difference from sorghum, maize and oat. Maize (19.55 cm ± 0.08) had the longest root at day 10 again, followed by oat (12.16 cm ± 0.09), wheat (7.07 cm ± 0.09), sorghum (6.13 cm ± 0.07), and cowpea (5.58 cm ± 0.07). Each of the species showed significant difference from each other on this day. Maize (28.59 cm ± 0.12) had the longest root length consistently even at the day 11, followed by oat (12.60 cm ± 0.06), wheat (8.18 cm ± 0.05), sorghum (6.30 cm ± 0.04), and cowpea (6.09 cm ± 0.05). Significant difference was not found between sorghum and cowpea but they were significantly different from wheat, maize and oat.

An examination carried out on hydroponic wheat fodder by Bari et al. (2022) revealed that the root lengths on day 6, day 7, and day 8 were 7.10cm ± 0.22, 8.56cm ± 0.21, and 9.72cm ± 0.32, correspondingly, indicating higher root length compared to the results of the present investigation. Another study demonstrated that root length of yellow maize on the sixth, seventh, and eighth days was 13.9cm ± 0.181, 14.5cm ± 0.331 and 17.5cm ± 0.26, respectively, which exceeded the outcomes of the present study. In case of sorghum (Jowar) recorded root length was 16.6cm ± 0.38, 17.9cm ± 0.22 and 20.3cm ± 0.35 in day 6, day 7 and day 8 respectively which is significantly higher than the current findings (Jemimah et al., 2018).

Another experiment revealed that root lengths at 8th day of fodder maize, wheat, oat and fodder cowpea was found 22.71cm, 15.70cm, 15.67cm and 18.57cm, respectively which is higher than the present investigation (Jolad et al., 2018). Difference in the root length may be attributed to several factors including the use of tap water instead of nutrient solution, pH level of the supplied water, temperature, humidity, available oxygen, type of hydroponic system implemented.

Table 4.3 Average primary root length (cm) of different species of hydroponic fodders at different stage of growth (d)

Day	Sorghum (*Sorghum bicolor*)	Cowpea (*Vigna unguiculata*)	Wheat (*Triticum aestivum*)	Maize (*Zea mays*)	Oat (*Avena sativa*)	F-value	Level of significance
6th	$2.74^{d} \pm 0.09$	$3.61^{c} \pm 0.05$	$2.59^{d} \pm 0.05$	$7.90^{a} \pm 0.12$	$3.99^{b} \pm 0.11$	728.324	***
7th	$4.47^{c} \pm 0.12$	$4.30^{c} \pm 0.06$	$3.34^{d} \pm 0.04$	$8.40^{a} \pm 0.11$	$5.82^{b} \pm 0.10$	451.671	***
8th	$5.54^{c} \pm 0.12$	$4.94^{d} \pm 0.06$	$4.29^{e} \pm 0.12$	$10.10^{a} \pm 0.10$	$7.26^{b} \pm 0.03$	478.458	***
9th	$5.81^{c} \pm 0.13$	$5.25^{d} \pm 0.09$	$5.27^{d} \pm 0.11$	$19.25^{a} \pm 0.09$	$9.61^{b} \pm 0.06$	2936.868	***
10th	$6.13^{d} \pm 0.07$	$5.58^{e} \pm 0.07$	$7.07^{c} \pm 0.09$	$19.55^{a} \pm 0.08$	$12.16^{b} \pm 0.09$	5037.247	***
11th	$6.30^{d} \pm 0.04$	$6.09^{d} \pm 0.05$	$8.18^{c} \pm 0.05$	$28.59^{a} \pm 0.12$	$12.60^{b} \pm 0.06$	18780.580	***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$; Means with uncommon superscripts in a row differed significantly ($p<0.05$).

4.4 Chlorophyll index (SPAD reading)

Chlorophyll level of different hydroponic fodder species was measured during day 7 to day 11 which are shown in Table 4.4.

During day 7 cowpea (36.12 ± 0.44) had the highest chlorophyll level, followed by oat (31.34 ± 0.45), wheat (28.82 ± 0.54), maize (28.59 ± 0.41), and sorghum (24.38 ± 0.29). Chlorophyll level of cowpea was significantly different from that of all other species. Oats differed significantly from wheat, maize, and sorghum for chlorophyll level. Cowpea (34.73 ± 0.75) showed the highest chlorophyll level on day 8, followed by wheat (32.82 ± 0.43), oat (32.47 ± 0.44), maize (29.55 ± 0.27), and sorghum (23.63 ± 0.13) where sorghum had the lowest chlorophyll level. Chlorophyll level of cowpea differed significantly from that of all other species. Wheat and oat were significantly different from maize and sorghum for this trait. On day 9, cowpea (39.03 ± 0.63) had the highest chlorophyll level, followed by wheat (29.70 ± 0.37), oat (29.47 ± 0.19), maize (26.20 ± 0.34), and sorghum (23.01 ± 0.15). Chlorophyll level of cowpea was also significantly different from all other species at this stage of growth. Chlorophyll level of wheat and oat were significantly different from maize and sorghum. Cowpea (40.20 ± 0.47) exhibited the highest chlorophyll level again on day 10, followed by wheat (33.77 ± 0.39), oat (31.11 ± 0.30), maize (24.33 ± 0.34), and sorghum (22.02 ± 0.10). Each species was significantly different from each other for chlorophyll level at this stage of growth. Chlorophyll level of cowpea (39.17 ± 0.69) remained consistently high even during the day 11 followed by wheat (31.96 ± 0.43), oat (28.64 ± 0.07), maize (26.31 ± 0.30), and sorghum (21.81 ± 0.24). Chlorophyll level of cowpea differed significantly from all other species. Each species again was significantly different from each other on this stage. Cowpea consistently exhibited the highest chlorophyll levels from day 7 through day 11, significantly outperforming all other species. Wheat and oat generally had higher chlorophyll levels but showed significant differences from maize and sorghum. Chlorophyll level of different hydroponic fodder at different stage of growth are shown in Figure 4.3.

It was revealed in a study that for fodder maize, wheat, oat, and fodder cowpea on the seventh day nitrogen content (chlorophyll index) was determined to be 32.18, 31.89, 31.84, and 38.11, respectively. On the eighth day, the chlorophyll index for fodder maize, wheat, oat, and fodder cowpea was recorded as 33.78, 32.80, 32.76, and 39.10, respectively. Chlorophyll index at 7th day for fodder maze fodder, wheat and fodder cowpea was higher than the current findings but oat is in accordance with the present study. During eighth day, wheat and oat was in accordance with current findings but in case of fodder maize and fodder cowpea it was higher (Jolad et al., 2020). The chlorophyll levels in hydroponic fodder vary due to factors such as light intensity and quality, nutrient availability, water quality, environmental stresses, and genetic differences among plant species.

Table 4.4 Chlorophyll level of different species of hydroponic fodders at different stage of growth (d)

Day	Sorghum (*Sorghum bicolor*)	Cowpea (*Vigna unguiculata*)	Wheat (*Triticum aestivum*)	Maize (*Zea mays*)	Oat (*Avena sativa*)	F-value	Level of significance
7th	24.38d ± 0.29	36.12a ± 0.44	28.82c ± 0.54	28.59c ± 0.41	31.34b ± 0.45	106.832	***
8th	23.63d ± 0.13	34.73a ± 0.75	32.82b ± 0.43	29.55c ± 0.27	32.47b ± 0.44	80.562	***
9th	23.01d ± 0.15	39.03a ± 0.63	29.70b ± 0.37	26.20c ± 0.34	29.47b ± 0.19	214.368	***
10th	22.02e ± 0.10	40.20a ± 0.47	33.77b ± 0.39	24.33d ± 0.34	31.11c ± 0.30	436.903	***
11th	21.81e ± 0.24	39.17a ± 0.69	31.96b b± 0.43	26.31d ± 0.30	28.64c ± 0.07	203.123	***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$; Means with uncommon superscripts in a row differed significantly ($p<0.05$).

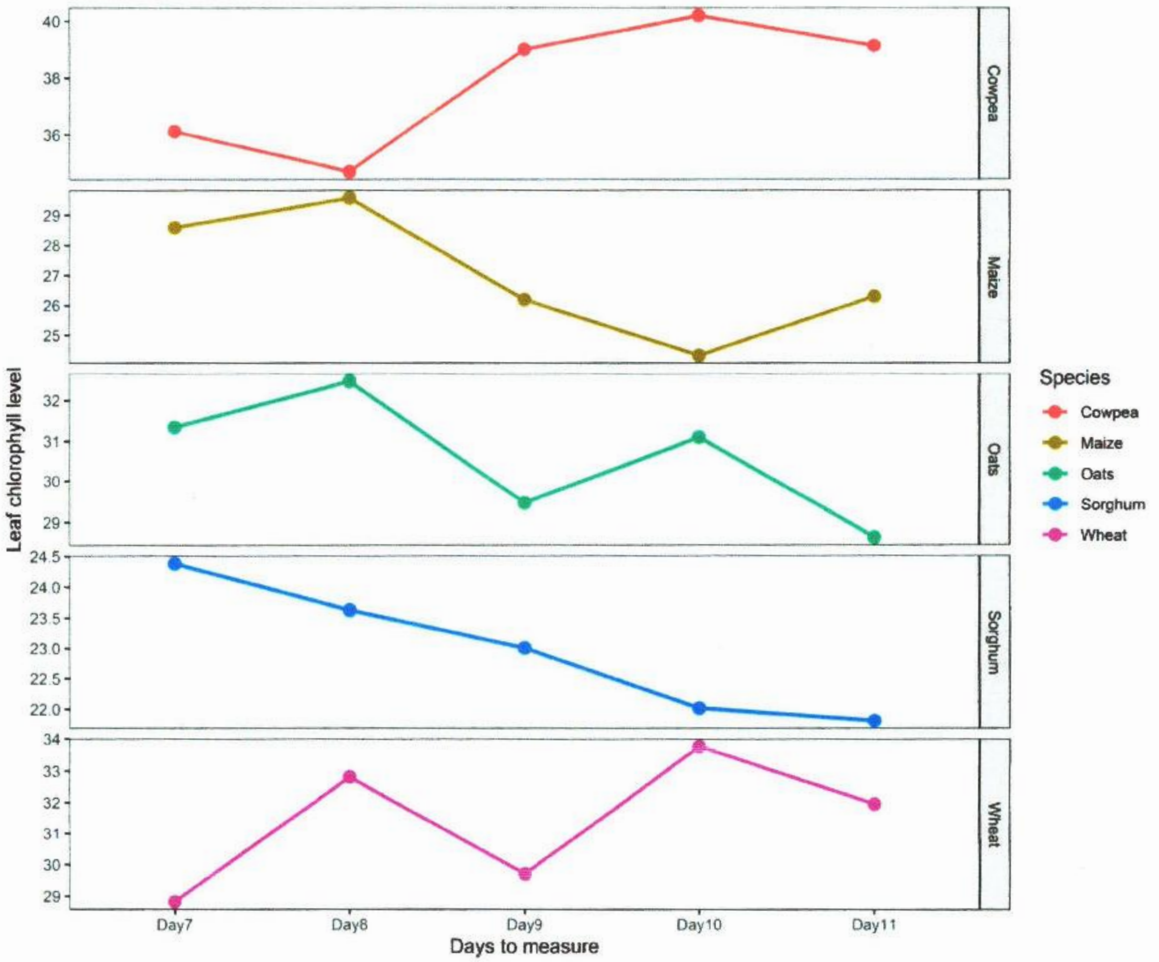

Figure 4.3 Chlorophyll level of different hydroponic fodder species over time (days)

4.5 Cost analysis

Production costs per kilogram (in Bangladeshi Taka, BDT) for different hydroponic fodder species is shown in Table 4.5.

Sorghum (51.16 BDT/kg ± 3.90) had the highest production cost, closely followed by cowpea (50.52 BDT/kg ± 3.99) followed by Oats (39.25 BDT/kg ± 8.60) which had a moderate production cost, while maize (33.01 BDT/kg ± 2.22) showed a lower production cost. Wheat (21.12 BDT/kg ± 1.17) had the lowest production cost among the hydroponic fodder species. Sorghum and cowpea were not significantly different from each other for production costs. Production cost of oats differed significantly from wheat but not significantly from sorghum, cowpea, and maize. Maize had a significantly different production cost compared to sorghum, cowpea and wheat but was not significantly different from oat. Wheat had a significantly different production cost compared to all other species. Cost analysis is shown in Figure 4.4

It was revealed in an investigation that cost of production of per kg wheat hydroponic fodder was 4.97BDT. ± 0.12 which lower than our findings (Bari et al., 2022). Another investigation showed that hydroponic maize fodder, oat fodder and wheat fodder required total cost of 20.64, 24.67 and 18.76 Nepalese rupee for one kg of hydroponic fodder production, respectively, which is lower than our current findings (Upreti et al., 2022). In a different experiment it was demonstrated that costs to produce 1kg hydroponic fodder for yellow maize, cowpea, sorghum were 3.20, 10.90, 7.90 Indian Rupee, respectively, which is significantly lower than the present study (Jemimah et al., 2018). According to Jolad et al. (2020), cost of fodder maize, wheat, oat, and cowpea was 22.14, 40.14, 52.14, 72.14 Indian Rupee per kg seed and cost of fodder maize was found similar to our study but wheat, oat and fodder cowpea showed lower production cost in the current study. The cost difference can be caused by high costing of the seed and lower biomass yield.

Table 4.5 Production cost of different hydroponic fodder species

Species	**Production cost (BDT. /kg)**
Sorghum (*Sorghum bicolor*)	$51.16^{a} \pm 3.90$
Cowpea (*Vigna unguiculata*)	$50.52^{a} \pm 3.99$
Wheat (*Triticum aestivum*)	$21.12^{c} \pm 1.17$
Maize (*Zea mays*)	$33.01^{b} \pm 2.22$
Oat (*Avena sativa*)	$39.25^{ab} \pm 8.60$
F-value	14.957
Level of significance	***

*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

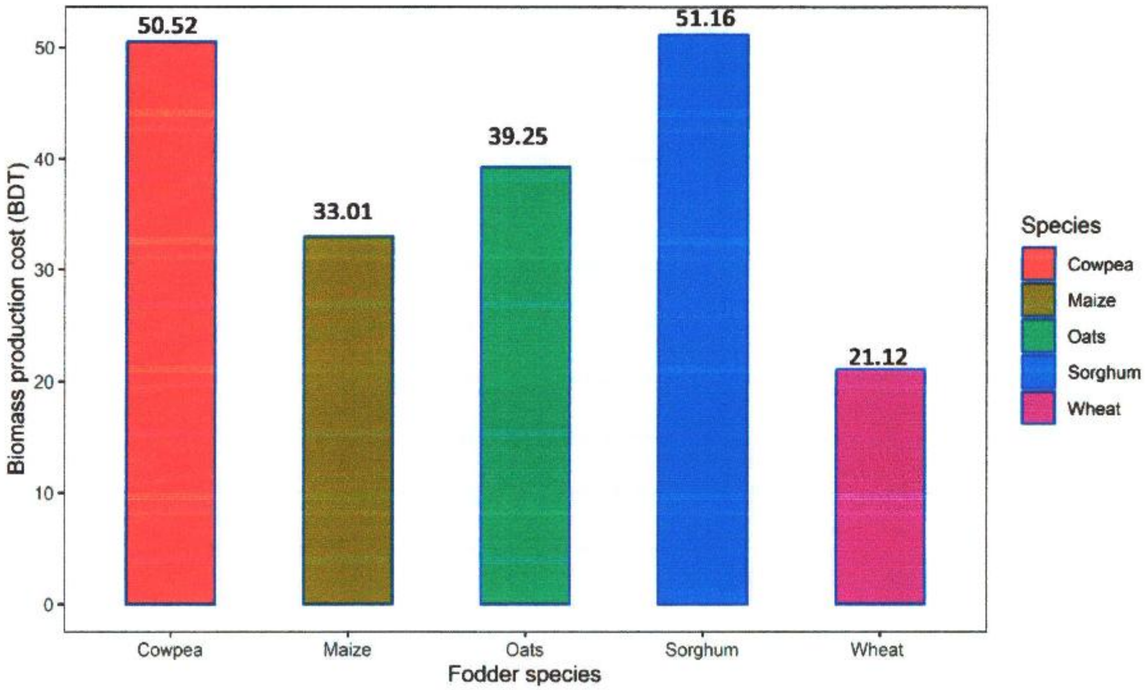

Figure 4.4 Cost analysis of different hydroponic fodder

4.6 Chemical composition

Chemical composition of different hydroponic fodder species is presented in Table 4.6. Wheat fodder (26.62% ± 2.91) had the highest dry matter (DM) content, followed by sorghum (18.11% ± 0.69), maize (17.52% ± 2.51) and oat (13.20% ± 1.47) with cowpea (9.87% ± 0.22) had the lowest DM content. Wheat DM was significantly different from sorghum, cowpea, oat, and maize. Cowpea (25.80% ± 0.48) showed highest crude protein (CP) content, followed by wheat (18.78% ± 0.30), oat (13.80% ± 0.52) and sorghum (13.12% ± 0.37) where maize (11.38% ± 0.26) had the lowest CP content. Cowpea was found significantly different from sorghum, oat, wheat, and maize for their CP contents. In term of crude fiber, oat (19.31% ± 1.62) had the highest content, followed by cowpea (17.08% ± 0.23), maize (9.75% ± 0.10), sorghum (8.16% ± 0.10), and wheat (8.00% ± 0.07). Wheat had lowest CF content. Oats DM was found significantly different from sorghum, wheat, maize, and cowpea. Regarding ether extract (EE), maize (3.59% ± 0.17) had the highest content, followed by wheat (3.35% ± 0.05), oat (3.18% ± 0.10) and sorghum (3.13% ± 0.17), where cowpea (2.39% ± 0.13) had the lowest EE content. Maize was significantly different from sorghum, oat, wheat, and cowpea for EE content. Cowpea (9.61% ± 0.36) had the highest total ash (TA) content, followed by sorghum (4.42% ± 0.22), maize (3.61% ± 0.17), wheat (3.49% ± 0.13), and oat (3.39% ± 0.06). Oats showed lowest TA content. Cowpea was noticed significantly different from sorghum, oat, wheat, and maize. In case of nitrogen-free extract (NFE), maize (54.15% ± 2.48) showed highest result, followed by sorghum (53.05% ± 0.92), oat (47.11% ± 2.41) and wheat (39.76% ± 2.59), while cowpea (35.26% ± 0.92) had the lowest NFE content. Maize was found significantly different from sorghum, cowpea, oat, and wheat.

A study conducted by Bari et al. (2022) noticed that when harvested at day eight CP, EE, CF, NFE and ash content per 100g DM for wheat were 19.83g ± 0.35, 2.70g ± 0.03, 4.68g ± 0.03, 69.82g ± 0.33, 2.96g ± 0.01, respectively, where CP content was similar to our findings but EE, CF, Ash content was higher in the present study and NFE content was lower. Another investigation demonstrated that when harvested at 11th day, DM and CP contents for maize hydroponic fodder was 12.55% ± 2.05 and 12.51% ± 0.3, respectively. In case of oat, it was 14.13% ± 0.71 and 13.96% ± 2.08, respectively, and in case of wheat it was 14.49% ± 1.18 and 16.16% ± 1.59. Crude protein content of the oat is in accordance with our findings but CP content of maize was lower and for wheat it was higher in our study and DM contents of oat was lower and for maize and wheat it was higher in the present investigation (Upreti et al., 2022). According to Jemimah et al. (2018), CP, CF, EE, TA and NFE of yellow maize hydroponic fodder was 10.55%, 5.51%, 6.42%, 1.80% and 77.52%, respectively, where CP, CF and TA content of the present study were higher and EE and NFE was lower. In case of cowpea nutritional composition was 27.84%, 6.51 %, 1.93%, 4.88% and 58.84%, respectively, and CP, EE and TA content were higher in the current findings but CP and NFE contents were lower. For sorghum CP, CF, EE, TA and NFE was, 13.27% 13.39%, 4.99%, 2.98% and 65.37% where CP content was similar to our findings but TA content in the present study was higher but CF, EE and NFE was lower.

In another investigation Jolad et al. (2020) found that total protein content of fodder maize, wheat, oat and fodder cowpea was 14.58%, 12.75%, 12.38% and 16.06%, respectively, and current study found higher CP content in wheat, oat, cowpea but lower in maize hydroponic fodder. Crude fat was found 7.20%, 6.11% and 6.07% for fodder maize, wheat and oat, respectively. Crude fat of all of species of hydroponic fodder was higher than the current study. In a separate study conducted on maize hydroponic fodder found that CP, EE, CF, NFE and TA contents were 13.57%, 3.49%, 14.07%, 66.72% and 3.84%, respectively, when harvested at seventh day (Naik et al., 2015b). Present study found higher EE content and lower CP, CF, NFE and TA contents than that of Naik et al. (2015b). In another observation maize hydroponic fodder had lower DM, ash and higher CP, EE, CF, NFE contents than the present study. In their observation by Kide et al. (2015), it was found that DM, CP, EE, CF, NFE and Ash was 18.25% ± 0.12, 14.56% ± 0.29, 4.67% ± 0.19, 10.00% ± 0.17, 68.47% ± 1.63 and 2.83% ± 0.03, respectively. In a different study it was observed that DM, CP, EE, CF, TA and NFE contents were higher in case of maize when harvested at 14th day. In case of wheat, CP and CF contents were similar but it had increased NFE content and lower DM, EE and TA contents than the present findings. Average DM, CP, EE, CF, TA and NFE contents of maize were 20.15% ± 0.40, 17.43% ± 0.24, 4.85% ± 0.05, 18.39% ± 0.12, 3.94% ± 0.01, 55.39% ± 0.019, respectively, and wheat had 14.64% ± 0.16, 18.94% ± 0.01, 3.13% ± 0.06, 8.10% ± 0.22, 3.38% ± 0.09 and 66.46% ± 0.18, respectively (Mahale et al., 2020). Another study demonstrated significantly higher DM with higher CP and ash contents, lower EE content and similar CF and NFE content in maize hydroponic fodder which was allowed to grow to 7days. Same experiment also showed in case of red sorghum that dry matter was significantly higher, lower CP contents, higher EE, CF and ash contents and same NFE contents Average DM, CP, EE, CF, NFE, ash contents for maize hydroponic fodder were 87.63%, 12.84%, 3.14%, 9.65%, 57..35%, 4.67% and for red sorghum hydroponic fodder were 88.09%, 15.33%, 3.36%, 11.55%, 53.05%, 4.81%, respectively (Akinmutimi et al., 2022). Hiller & Perry (1969) observed higher DM, NFE and EE contents with lower CP, CF and ash contents in hydroponically grown oat fodder with growing period of 6 days. Average DM, CP, CF, NFE, EE and ash contents were 89.7%, 12.3%, 10.1%, 69.5%, 4.9% and 3.2%, respectively. The proximate composition of hydroponic fodder may vary due to factors such as implemented hydroponic techniques, composition of nutrient solution, plant species and varieties, environmental conditions, water quality, growth stage, stress factors and harvesting time.

McDonald et al. (2002) reported that sorghum grain had a crude protein (CP) content of 10.8%, a crude fiber (CF) content of 2.1%, an ether extract (EE) content of 4.3%, a total ash content of 2.7%, and a nitrogen-free extract (NFE) content of 74.5%. In contrast, sorghum (CSH-5) grain as reported by Udachan et al. (2012) displayed lower CP at 8.9%, CF at 1.4%, EE at 2.5%, total ash at 1.55%, and NFE at 72%. Sorghum fodder from Reddy (2001) showed notably lower nutritional values, with CP at 1.5%, CF at 9%, EE at 1%, total ash at 1.5%, and NFE at 12%. Sorghum (prime) fodder from Banerjee (2005) exhibited CP at 7.75%, CF at 32.3%, EE at 1.73%, total ash at 8.55%, and NFE at 49.61%. The experimented sorghum hydroponic fodder demonstrated comparatively higher values in most cases, with CP at (13.12% ± 0.37), CF at (8.16% ± 0.10), EE at (3.13% ± 0.17), total ash at (4.42% ± 0.22), and NFE at 53.05% ± 0.92.

Reddy (2001) indicated that cowpea grains possess a high crude protein (CP) content of 25%. These grains are characterized by a moderate crude fiber (CF) level of 5%, an ether extract (EE) of 2%, total ash of 4%, and a substantial nitrogen-free extract (NFE) content of 64%. Conversely, cowpea grains/seeds (87209007) from Antova et al. (2014) displayed a slightly lower CP content of 22.5% ± 0.5, notably lower CF content at 1.7% ± 0.1, and EE content at 1.3% ± 0.1, with a similar total ash content of 3.7% ± 0.1, but a substantially lower NFE content of 33.5% ± 0.2. Cowpea fodder from Reddy (2001) presented a lower CP content of 4.5%, with CF and EE contents of 5% and 1% respectively, and a total ash content of 4%, with NFE content of 5.5%. Another cowpea fodder from Banerjee (2005) exhibited a high CP content of 28.12%, substantially higher CF content of 26.66%, EE content of 3%, and a higher total ash content of 9.17%, with a comparable NFE content of 33.05%. The experimented cowpea hydroponic fodder displayed a CP content of (25.80% ± 0.48), CF content of (17.08% ± 0.23), EE content of (2.39% ± 0.13), total ash content of (9.61% ± 0.36), and NFE content of (35.26% ± 0.92).

McDonald et al. (2002) reported that the wheat grain contained a crude protein (CP) content of 12.4%, alongside a low crude fiber (CF) content of 2.6%. The ether extract (EE) was found to be 1.9%, the total ash content was 2.1%, and the nitrogen-free extract (NFE) content was high at 70.1%. Conversely, wheat grain from Banerjee (2005) exhibited a slightly lower CP content of 10.5% and CF content of 1.89%, with similar EE and total ash contents. Wheat straw from Reddy (2001) displayed substantially lower CP content at 3%, significantly higher CF content at 38%, and comparable EE and total ash contents, with a lower NFE content of 46%. Similarly, wheat straw from Banerjee (2005) showed a CP content of 3.26%, CF content of 38.91%, and EE and total ash contents similar to Reddy (2001), with a slightly higher NFE content of 45.24%. The experimented wheat hydroponic fodder demonstrated a significantly higher CP content of (11.38% ± 0.26) which is similar to wheat grain, substantially lower CF content of (9.75% ± 0.10) than wheat straw but higher than wheat grain, EE content of (3.59% ± 0.17), total ash content of (3.61% ± 0.17), and a higher NFE content of (54.15% ± 2.48) than wheat straw and but lower than wheat grain.

Reddy (2001) reported that maize grain had a relatively high crude protein (CP) content of 11%, with a low crude fiber (CF) content of 2%. Furthermore, the grain included an ether extract (EE) of 2.5%, total ash of 2%, and a considerable nitrogen-free extract (NFE) content of 82.5%. In comparison, maize grain from Banerjee (2005) displayed a slightly lower CP content of 10.6% and a marginally higher CF content of 2.2%, with slightly higher EE content at 3.3% and similar total ash content. Maize fodder from Reddy (2001) showed a significantly lower CP content of 2%, increased CF content of 8%, and distinctly lower EE and total ash contents, with a NFE content of 13%. Maize fodder from Banerjee (2005) demonstrated higher CP content of 6.74%, substantially higher CF content of 35.95%, and higher EE and total ash contents compared to Reddy (2001), with a higher NFE content of 47.07%. The experimented maize hydroponic fodder displayed a higher CP content of (11.38% ± 0.26) which is similar to maize grain, CF content of (9.75% ± 0.10), increased EE content of (3.59% ± 0.17), total ash content of (3.61% ± 0.17), and a higher NFE content of (54.15% ± 2.48) than maize fodder but lower than maize seed.

Reddy (2001) reported that the oat grain contained a moderate level of crude protein (CP) at 9%, a lower level of crude fiber (CF) at 5%, an ether extract (EE) of 1.5%, a total ash content of 4.5%, and a considerably high nitrogen-free extract (NFE) content of 80%. In comparison, oat grain from Banerjee (2005) exhibited a slightly higher CP content of 10.07% and higher CF content of 12.71%, with substantially higher EE content at 6.55% and similar total ash content. Green oat from Reddy (2001) showcased a significantly lower CP content of 3%, CF content of 6%, and distinctly lower EE and total ash contents, with a substantially reduced NFE content of 14%., Green oat from Banerjee (2005) demonstrated a similar CP content of 9.9%, substantially higher CF content of 26.6%, and lower EE and total ash contents compared to Reddy (2001), with a higher NFE content of 50.5%. The experimented oat hydroponic fodder displayed a significantly higher CP content of (13.80% ± 0.52), significantly CF content of (19.31% ± 1.62), EE content of (3.18% ± 0.10), lower total ash content of (3.39% ± 0.06), and NFE content of (47.11% ± 2.41).

Table 4.6 Chemical composition (%) of different species of hydroponic fodders

Fodder species	Chemical composition (%)					
	Dry matter (DM)	Crude Protein (CP)	Crude Fiber (CF)	Ether extract (EE)	Total ash (TA)	Nitrogen Free Extract (NFE)
Sorghum	$18.11^{b} \pm 0.69$	$13.12^{b} \pm 0.37$	$8.16^{b} \pm 0.10$	$3.13^{b} \pm 0.17$	$4.42^{b} \pm 0.22$	$53.05^{c} \pm 0.92$
Cowpea	$9.87^{bc} \pm 0.22$	$25.80^{a} \pm 0.48$	$17.08^{bc} \pm 0.23$	$2.39^{bc} \pm 0.13$	$9.61^{a} \pm 0.36$	$35.26^{b} \pm 0.92$
Wheat	$26.62^{a} \pm 2.91$	$18.78b^{c} \pm 0.30$	$8.00^{b} \pm 0.07$	$3.35^{c} \pm 0.05$	$3.49^{bc} \pm 0.13$	$39.76^{b} \pm 2.59$
Maize	$17.52^{b} \pm 2.51$	$11.38^{bd} \pm 0.26$	$9.75^{b} \pm 0.10$	$3.59^{a} \pm 0.17$	$3.61^{bd} \pm 0.17$	$54.15^{a} \pm 2.48$
Oat	$13.20^{b} \pm 1.47$	$13.80^{b} \pm 0.52$	$19.31^{a} \pm 1.62$	$3.18^{d} \pm 0.10$	$3.39^{be} \pm 0.06$	$47.11^{bc} \pm 2.41$
Total	16.86 ± 1.29	16.60 ± 1.05	12.38 ± 0.94	3.12 ± 0.10	5.01 ± 0.48	46.04 ± 1.66
F-value	11.701	225.646	64.809	11.274	146.998	18.853
Level of significance	***	***	***	***	***	***

*** $p<0.001$; Means with uncommon superscripts in a row differed significantly ($p<0.05$).

4.7 Correlation matrix

Table 4.7 presents correlations between various parameters related to plant growth and development, including germination weight, biomass yield, height, root length, and chlorophyll level, all measured on the 11th day after germination. Table contains a Pearson correlation coefficient, indicating the strength and direction of the linear relationship between two variables. Significance levels (Sig.) are provided to determine whether observed correlations are statistically significant. The correlation coefficient, which can take values from -1 to 1, illustrates the direction and strength of the linear relationship that exists between two variables. Germination weight shows significant positive correlations with biomass yield and chlorophyll level, implying that seeds with greater initial weight tend to produce higher biomass and exhibit higher chlorophyll content. Chlorophyll level strongly correlates with both germination weight and biomass yield, suggesting that plants with higher chlorophyll content tend to have heavier seeds and greater biomass. Height correlates positively with root length, indicating a relationship between above-ground and below-ground growth. A notable negative correlation exists between germination weight and root length, indicating that seeds with greater weight tend to yield plants with reduced root lengths.

Table 4.7 Correlation matrix (r) among germination weight, biomass weight, height, root length and chlorophyll levels of hydroponic fodders at day 11.

	Germination wt. (g)	Biomass wt. at day 11 (g)	Height at day 11 (cm)	Root length at day 11 (cm)	Chlorophyll level at day 11
Germination Wt. (g)	1				
Biomass yield at day 11 (g)	.525**	1			
Height at day 11 (cm)	.115	.112	1		
Root length at day 11 (cm)	-.398**	-.204	.511**	1	
Chlorophyll level at day 11	.869**	.381*	.005	-.293	1

CHAPTER 5

SUMMARY AND CONCLUSION

5.1 Summary

Hydroponic technology offers an efficient alternative to traditional soil-based methods of fodder production. Cultivation of various fodder crops in nutrient-rich fluid or tap water, including fodder species like maize, oat, wheat, sorghum, cowpea is feasible without soil for animal feed. In countries like Bangladesh, where arable land is scarce and urbanization is expanding into agricultural areas there is a substantial need for high-quality animal feeds. To address these issues, alternative technologies like hydroponics can offer benefits for sustainable livestock production. The examination took place at the Animal Husbandry Laboratory and the Dr. Purnendu Gain Field Laboratory, which are affiliated with the Agrotechnology Discipline at Khulna University.

Experiment evaluated five fodder species which are maize, wheat, oat, sorghum, and cowpeas using hydroponic techniques based on Completely Randomized Design (CRD). The research focused on comparative analysis among the treatment groups, with each species being represented as a treatment group and no control group being included. Good quality seeds were collected from local source. The growing area was prepared, with thorough cleaning and disinfection to prevent mold or disease, and also a proper drainage system was installed. Seeds underwent rinsing, soaking, and sprouting processes before being evenly spread on clean trays. Uniform environmental conditions were maintained by systematically shuffling the trays and providing artificial lighting. The seeds were watered 3-4 times daily using tap water, and the fodder was harvested on the 11th day post-germination. After harvesting, the growing area was cleaned and prepared for the next cycle. Daily observations included the recording of biomass yield, plant height, primary root length, and chlorophyll content. Production costs were analyzed to determine economic feasibility, and the chemical composition of dried fodder was assessed using AOAC standards.

Biomass yields of various hydroponic fodder species were evaluated over 11 days, revealing significant differences in growth. Cowpea and oat exhibited the highest germination weights (514.72g ± 4.95 and 399.89g ± 5.38, respectively), while sorghum and maize had the lowest (332.20g ± 4.12 and 337.28g ± 3.34). Oat had the highest biomass yield, peaking at 1254.22g ± 249.98 by day 11, whereas maize had the lowest at 707.79g ± 56.81. Plant height measurements showed oat consistently being the tallest, reaching 19.81 cm ± 1.34 on day 11, and sorghum the shortest at 13.74 cm ± 0.54. Root length at day 11 was highest in maize at 28.59 cm ± 0.12 and shortest in cowpea at 6.09 cm ± 0.05. Cowpea consistently had the highest chlorophyll levels, peaking at 40.20 ± 0.47 on day 10, while sorghum had the lowest at 21.81 ± 0.24 at day 11. Cost analysis indicated that sorghum had the highest production cost (51.16 BDT/kg ± 3.90), and wheat had the lowest (21.12 BDT/kg ± 1.17). Regarding chemical composition, wheat had the highest dry matter content (26.62% ± 2.91) and cowpea had the highest crude protein content (25.80% ± 0.48), whereas cowpea had the lowest dry matter (9.87% ± 0.22) and maize had the lowest crude protein content (11.38% ± 0.26). Correlation analysis revealed that higher germination weights positively influenced biomass yield and chlorophyll content, while a negative correlation was observed between germination weight and root length.

5.2 Conclusion

This study highlights feasibility of hydroponic technology when implemented on various fodder species in southwestern region of Bangladesh. This technology can be utilized if traditional agricultural system faces significant challenges. A comparative study of biomass yield, plant height, root length, and chlorophyll content in maize, wheat, oat, sorghum, and cowpea demonstrates that hydroponic cultivation can be effectively utilized for fodder production. The higher nutrient content associated with this method could potentially lessen or eradicate the need for concentrate feed in ruminant animals, while also delivering essential fiber and nutrients for poultry. Oat and cowpea demonstrated high biomass production, with oat achieving the highest yield and height, while maize exhibited the most extensive root development. Cowpea showed higher chlorophyll index suggesting higher photosynthetic activity, translating to potentially better nutritional quality. Limitations of this study include lack of microbiological profiling as potential fungus may occur. Overall, this experiment represents potential of hydroponic technology in the climate of southwestern region of Bangladesh and it can be used to mitigate fodder shortages and improve livestock nutrition sustainably. It offers a promising solution to meet the rising demand for animal feed and supply them with versatile nutrients. The adoption of this technology could benefit farmers in enhancing agricultural productivity and sustainability in fodder production.

5.3 Scope of future work

a. Microbiological profiling should be done carefully to observe potential pathogen that may cause toxicity or infection or any kind of pathogenesis in the animal's body.

b. There are many techniques/ways of producing hydroponic fodder. Different techniques and combination of this techniques should be studied to understand which can show most benefit and less disease/fungal growth because techniques that utilize still water or have lack of air flow are vulnerable to fungal growth.

c. In most cases, fodder is cultivated with hydroponic technology by providing tap water as nutrient solution. Other potential nutrient solutions should be studied to maximize production and animal safety should also be considered. Urea maybe used in the nutrient solution to investigate the productivity and effects with this technology and its effects should also be investigated with ruminant animals, as they can utilize certain level of urea.

d. Potentiality of this technology can be studied when fed to poultry as poultry feed to investigate its effect on its digestive system. Proper inclusion level in the ration may improve poultry performance as hydroponic fodder has high nutrients other than fibers.

e. Analysis of micronutrients can provide better understanding of how animals can be benefitted.

5.4 Recommendations

a. Farmers with limited arable land in Bangladesh should consider adopting hydroponic technology due to its biomass yields and high nutritional content observed in this study to improve fodder availability when arable land is scarce.

b. Farmers should focus on high yielding fodder like oat which also displayed maximum plant height in this study.

c. For minimizing production cost use of wheat can be a viable option for the farmers.

d. Trays should be cleaned regularly and strict hygiene should be maintained to prevent fungal growth and other issues associated with stagnant water. Water circulation should be maintained for optimum productivity.

e. This technology should only be used under the circumstances where there is a lack of arable land or traditional agricultural system is facing extensive challenges because of the complexity of this technology and possible pathogen grown if not utilized properly and also due to the production results that can vary depending on parameters such as environment, technique that is employed, seed quality and costing.

f. Future work should be implemented to understand the safety and better utilization of this technology.

CHAPTER 6

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CHAPTER 7

APPENDIX

Figure 7.1 Soaking of seeds

Figure 7.2 Seed tied up with cloth before putting it into gunny bag

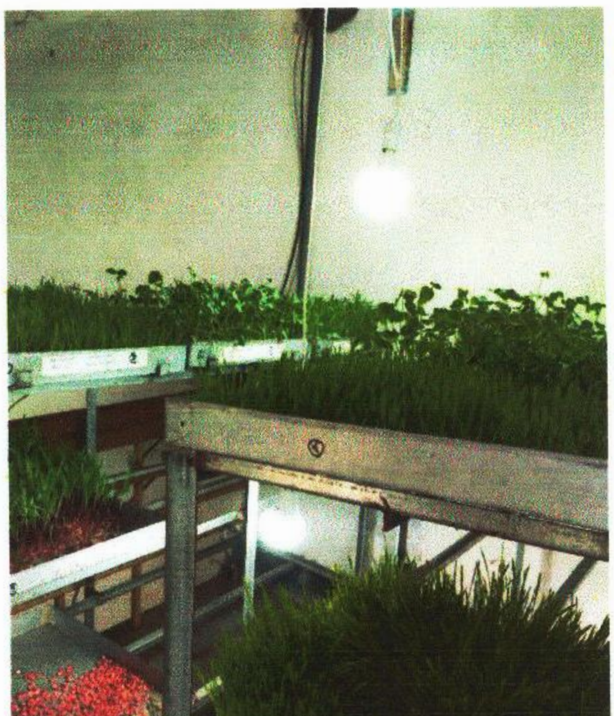

Figure 7.3 Supplementation of artificial lighting in hydroponic fodder

Figure 7.4 Weighing of sprouted cowpea seed

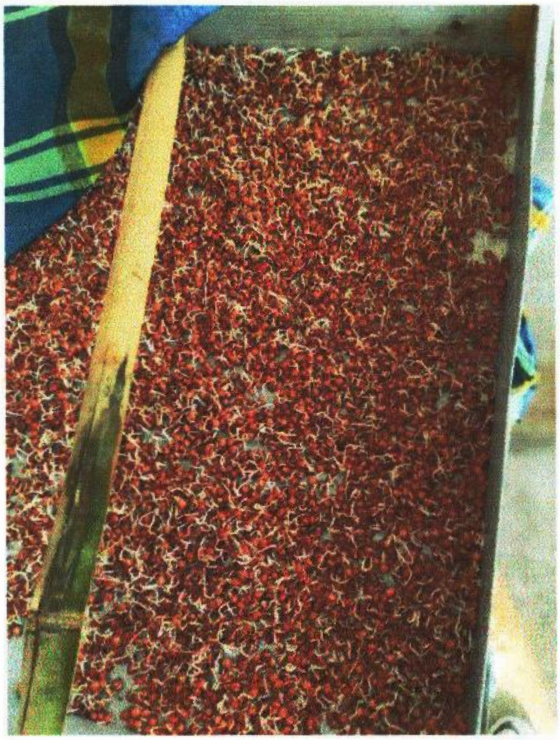

Figure 7.5 Sprouted sorghum seed on tray

Figure 7.6 Sprouted wheat seed on tray

Figure 7.7 Sprouted maize seed on tray

Figure 7.8 Sprouted oat seed on tray

Figure 7.9 Different species of hydroponic fodder at different growing stage

Figure 7.10 Maize hydroponic fodder at day 11

Figure 7.11 Sorghum hydroponic fodder at day 11

Figure 7.12 Wheat hydroponic fodder at growing stage

Figure 7.13 Oat hydroponic fodder at day 11

Figure 7.14 Sorghum hydroponic fodder at day 11

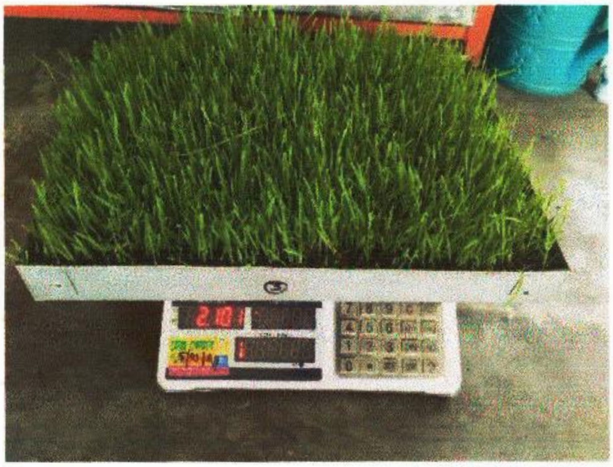

Figure 7.15 Weighing of wheat hydroponic fodder before harvest

Figure 7.16 Weighing of sorghum hydroponic fodder before harvest

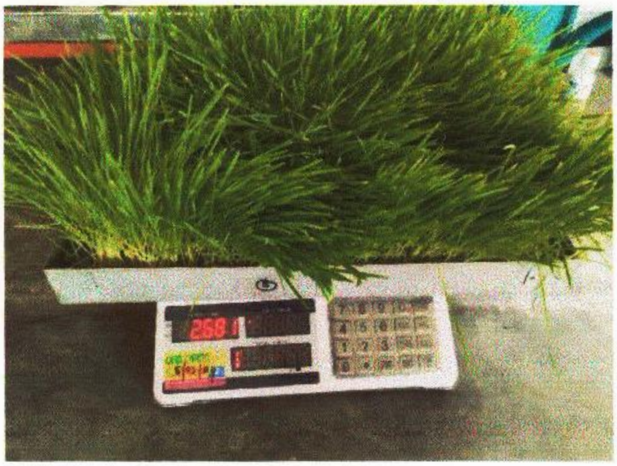

Figure 7.17 Weighing of oat hydroponic fodder before harvest

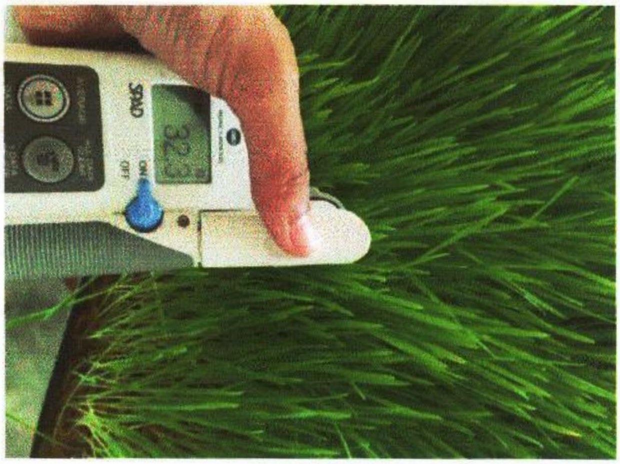

Figure 7.18 Taking of SPAD meter reading

Figure 7.19 Weighing of cowpea hydroponic fodder before harvest

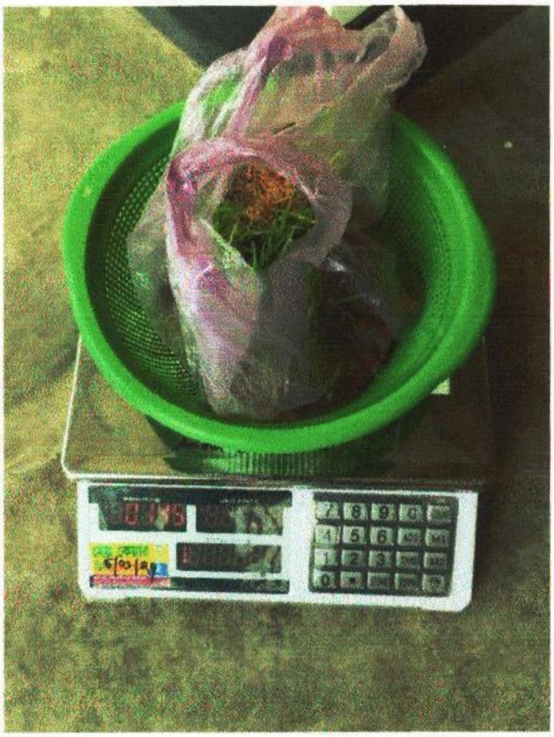

Figure 7.20 Weighing of sample for laboratory analysis

Figure 7.21 Drying of samples in hot air oven

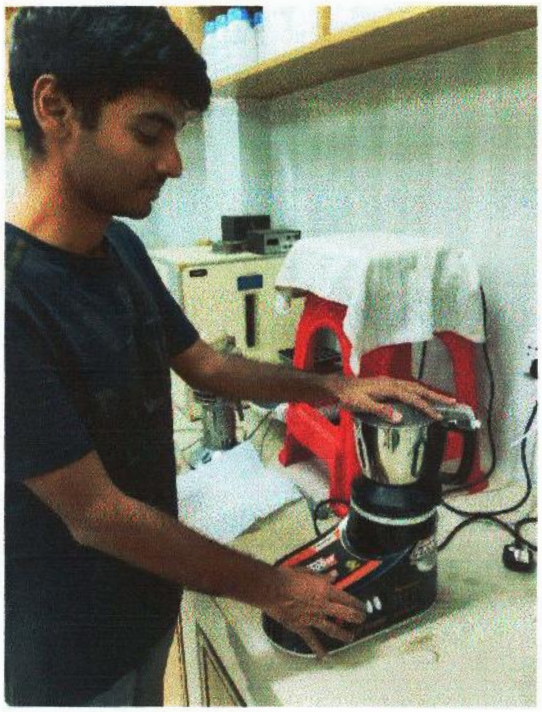

Figure 7.22 Grinding of dried sample

Figure 7.23 Grinded cowpea sample

Figure 7.24 Storage of different grinded samples

Figure 7.25 Ongoing ether extract test

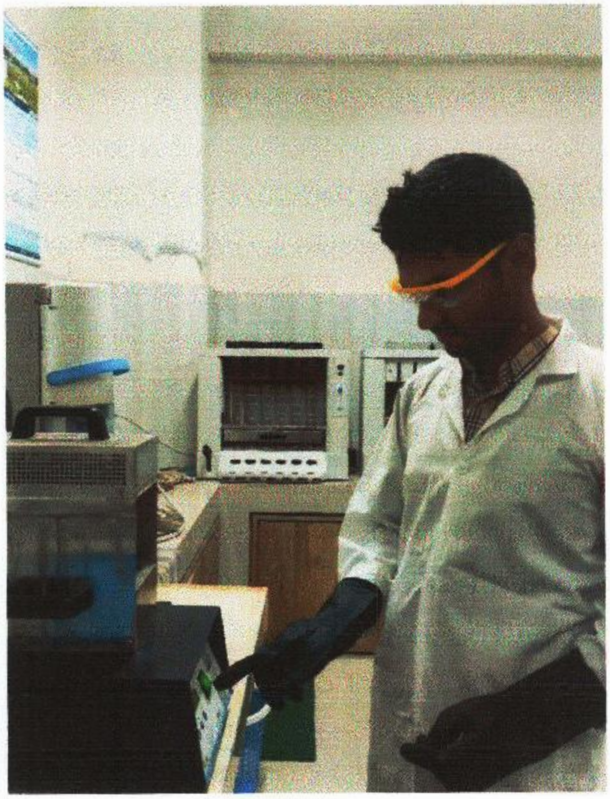

Figure 7.26 Vessels with sample inside desiccator for complete moisture removal for ether extract test

Figure 7.27 Ongoing digestion process for crude protein determination