

**INFLUENCE OF WATER SOURCES ON THE GROWTH AND
NUTRIENT COMPOSITION OF WHEAT FODDER IN A
HYDROPONIC CONDITION**

A THESIS

BY

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**AGROTECHNOLOGY DISCIPLINE
KHULNA UNIVERSITY
KHULNA-9208**



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**DEDICATED
TO
MY
BELOVED PARENTS**

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ABSTRACT

Fodder production technology is emerging as an alternative not only high-quality fodder but also part of increasing centralized livestock farms. The objectives of this study were to investigate the effect of different water sources on the production of wheat fodder hydroponically. The study was conducted at a small part of the underground basement of Acharya Jagadish Chandra Bose Academic Building, Khulna University, Khulna. The experiment was conducted using CRD with five treatments and three replications. The irrigation was applied with tap water, pond water, borehole water, river water and sewage water for BARI ghom-30 (*Triticum aestivum*) to measure yield, fodder quality, and water use efficiency under hydroponic conditions. The fodder was harvested on the 11th day. The sample was collected for analysis on different days (5th, 7th, 9th, and 11th). Using sewage water in irrigation has effectively increased the plant height and root and shoot length of hydroponic wheat fodder. The higher fodder yields obtained from tap water due to the higher root length than the other treatment. To produce one kg of fresh hydroponics wheat fodder (11-d), about 1.99-2.16 liters of water is required. Plant height was highly significant ($p<0.001$) at the 11th day of harvesting. Plant root and shoot length was highly significant ($p<0.001$) on the 9th day of harvesting. Total water use (liter kg⁻¹ fresh matter) was highly significant ($p<0.001$) on the 11th day of harvesting. Yield parameters included fresh yield was highly significant ($p<0.001$) on the 11th day of harvesting. Proximate contents of dry fodder were significantly higher in plants irrigated with sewage water than the others. The results of this study revealed that hydroponic green wheat fodder could be irrigated safely with tap water, pond water, borehole water, river water and sewage water to produce high yields and less water use. Moreover, the use of sewage water in irrigation of green forages in hydroponic systems is considered a useful alternative disposal method of wastewater.

Keywords: BARI ghom-30, Sewage water, Harvest



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ELABORATION

ADF = Acid Detergent Fiber	FCR = Free Chlorine Residual
NDF = Neutral Detergent Fiber	WWTP = Waste Water Treatment Plant
NFC = Non-Fibrous Carbohydrates	TWU = Total Water Use
GHG = Green House Gas	WUE = Water Use Efficiency
HBF = Hydroponic Barley Fodder	SPAD = Soil Plant Analysis Development
ADG = Average Daily Gain	AOAC = Association of Analytical Chemists
FCR = Food Conversion Ratio	GLM = General Linear Model
TMR = Total Mixed Ration	BARI = Bangladesh Agricultural Research Institute
ME = Metabolizable Energy	GW = Ground Water
TDN = Total Digestible Nutrient	EPA = Environment Protection Agency
PCA = Principal Component Analysis	WP = Water Productivity
GDP = Gross Domestic Product	DMRT = Duncan's Multiple Range Test
CF = Crude Fiber	DM = Dry Matter
CP = Crude Protein	NFE = Nitrogen Free Extract
EE = Ether Extract	

CHAPTER I

INTRODUCTION

Green fodder is a necessary element and natural source of dietary sustenance for ruminant animals. It is deficient in quantity and quality during the dry period, resulting in a poor overall performance of the animals. Therefore, to enhance the quality of livestock products, it is recommended to feed quality green fodder more frequently (Dung *et al.*, 2010). Green fodder helps boost the production and reproduction of dairy animals by giving them nutrients. They need a lot of green fodder for digestion and motility of the digestive system. It also helps reduce production costs by replacing concentrate feed.

Fodder production technology is emerging as an alternative to not only high-quality fodder but also part of increasing centralized livestock farms. In many countries, it is difficult to produce enough conventional green fodder, grain to feed the world's large livestock population. This is because of limited land, limited resources, labour, fertilizer, and fertilizer requirements for cultivation, and insufficient irrigation facilities. Other factors such as water scarcity, natural calamity, and frequent draught also contribute to the difficulty of producing sufficient fodder. Fodder shortage is a constant problem in sustainable livestock production, which results in poor reproductive and productive performance of the livestock (Bekuma, 2019).

The natural pasture supplies most of the feed resources for ruminants. The traditional way of producing green fodder isn't popular. Because it takes a lot of land to grow, fertilizer and irrigation. It takes a long time to grow (45-60 days) and can't harvest the same quality green fodder all year round (Mohapatra *et al.*, 2019). As the gap between the demand and supply of green fodder for increasing ruminant livestock, an alternative complementing fodder production method that would enhance fodder and livestock production is hydroponics (Bamikole *et al.*, 2020).

Hydroponic systems can be used to produce green fodder for a wide variety of forage crops free from chemicals such as insecticides, pesticides, fungicides and artificial growth promoters. This method ensures intensification fodder yields, consistent production year-round, and minimal water requirements (Tudor *et al.*, 2003).

demand going up and the uncertainty of water management due to climate change, it looks like the agricultural sector will be in trouble in many parts of the world in the future (Akhtar *et al.*, 2013).

For hydroponics, the growing conditions must be suitable for the forage seeds to germinate well in a short period in special growing rooms of green plants. Fresh forage is developed from wheat or oats, barley or other grains. Although there may be variations in forage grain development, the average forage mat height is 15-30cm, the average weight is 7-9kg, and the average dry matter content is 0.9-1.1kg.

For hydroponic production, there are recommendations to use water effectively in semi-retreat conditions (Girma *et al.*, 2018). Hydroponics can support a large number of people and enable third-world countries to feed themselves, even in areas with less fertile soil and limited water. It can also be a valuable resource for food production in areas where space is limited.

In hydroponics, mechanical support is provided to the roots, which hold the plant's weight and keep it upright. Common media used in hydroponic systems include Sand, Gravel, River rock, Oasis cubes, Floral foam, Vermiculite, Rockwool, Perlite, Peat moss, Coir, Coco-peat, Sew-dust (Gaikwad *et al.*, 2020). Hydroponic fodder is the world's best feed for livestock. It replaces grains such as dairy meal, pig's feed, or poultry feed concentrates, which are expensive. However, there's a huge gap in the knowledge and there's not enough data collected to know exactly how important hydroponics feed production is for sustainable livestock production against climate change. So, let's take a closer look at this aspect and focus on a few small details to get a better understanding of how hydroponics fodder is produced for sustainable livestock for climate change production. One of the ways to address the environmental and resource challenges is to create high values for the crops through the use of low water inputs and high fertilization efficiencies (Al-Karaki *et al.*, 2011). For example, hydroponic culture can be arranged with optimal environmental medium for crop growth to achieve maximum yield and high-quality products.

In addition to its unique characteristics, hydroponic systems are one of the most significant agricultural methods currently used for green fodder production in many countries around the world, particularly in arid and semi-arid areas. However, selecting the right forage crop is a key factor in achieving maximum fodder yield and quality, while also taking into account the economic aspects of the hydroponic process of green fodder production by reducing seed costs.

Recent research has shown that nutrients from treated wastewater can be cleaned up by using certain types of plants inside a hydroponic system. Very few research on fodder production using hydroponic system of irrigation has been conducted in Bangladesh. Hydroponic (soil-free) culture could help tackle global problems like water shortages, pollution, and environmental instability in different ways.

OBJECTIVES OF THIS RESEARCH

- i. To investigate the production performance of wheat fodder on different sources of water in hydroponic conditions.
- ii. To find out the nutritional value of wheat fodder.
- iii. To estimate the cost-benefit ratio in wheat fodder cultivation.

CHAPTER II

LITERATURE REVIEW

2.1 Background of Hydroponic Fodder

The Greek terms hydro, which means "water," and ponics, which means "working," are the roots of the phrase hydroponics. Thus, hydroponic feed, also known as sprouted grains or sprouted fodder, is feed made by growing plants in water or nutrient-rich solution without the need for soil (Dung *et al.*, 2010). The English scientist Woodward made an effort to cultivate plants in a variety of water sources in 1969. Gericke (1920–1930) created methods for large-scale plant growth in nutrient solutions. Leitch (1939) conducted a review of several trials involving sprouted fodder for various animals and poultry. He concluded that the commercial exploitation of plant water culture techniques to create stock fodder was known as sprouted fodder. In 2011, Goa Dairy established several hydroponic fodder production units under the Rastriya Krishi Vikas Yojana (RKVY) of the Indian government at several dairy cooperative societies, thereby introducing hydroponics technology to the state (Naik *et al.*, 2011; Naik *et al.*, 2012a; Naik *et al.*, 2012b).

An environmentally responsible way to cultivate fodder is hydroponically produced cereals, which grow up to 50% faster and yield higher yields of higher-quality fodder (Kide *et al.*, 2015). In a sanitary setting, animal feed seeds are germinated to produce a superior, highly nutritious, and disease-free product using a process known as hydroponic fodder production (Jensen and Malter, 1995; Al-Hashmi, 2008). Producing nutrient-rich grass and root combinations solely with water and nutrients is the process of producing hydroponically grown fodder in an intensive hydroponic growing arrangement (Emam, 2016).

Growing green fodder hydroponically uses less water and wastes less of the vital natural and artificial resources needed to produce fodder while managing the effects of climate and the growing environment (Elmulthum *et al.*, 2023). Hydroponic sprouted fodder has a significant nutritional advantage that can maximize young animals' overall health and performance while lowering feed expenses. Hydroponics technology can be used to produce a variety of fodder crops, including barley (Reddy *et al.*, 1988), oats, wheat (Snow *et al.*, 2008), sorghum, alfalfa, cowpea (Al-Karaki and Al-Hashmi, 2012), and maize (Naik *et al.*, 2011; Naik *et al.*, 2012). However, the choice of hydroponic fodder to be produced is contingent upon the agroclimatic conditions of the

region as well as the ease of access to seeds. Since maize grows quickly and is readily available, it is a suitable candidate for hydroponic fodder production in India since it produces good biomass and is inexpensive (Naik *et al.*, 2015). According to Kerr, the idea of hydroponic fodder originated in the 1800s, or even earlier, during the time of the "Hanging Gardens of Babylon," when European dairy producers fed sprouted grains to their cows in the winter to preserve milk output and increase fertility (Kerr *et al.*, 2014). For farmers without land, it offers a practical and sustainable alternative technology for producing fodder without soil. Hydroponic technology can be used to produce a variety of fodders, such as rye, alfalfa, horse gram, ragi, bajra, jowar, and triticale (Rachel Jemimah *et al.*, 2015). This fodder resembles a mat that is likely 20 to 30 cm tall and is made up of plants, seeds, and roots that are extremely tasty, easily digested, and nutrient-rich for animals. The forage mat height depends on the type of grain, and its production rate is approximately 7 to 9 kg of fresh forage, or 0.9 to 1.1 kg of dry matter (Rajesh *et al.*, 2018).

2.2 Fundamentals of Hydroponic Fodder Production

Cereal grains are grown hydroponically, without the use of a solid growing medium, with the required moisture and nutrients. In reaction to the moisture and nutrients supplied, germination occurs, producing a 20–30 cm long forage green stem with intertwined roots in 7–10 days. Various cereal grains, such as horse gram, bajra, millet, and maize, can be used to produce fodder, and they will undergo different structural and chemical changes as they mature. It's been discovered that the breakdown of nutrients into their more basic forms requires enzyme activation. The amount of sprouted and high-quality fodder is dependent on a number of parameters, including grain variety, quality, and treatments such as fertilizer availability, pH, water quality, and soaking time (Sneath and McIntosh, 2003).

2.3 Reasons for Hydroponic Fodder Production

2.3.1 Conservation of Water

Water waste is reduced by hydroponic systems since water is delivered directly to the roots and is frequently recycled and utilized multiple times. According to study results, a hydroponic system uses just 2% to 5% of the water in a typical system for producing feed (AI-Karaki and AI-Hashimi, 2012; Naik and Singh, 2014). According to reports, producing one kilogram of hydroponically grown fodder requires only 1.5 to 2 liters of water, while typical field circumstances require 73, 85, and 160 liters of water to produce one kilogram of barley, alfalfa, and Rhode's grass,

respectively (Rachel Jemimah *et al.*, 2015). This is particularly crucial in places where there is a persistent lack of water or where there is no irrigation infrastructure.

2.3.2 Appropriate Use of Space

Urban residents with small yards would find hydroponic systems excellent as they require far less area. Up to 1000 kg of maize fodder can be produced daily using hydroponics technology in 45–50 m² of space, which is comparable to conventional fodder produced in 25 acres of cultivable land (Naikand Singh, 2013; Rachel Jemimah *et al.*, 2015). In order to preserve land, a hydroponic system can be easily started indoors using several racks with multiple stages. A square meter of land can practically provide enough feed for two cows per day, and this increases the milk yield by 13% (Yvonne Kamanga, 2016).

2.3.3 Reduces the Growth Time

Whereas conventional fodder takes at least 45 days to grow, hydroponic technology grows fodder from seed to fodder in just 8 days.

2.3.4 Fodder Yield

By providing the nutrients directly to the plants, instead of requiring them to grow extensive root systems in search of food, fodder production can be sped up by up to 25%. In 7–8 days, one kilogram of unsprouted seed produces 8–10 kilograms of green forage (Sneath and McIntosh, 2003). According to Naik (Naik *et al.*, 2014), the output of fresh maize fodder produced hydroponically is 5 to 6 times higher and more nutritious than that of traditional farm production.

2.3.5 Provides Essential Nutrients

In the hydroponic green fodder, the content (DM basis) of calcium, neutral detergent fiber (NDF), acid detergent fiber (ADF), and crude protein (CP) increased relative to the unsprouted seed, whereas non-fibrous carbohydrates (NFC) and organic matter declined (Kide *et al.*, 2015; Mehta and Sharma, 2016). Hydroponic fodder is a rich source of vitamin A, vitamin E, vitamin C, thiamin, riboflavin, niacin, biotin, free folic acid, and anti-oxidants like α -carotene (Finney, 1983; Cuddeford, 1989; Naik *et al.*, 2015) and minerals (Bhise *et al.*, 1988; Chung *et al.*, 1989; Fazaeli *et al.*, 2011). When compared to traditional green fodder produced for 65–80 days, the biomass conversion ratio can reach up to 6–7 times higher. Additionally, the growth of fodder and the performance of livestock are directly impacted by the presence of hydroponic fodder, which is a

good source of minerals, vital fatty acids, and bioactive enzymes (Chavan *et al.*, 1989; Naik *et al.*, 2015).

2.3.6 Persistent Flow of Green Fodder

It is possible to produce fodder year-round, regardless of the monsoon's success, land availability, natural disasters, or labour scarcity, which promotes sustainable agricultural and cattle production. Perhaps because of this uniformity, there will likely be a promising yield of milk and better-quality meat and other animal products. The cultivation of fodder hydroponically can significantly raise the caliber of animal products (Maxwell Salinger, 2013).

2.3.7 Reduced Carbon Footprints

When it comes to the usage of inorganic chemicals, hydroponic agriculture is more environmentally friendly than traditional agriculture. As a result, there is a significant reduction in global warming and GHG emissions (Xu *et al.*, 2015). In response, hydroponic systems contribute to a reduction in carbon emissions and fuel usage for product delivery from remote agricultural farms.

2.3.8 Limits of Pesticides, Insecticides and Herbicides

For best results, traditional outdoor farming has to use herbicides, fungicides, and/or insecticides. The cultivation of hydroponic fodder takes place in a regulated setting devoid of soil, hence reducing the need for pesticides, insecticides, and herbicides. With a particular substance, the susceptibility of any virus in hydroponically grown fodder can be simply ruled out (Shit, 2019).

2.3.9 Impact on Animal Production

The animals love the extremely digestible, tasty fodder that comes from hydroponics. They are extremely succulent and can be consumed by big ruminants, mature pigs, small ruminants, and rabbits at rates of 1–1.5% of body weight (Jeton, 2016) or 15–25, 0.25–2.0, 1.5–2.0, and 0.1–0.2 kg/animal/day, respectively (Naik *et al.*, 2013; Rachel Jemimah *et al.*, 2015). According to Saidi and Abo Omar's (2015) research, hydroponic barley fodder (HBF) improved ewe health, mortality, conception rate, and abortion but did not influence feed consumption, body weight change, milk yield, or milk composition. When kids and rabbit kittens were fed hydroponic horse gram or sun hemp fodder in place of 50% of a concentrate combination, no negative effects were observed on the average daily gain (ADG) and feed conversion ratio (FCR) (Naik *et al.*, 2013; Rachel Jemimah *et al.*, 2015). Reddy observed considerable increases in the digestibility of nutrients in nursing

cows fed hydroponic fodder compared to those fed Napier bajra (NB-21) green fodder (Reddy *et al.*, 1988).

The daily milk output was 8.0-14.0% higher in animals fed total mixed ration (TMR) incorporating hydroponic maize or barley fodder than those fed standard green fodder (Rachel Jemimah *et al.*, 2015; Yvonne Kamanga, 2016). Longer lactation periods, higher fat percentages, and overall herd health are all improved by hydroponic fodder. In addition to higher milk yield and conception rate, other improvements included longer herd life and better health, as well as lower veterinary aid costs (Naik *et al.*, 2015).

The fast-growing poultry industry gains several benefits from hydroponic fodder i.e., faster weight increase, good quality carcass, cheaper feed cost per kg of weight gain and improved health and production potentials (Rachel Jemimah *et al.*, 2015). The nutritional content of diverse hydroponic fodders and their nutrient digestibility are evident for better cattle use and production.

2.4 Health Hazzard of Infected Hydroponic Fodder

Feeding dairy or beef animals hydroponically contaminated with *Aspergillus clavatus* is not recommended. Animals may have colonic convulsions, stiff gait, tremors, progressive paresis, knuckling of the fetlocks, dragging of the hind legs, high stepping in the hind limbs, posterior ataxia, hypersensitivity, recumbency, decreased milk supply, and maybe even death (McKenzie *et al.*, 2004).

2.5 Production of Hydroponic Fodder

In greenhouses with regulated environments, hydroponics is produced quickly (Sneath and McIntosh, 2003). A greenhouse is a framed or inflatable structure that is covered in a transparent material that allows crops to be grown in an environment that is at least somewhat regulated. Nonetheless, the structure needs to be sufficiently large to allow an individual to perform cultural processes. For the purpose of producing hydroponically grown fodder, two types of greenhouses are available: high-tech greenhouses and low-tech greenhouses, depending on the farmer's budget and the availability of building materials.

2.6 Nutrient Solution for Hydroponic Production

For hydroponic systems, a nutrient solution is an aqueous solution mostly composed of inorganic ions, which are essential to the full life cycle of plants physiologically (Taiz and Zeiger, 1998). As

of right now, the majority of plants are thought to require 17 elements: carbon, hydrogen, oxygen, nitrogen, phosphorus, copper, potassium, calcium, magnesium, sulphur, zinc, manganese, molybdenum, boron, chlorine, iron, and nickel (Salisbury and Ross, 1992). Other elements, including sodium, silicon, vanadium, selenium, cobalt, aluminum, and iodine, are also thought to be advantageous since they can either promote growth, counteract the harmful effects of other elements, or take the place of vital nutrients in a less focused capacity (Trejo Tellez *et al.*, 2007). The critical pH, electrical conductivity, and osmotic potential of a solution are determined by the content of its nutrients.

2.7 Land for Hydroponic Technology

In severe environments like deserts, places with inadequate soil, or metropolitan areas where traditional agriculture has been forced out by excessive land costs, hydroponic technology is applied. It is most likely suited to semi-arid, arid, and drought-prone parts of the world that experience regular water shortages or where resources for fencing, irrigation, and land preparation are scarce. Farmers from the coastal belt and mining regions, whose land is stony and unproductive, benefit greatly from the technology's ability to produce green fodder. The main reasons to switch to hydroponic fodder production include the destruction of fodder by stray cattle and wild animals, increased labour costs for growing methods, and inadequate involvement of educated unemployed youths in fodder farming (Shit, 2019).

2.8 Environmental Factors for Hydroponic System

To maximize the growth and production of hydroponically grown feed, environmental conditions are crucial. The average concentration of environmental cues such as length (12–16 hours), temperature (19–22 °C), average 60% humidity, light intensity (2000 lux), and aeration for 3 minutes every two hours should be maintained (El-Deeba *et al.*, 2009). Compared to conventional fodder cultivation, hydroponic fodder production requires a lot less electricity. The sixth day after sowing, when the barley seed sprouts retain their maximum biomass and nutrient production, is the last step of harvesting. Additionally, sprouted barley has the highest feed quality of all the hydroponic fodders, including rye, wheat, oats, and triticale (Heins *et al.*, 2015).

2.9 Nutritive Value of Hydroponic Fodders

The nutritional composition of hydroponically grown fodder made from cereal grains varies

(Fazaeli *et al.*, 2011). As the starch content drops, the dry matter and organic matter content is reduced. As plants go through their metabolic transformation, sprouting catabolizes starch into soluble sugar. Nonetheless, when the plant grows, the amount of structural lipids and chlorophyll increases, which causes the ether extract of hydroponic feed to rise. Along with sprouting, there is an increase in concentration. While nitrogen-free extract (NFE) diminishes, the content of linoleic acid, neutral detergent fiber (NDF), crude fiber (CF), and acid detergent fiber (ADF) increases with the development of structural carbohydrates. The process of sprouting causes a decrease in organic matter and an increase in total ash content. From day four onward, the mineral content of the sprout increases due to root growth, which enhances mineral uptake and is clearly more beneficial as a nutrient. Rather than water, a solution is employed (Dung *et al.*, 2010).

Hydroponic fodder has higher nutrient quality than conventional non-leguminous fodders in terms of NFE, ether extract (EE), organic matter, and crude protein (CP). According to Al-Ajmi, there is a decrease in energy absorption during plant respiration, as well as in the gross energy (GE), metabolizable energy (ME), and total digestible nutrient (TDN) content (Al-Ajmi *et al.*, 2009). Respiration during the sprouting phase is the primary cause of the 7–47% dry matter (DM) loss from the initial seed that occurs throughout the 6-7day period (Sneath and McIntosh 2003, Dung *et al.*, 2005, Fazaeli *et al.*, 2012, Putnam *et al.*, 2013). By activating enzymes, soaking seeds releases water and carbon dioxide, which releases energy and causes the endosperm's starch to break down into simple sugar. This results in a loss of dry matter (DM), with the starch in the seed changing into fiber and pectin in the roots and young shoots.

The maximum level of enzymes is maintained by sprouts from germination to seven days of maturity, making them the most enzyme-rich plants. They are abundant in antioxidants, particularly alpha-carotene (Sneath and McIntosh, 2003). Palatability-wise, there is no nutritional waste because the roots and shoots are eaten simultaneously. Depending on their physiological state, dairy animals can be fed up to 25 kg of low-concentrate roughage each day.

2.10 Hydroponic Feed on Livestock Productivity

2.10.1 Milk Production

Research has shown that feeding hydroponically produced fodder increases milk output more than feeding cows grain, hay, or silage. Aquaponic providing hydroponic fodder to nursing cows increases milk yield by 13.73% (Naik *et al.*, 2013), 10.07% (Reddy *et al.*, 1988), and 12.5%.

According to Canadian dairy farmers, providing their cows with hydroponic fodder boosts their intake of feed and improves milk production by 3.6 kg per day throughout the lactation phase. Additionally, South African farmers recorded a reduction of 3.6 liters of milk following a daily feed break of 6.8 kg (Mooney, 2005). Farmers in Maharashtra's Satara area reported that their milk yields had increased by 0.5 to 2.5 liters per animal. Daily and net profit of INR 25–50/-per animal daily as a result of feeding their dairy animals hydroponically produced fodder (Bakshi *et al.*, 2017). According to Agius, the principal component analysis (PCA) showed that dietary hydroponic supplementation raises the pH and milk fat percentage while maintaining higher milk quality (Agius *et al.*, 2019). According to Mincera, Comisana sheep fed hydroponically germinated oats showed improvements in welfare and milk yield (Mincera *et al.*, 2009).

2.10.2 Meat Production

Lambs' body weight gain is enhanced by hydroponic fodder, which may be attributed to the presence of high bioactive enzymes and components that enhance the performance of cattle (Naik and Singh, 2013). Furthermore, improved food digestibility and microbial activity in the rumen are also reflected in the increase in body weight. When beef cattle are fed hydroponic fodder instead of corn, there is an average gain of 200 g. Similarly, it has been found that birds and other animals see an 8% improvement in body weight gain (Muhammad *et al.*, 2013). Cross-breed calves (Rajkumar *et al.*, 2017), Awassi lambs (Atta, 2016), and goats (Kide *et al.*, 2015a) fed hydroponic maize and barley fodder, respectively, showed better body weight gain.

2.10.3 Overall Performance

There are other possible health advantages to hydroponic fodder. The highest concentration of enzymes found in food is found in sprouts, and the peak enzyme activity occurs between germination at the age of 7-8 days. They are abundant in naturally occurring antioxidants such as beta-carotene, vitamins C and E, and associated trace elements like zinc and selenium. By strengthening the immune system and neutralizing the acidic environment through the provision of alkaline digestive enzymes through sprouted grains, feeding animals sprouted grains increases their production. Sprouted grains are an excellent source of pigments that include xanthophylls, chlorophylls, protein-sparing factors, and grass juice, all of which enhance cattle reproduction and productivity (Shit, 2019).

2.11 Yield of Hydroponics Fodder

The fresh yield and DM content of the crops are critical for the effective production of fodder under hydroponics. The imbibition of water (leaching) and enzymatic activities (oxidation) that deplete the food reserves of the seed endosperm without any adequate replenishment from photosynthesis by the young plant during the short growing cycle are primarily responsible for the increase in fresh weight and subsequent decrease in DM content observed during seed sprouting (Sneath and McIntosh, 2003). When the chloroplasts are triggered on day five of a seven-day sprout, photosynthesis begins, but there isn't enough time for any appreciable DM accumulation (Dung *et al.*, 2010b). According to reports (Hillier and Perry 1969; Peer and Leeson 1985a), fresh yields of 2.8–8 folds in 6–8 days with a DM content of 8–19.7% in hydroponic barley and 3.5–6.0 folds in 7–8 days with a DM level of 10.3–18.5% in wheat fodder have been recorded. In 7–10 days, farmers growing hydroponically grown maize fodder in inexpensive greenhouses or devices reported a fresh yield of 8–10 kg from one kilogram of locally grown wheat seeds (Naik *et al.*, 2013b). The type of crops, harvesting days, amount of free water drained before weighing, type and quality of seed, seed rate, seed treatment, water quality, pH, irrigation frequency, nutrient solution used, light, growing period, temperature, humidity, clean and hygienic condition of the greenhouse, etc. are the main factors influencing the fresh yield and DM content of the hydroponics fodder (Trubey and Otros, 1969).

2.12 Livestock Feeds and Forage Status

Livestock production is a crucial component of agriculture that can support the livelihoods and food security of large numbers of people in the developing world. Including ruminant and nonruminant output, the livestock industry as a whole contributes between 15 and 17% of the GDP and 37 and 87% of household income (Mengistu *et al.*, 2021). Zaharaby reported that feeds and fodder are considered as the biggest problem for obtaining optimum return from livestock and their development in the country (Zaharaby, 2002). According to a previous study, only about 44% of the dry matter, 26% of the crude protein and 17% of the energy requirements are met by the available feed resources in the country (Saadullah, 2000). With 19.95% of the nation's GDP coming from agriculture (BBS, 2011), Bangladesh's agriculture has been changing since independence, going from a traditional to an input-supported system and tackling shifting agroecological, socio-economic, and climatic conditions. According to Sere (Sere *et al.*, 2008), inadequate livestock nutrition is a common problem in the developing world, and a major factor

affecting the development of viable livestock industries in poor countries. In livestock farming, optimum production may not be achieved without ensuring an abundant supply of feeds and fodder to the animals. One of the main barriers to Bangladesh's livestock development is the severe lack of feed and fodder. Roughage and concentrate are the main foods that ruminant animals consume. The main sources of roughage for Bangladeshi ruminants are crop residues (rice and wheat straw, maize stover, sugar cane by-products, pulse crop shreds, banana pseudo stem), green grasses (winter and monsoon fodder, natural green biomass, water, and crop weeds), and tree foliage and leaves (jackfruit, *Leucaena*, mulberry, and other edible tree leaves and bushes). Losses from natural disasters, roughage transportation challenges, lack of preservation and processing facilities, user ignorance, and other applications impact the availability of roughages for animals (Sarker *et al.*, 2016). Conversely, concentrate feeds are mostly made of grain by-products, which are thought to have the necessary nutritional quality but whose quantitative supply is insufficient to meet demand. Due to this, the feed crisis for rearing cattle has gotten worse, and the free-market trade policy has made dairy and fattening farms extremely competitive and difficult to maintain. According to Tareque, there are 29.1 million tons of roughage accessible for ruminants (Tareque, 1985). However, according to other reports (Tareque and Saadullah, 1988), the average amount of fresh green grass available per animal per day is roughly 1 kg from roadside, fallow areas, homesteads, and embankments.

Huque and Sarker (2013) calculated the nation's feed needs. The expected yearly production of concentrates is 2.76 million tons, while the overall production of fibrous feed, excluding roadside grazing and cut-and-carry grasses, is 32.8 million tons. However, it is reported that animals only have access to 50% of the fibrous feed available and that a percentage of the concentrate is lost to other purposes. It was determined that the current stock of farm animals requires an estimated 27.0 million tons of dry matter in fibrous feed and that the concentrate, which includes fish and poultry, requires 12.6 million tons. The estimated annual deficiency of roughage dry matter would be calculated as 39.3%, and that of concentrate dry matter as 78.1% of the total quantitative requirement, taking into account the availability of fibrous dry matter to animals (50.0% of the total production makes 16.4 million tons). The quantitative requirement for roughage dry matter is nevertheless somewhat reduced by roadside grazing and cut-and-carry grasses; however, the animals' production performances are still impacted by their qualitative deficiencies (av. M/D-5.5 MJ/Kg DM and CP-6.5% DM) and the time interval between production and demand. If the

byproducts are used improperly, the concentrated dry matter deficit could increase even further. According to a published report, the average availability of green grass is only 2.5 kg/h/day (Sarker *et al.*, 2016). The demand and supply gaps of feeds and fodders (Huque and Sarker, 2014) and seasonal and regional variations in biomass availability often limit ruminant production and productivity in many developing countries including Bangladesh. In Bangladesh, plenty of information on seasonal feeds and fodder dynamics is very scanty.

2.13 Water uses in Crops

Irrigation is becoming increasingly important in the world's agriculture. Supplemental irrigation is becoming more common in semi-humid areas as well while being mostly used in arid and semi-arid zones. The track record of enhanced crop yield owing to irrigation is unmistakable (Shalhevet, 1994).

The amount of water extracted worldwide has nearly doubled in the last 40 years. The irrigated land increased from 138 million ha in 1961 to 277 million ha in 2003 in order to increase food production. Due to population and economic expansion, water use will continue to rise in the ensuing decades (Liu *et al.*, 2009). All living things depend on water, which makes up between 50 and 97 per cent of plant and animal matter as well as roughly 70 per cent of the typical human body weight (Buchholz, 1998). Unfortunately, water is also the most mismanaged resource in the world (Fakayode, 2005). The majority of the world's groundwater (GW) resources are depleting at an alarming rate, and in the future, they might not be able to keep up with the needs of industry and agriculture. According to estimates, the agricultural industry uses the most greenhouse gas emissions (GW) and uses around 80% of the real water resources for irrigation. Due to a lack of better options, many farmers in locations adjacent to urban and peri-urban areas are even forced to irrigate their crops with wastewater (Ghimire, 1994). Eighty to ninety per cent of the freshwater consumed by people comes from agriculture as, in stark contrast to household and industrial withdrawals, the majority of the water used by agriculture is lost through transpiration and evaporation. It is evident that in many areas, significantly reducing water use is necessary to achieve sustainable agriculture (Morison *et al.*, 2008).

2.13.1 Surface Water

Irrigation is becoming increasingly important in the world's agriculture. Supplemental irrigation is becoming more common in semi-humid areas as well while being mostly used in arid and semi-arid zones. The track record of enhanced crop yield owing to irrigation is unmistakable.

Water and land resources are vital in cities and are increasingly important in the development of many rural communities. Farming, grazing, wildlife, natural vegetation, cattle, residential development, water retention, and transportation infrastructure are some of the significant land uses. Global conflicts over land usage are becoming more common, and one of the main causes of these conflicts is population expansion. Large tracts of land are used for agriculture in various parts of the world, including livestock farms, paddy fields, row crops, and specific income crops (Seeboonruang, 2012).

2.13.2 Groundwater

Nearly 2 billion people receive their water from groundwater worldwide, which also provides more than 40% of the water used for irrigation and, by overcoming local rainfall limitations, allows for 13% of total food production. Both large- and small-scale growers can boost agricultural output by using groundwater. With careful planning, it increases food security globally and may result in healthier diets. Many significant agricultural areas regularly and progressively overuse groundwater supplies (Yang X. *et al.*, 2021).

The procedures used in agricultural production are often blamed for the degradation of groundwater in rural regions. It may take years for nonpoint sources of contamination to cause noticeable changes in groundwater quality; as a result, these changes reflect the cumulative effect of previous N and water management techniques. Due to challenges in collecting representative soil samples, it is sometimes difficult to assess the combined effects of N and water management in the soil vadose zone. As a result, it is commonly believed that monitoring groundwater quality represents a reasonable integration of all management techniques across time (Schepers *et al.*, 1991).

One adaptable and dependable source of water is groundwater. On the other hand, shallow fresh groundwater is not used, and excessive pumping by deep public and private tube-wells frequently

pulls up water with significant salinity and causes secondary soil salinization. As a result, it is necessary to use this valuable water more wisely. By using appropriate irrigation scheduling, shallow groundwater can also be utilized for sub-irrigation to assist close the gap between water supply and demand.

2.14 Water Scarcity

Water scarcity affects various ecosystems and over 40% of the world's population. Population expansion and rising per-capita protein and food-energy demands are putting more strain on the world's water and land resources. Most of the world's consumptive freshwater use is currently attributed to agriculture, and by 2050, that share is expected to increase. The increasing production of biologically produced energy and materials worldwide is expected to result in a significant rise in agricultural output in the future. Due to these pressures, in many parts of the world, land degradation and water scarcity are more pressing environmental issues than climate change (Pfister *et al.*, 2011). The effective use of water in crop production has been a source of concern for man for generations. It's true that managing the water requirements of crops and cultivating them was likely a prerequisite for civilization (Tanner *et al.*, 1983).

Any type of water that has been contaminated is considered wastewater. In many nations around the world, rapid industrialization and urbanization have led to problems with water quantity and quality. Wastewater production has increased as a result of this. Worldwide, improper water handling and use in a variety of sectors, including municipalities, agriculture, and industry, results in 380 trillion L/y of wastewater (McAteer *et al.*, 2020). According to Environment Protection Agency (EPA), the wastewater is categorized as grey water (household wastewater from washing), black water (toilet wastewater), sewage (greywater, blackwater, and trade waste), and industrial wastewater. Given the potential for future water scarcity, this enormous volume of wastewater output is cause for concern (Hao *et al.*, 2019).

2.15 Reutilization of Different Wastewater

The current global population of 6000 million will increase by 35% to approximately 8100 million by 2030. There will be a significant increase in the demand for food due to the expanding population. Water consumption from non-agricultural sectors will continue to rise concurrently in both developed and emerging nations. The world's geographical area is approximately 40%

covered by dry and semi-arid climates. Under these circumstances, it's critical to maximize crop water productivity (WP) and make efficient use of wastewater (Ali *et al.*, 2008). Utilizing wastewater for crop irrigation can have a positive economic impact by utilizing its N and P levels, supplying plants with nutrients while reducing the need for fertilizers, and promoting regional food production. Since the beginning of the industrial revolution, wastewater treatment has been seen as a social and environmental issue. Numerous studies conducted in the 19th and 20th centuries attempted to identify the components of wastewater to develop more effective methods for eliminating and disposing of pollutants from wastewater (Tang, 2004).

The most popular technique for disinfecting wastewater is chlorination, yet this process can produce hazardous and mutagenic byproducts that could be dangerous to aquatic and human life (Monarca *et al.*, 2000). Since chlorine inactivates the majority of bacterial and viral pathogens quickly and affordably while leaving a free chlorine residual (FCR) in the water for protective benefits, chlorine is a disinfection technique that is frequently employed in humanitarian emergencies to treat water supplies (Wu *et al.*, 2022). Chlorination has been the most widely used wastewater disinfection technique since the late 1940s and is a key component in the global prevention of waterborne infectious illnesses. It is possible to use a variety of chlorine derivatives, including gaseous chlorine, hypochlorite, and chloramine compounds. In recent years, a number of WWTPs in the United States have switched from gaseous chlorine to hypochlorite in an effort to reduce operating and maintenance (O&M) costs and enhance operator safety (Lazarova *et al.*, 1999).

2.16 Reuse of Wastewater for Agriculture Irrigation

There is a limited amount of fresh water, therefore it is essential to preserve it and use lower-quality irrigation water. As freshwater scarcity increases in areas like dry and semi-arid countries, agriculture—which depends greatly on it and uses most of it worldwide—may face life-threatening consequences (Rusan *et al.*, 2007). Approximately 70% of the water collected is used for agricultural irrigation in arid and semi-arid regions of the world. To complement the current freshwater sources, it is imperative to identify additional alternative water sources, such as desalinated river water and treated wastewater (surface water, groundwater). gradually replacing freshwater used for irrigation with purified wastewater (Ofori *et al.*, 2021). In Pakistan, 30% of wastewater is used directly for irrigation, whereas 64% of it is disposed of untreated in rivers (Choudhary & Mushtaq, 2023).

CHAPTER III

METHODOLOGY

3.1 Experimental Site

The experiment was conducted at the small part of the underground basement of Acharya Jagadish Chandra Bose Academic Building (academic building-2) Khulna University, Khulna. The minimum and maximum temperature of the house were 18°C - 23°C respectively.

3.2 Preparation of Shelf and Tray

Trays were made from tin sheets. Fifteen (15) steel trays have the same dimensions of 46cm long and 41cm wide for each plot. Every day location of each tray was changed to get better results from the experiment. The tray was poured on one side so that water could be removed rapidly. The shelf was made on such a slope that water could be poured into another tray that stayed on the bottom side. The shelf was made around the inside of the shed. It was made of local instruments at least cost. Wood was used to make the shelf. Three shelves were made on each side of the shed. The well drainage system was available there. There was enough ventilation system for proper light and air.

3.3 Experimental Seed Collection and Preparation

Wheat seed (BARI ghom-30) was purchased for a fair price from the Khulna local market. These seeds were quickly sun-dried to reduce their moisture content to 12–14%. The seeds were twice washed in a pail with freshwater after they had been weighed. The cleaned seeds sterilized by soaking 30 minutes in a 20% sodium hypochlorite solution (household bleach) to control the formation of mold. The seeds were washed twice more with fresh water. After that, soak the seeds for at least 12 hours in treatments water. The optimum temperature at soaking is 23°C. Water was removed after 12 hours and the seeds was left without water for at least one hour. Seeds were placed in a gunny bag after being given time to breathe. The germination stage being very sensitive to the salinity level or others, due to this reason the salinity level of all treatments was checked before germination to reach maximum result.

3.4 Steps of Operation

Operation related to hydroponic fodder production was followed below: -

- i. At first seeds were weighed after buying from the market.
- ii. The seeds were washed with fresh water two times.
- iii. The cleaned seeds sterilized by soaking 30 minutes in a 20% sodium hypochlorite solution (household bleach) to control the formation of mold.
- iv. Then soak the seeds for at least 12 hours in each treatments water.
- v. After 12 hours of soaking passing away seeds were given breathing time about one hour.
- vi. After breathing time, the seeds were placed into a gunny bag (12 hours for wheat seed).
- vii. After germination occurred properly, seeds were placed in the trays through spreading.
- viii. Water was given timely. The samples were collected at 5th, 7th, 9th and 11th days for analysis. Lastly harvested on the 11th day and recorded the performance data.

3.5 Experimental Water Collection

In this experiment, five (5) types of different water were collected.

- i. Tap water: Tap water was collected from the Gollamari area, Khulna.
- ii. Pond water: Pond water was collected from Khulna University campus (Near the central field).
- iii. River water: River water was collected from the Rupsha river, Khulna.
- iv. Borehole water: Borehole water was collected from the Nirala residential area, Khulna.
- v. Sewage water: Sewage water was collected from the drain of residential halls of Khulna University.

3.6 Experimental Water Preparation

Sewage water was treated to remove the microbes. Chlorine tablet is very popular to remove the microbes from the wastewater. The simplest way to get rid of the chlorine is to let it sit out in an open container for 24 hours until the chlorine evaporates (USEPA, 1999).

Every water was mixed with nutrient solution at 3ml solution for 1-litre water.

applied was 2400 ml.

Table 3.9 Amount of water applied per day

Day	Water Use	Day	Water Use
1 st	100 ml	7 th	300 ml
2 nd	100 ml	8 th	300 ml
3 rd	200 ml	9 th	300 ml
4 th	200 ml	10 th	200 ml
5 th	250 ml	11 th	200 ml
6 th	250 ml		

3.10 Percentage of Germination

The percentage of germination indicates the proportion by number of seeds which have produced normal seedlings within specified period under favorable conditions. It is calculated by using the following formula-

$$\text{Percentage of germination} = \frac{\text{No. of normal seedlings}}{\text{No. of seeds set for the test}} \times 100$$

3.11 Total Water Use and Water Use Efficiency

The total added and drained water out of trays throughout the course of the experiment was recorded per tray every day to compute total water use and water use efficiency (AI-Karaki and AI-Hashimi, 2012). The total water used by plants (liters/tray) was computed according to the equation:

1. Total water use (liter/tray) = Total applied water by irrigation – Total drained out water.
2. Water use efficiency (WUE) in kg fresh weight/m³ water was computed according to the equation:

$$\text{WUE} = \frac{\text{Total green fodder produced (kg/tray)}}{\text{Total water used (liter/tray)}}$$

3.12 Lighting

The light was provided at 18 hours daily. In the daytime the lighting system was stopped for 6 hours. The lux meter reading in the room was 280-320 lux during the day and 180-220 lux at night.

3.13 Treatment and Design of Experiment

The experiment was conducted using CRD (Completely Randomized Design) with five treatments having three replications. The five sources of irrigation water were the treatments; i.e., T₁= Tap water, T₂= Borehole water, T₃= Pond water, T₄= River water and T₅= sewage water.

Table 3.13 Layout of the Experiment

Treatment(T)	Replication(R)		
	R ₁	R ₂	R ₃
T ₁	T ₁ R ₁	T ₁ R ₂	T ₁ R ₃
T ₂	T ₂ R ₁	T ₂ R ₂	T ₂ R ₃
T ₃	T ₃ R ₁	T ₃ R ₂	T ₃ R ₃
T ₄	T ₄ R ₁	T ₄ R ₂	T ₄ R ₃
T ₅	T ₅ R ₁	T ₅ R ₂	T ₅ R ₃

T₁ = Tap water; T₂ = Borehole water; T₃ = Pond water; T₄ = River water; T₅ = Sewage water

In each treatment 3ml nutrient solution liter⁻¹ of treatment water was added. A nutrient solution for hydroponic systems is an aqueous solution containing mainly inorganic ions which play vital physiological role to complete plant life cycle.

3.14 Harvesting

After 5th, 7th, 9th and 11th days of seed placing, the samples of the fodders were collected for data collection. Leaf chlorophyll content index was measured at 7th, 9th and 11th day.

3.15 Collection of Data

3.15.1 Agronomic Data

The physical data collected from the experiment are

- ✓ Leaf chlorophyll content index
 - ✓ Plant height(cm)
 - ✓ Root length(cm)
 - ✓ Root and shoot length(cm)
 - ✓ Biomass index
- i. Plant height: Plant height was recorded at 5th, 7th, 9th and 11th days by the help of meter scale.

- ii. Root length: Root length was recorded at 5th, 7th, 9th and 11th days by the help of meter scale.
- iii. Root and shoot length: Root and shoot length was recorded at 5th, 7th, 9th and 11th days by the help of meter scale.
- iv. Biomass index: Each tray's total plant quantity was measured and compared with the seed mass.

The leaf chlorophyll content index (SPAD meter readings) was recorded at 7th day, 9th day, 11th day of crop growth. The numerical SPAD value is proportional to the concentration of chlorophyll present in the leaf and is calculated from the measured absorbance of a leaf in the red and near-infrared regions. Since chlorophyll index increases with the amount of nitrogen, a higher SPAD value indicates better nitrogen nutrition of the plant. Based on the plant development, readings were taken on young leaves from 5 plants per substrate. This data was collected at the time of 12 pm to 2 pm.

3.16 Preparation of Samples for Laboratory Analysis

The fodder samples were dried before grinding. After grinding, the samples were kept in polyethylene bags, labelled and stored for further analysis.

3.17 Proximate Analysis

The chemical composition was determined as per the standard method of the Association of Analytical Chemists (AOAC, 1990).

3.18 Gross Energy Calculation

Gross energy was calculated by the formula (Crisan & Sands, 1978)-

$$\text{Gross Energy} = (5.7 * \text{protein(gm)}) + (9.4 * \text{fat(gm)}) + (4.1 * \text{NFE (gm)} + \text{fiber(gm)})$$

3.19 Statistical Method and Analysis

Data were analyzed using the General Linear Model (GLM) procedure of SAS version 9.1, 1994 (SAS Institute, Inc.). DMRT was used to compare the treatment means with significance consider at $p < 0.001$.

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Agronomic Growth Parameters of Hydroponic Wheat Fodder

4.1.1 Germination rate and plant height of hydroponic wheat fodder

It is shown in table 4.1.1 that the highest germination was found in T₄ (90 %) and the lowest one was in T₅ (86%). There was no significant effect on the germination percentage among all the treatments. In a study it is found that the highest germination of wheat fodder was 98% (Yurina *et al.*, 2019) which is partially matched with present study and in the case of barley fodder same germination, 92% (Natsheh, 2020) was found which supports the present result. Yams (*Dioscorea dregeana*) seed germination was found 95% (Kulkarni *et al.*, 2007). The highest plant height at 5th day was found in T₅ (12.07 ± 0.26 cm) and the lowest one was in T₃ (6.51 ± 0.20 cm). Treatments had highly significant effect ($p < 0.001$) on plant height at 5th day. Similarly, the highest plant height at 9th day was found in T₅ (19.79 ± 0.30 cm) but the lowest one was in T₁ (13.15 ± 0.32 cm) which was significantly ($p < 0.001$) affected. In a study it is found that the plant height of wheat fodder at 8th day was 14.10 cm (Bari *et al.*, 2022) which is partially matched with present study and in the case of maize fodder plant height, 24.87 cm (Jolad *et al.*, 2020) was found which supports the present result. The highest plant height at 11th day was found in T₅ (21.35 ± 0.64 cm) and the lowest one was in T₃ (17.15 ± 0.96 cm) which was also significantly ($p < 0.001$) affected.

Table 4.1.1 Germination rate and plant height of hydroponic wheat fodder

Treatment	Germination (%)	Plant height at 5 th day (cm)	Plant height at 7 th day (cm)	Plant height at 9 th day (cm)	Plant height at 11 th day (cm)
T ₁	89.33 ± 0.67	6.98 ^b ± 0.39	8.96 ^b ± 0.35	13.15 ^c ± 0.32	17.86 ^b ± 0.23
T ₂	89.33 ± 2.67	6.53 ^b ± 0.32	8.95 ^b ± 0.40	13.96 ^c ± 0.55	18.33 ^b ± 0.38
T ₃	88.67 ± 2.91	6.51 ^b ± 0.20	9.36 ^b ± 0.28	13.70 ^c ± 0.23	17.15 ^b ± 0.96
T ₄	90 ± 1.15	11.90 ^a ± 0.06	14.35 ^a ± 0.02	18.41 ^b ± 0.02	21.32 ^a ± 0.87
T ₅	86.67 ± 1.76	12.07 ^a ± 0.26	14.77 ^a ± 0.56	19.79 ^a ± 0.30	21.35 ^a ± 0.64
CV (%)	3.94	5.31	5.64	3.63	6.12
P value	NS	***	***	***	***

T₁ = Tap water; T₂ = Borehole water; T₃ = Pond water; T₄ = River water; T₅ = Sewage water;

NS=non-significant, Means with different superscripts in a column differ significantly; ***= $p < 0.001$, **= $p < 0.01$, *= $p < 0.05$

4.1.2 Root length of hydroponic wheat fodder

It is shown in table 4.1.2 that the highest root length at 5th day was found in T₄ (9.57 ± 0.14 cm) and the lowest one was in T₃ (5.59 ± 0.18 cm) which was significantly ($p < 0.001$) affected. Similar trend was found in case of 7th day. In a study it is found that the root length of wheat fodder at 8th day was 9.72 cm (Bari *et al.*, 2022) which is partially matched with present study and in the case of maize fodder root length, 17.5 cm (Jemimah *et al.*, 2015) was found which supports the present result. Due to adding nutrient solution the present result might be better rather than those of other studies. The highest root length at 11th day was found in T₁ (15.15 ± 0.97 cm) and the lowest one was in T₅ (12.87 ± 0.23 cm). There was no significant effect on the root length at 11th day among all the treatments.

Table 4.1.2 Root length of hydroponic wheat fodder

Treatment	Root length at 5 th day (cm)	Root length at 7 th day (cm)	Root length at 9 th day (cm)	Root length at 11 th day (cm)
T ₁	$5.91^b \pm 0.47$	$9.37^b \pm 0.52$	12.56 ± 0.79	15.15 ± 0.97
T ₂	$6.02^b \pm 0.19$	$9.68^b \pm 0.38$	13.35 ± 0.59	14.80 ± 0.48
T ₃	$5.59^b \pm 0.18$	$8.53^b \pm 0.38$	12.49 ± 0.71	13.95 ± 0.66
T ₄	$9.57^a \pm 0.14$	$11.23^a \pm 0.16$	12.26 ± 0.16	13.38 ± 0.29
T ₅	$9.53^a \pm 0.14$	$11.18^a \pm 0.58$	11.69 ± 0.57	12.87 ± 0.23
CV (%)	6.03	7.42	8.38	7.26
P value	***	***	NS	NS

T₁ = Tap water; T₂ = Borehole water; T₃ = Pond water; T₄ = River water; T₅ = Sewage water
*NS=non-significant, Means with different superscripts in a column differ significantly; ***= $p < 0.001$, **= $p < 0.01$, *= $p < 0.05$*

4.1.3 Root and shoot length of hydroponic wheat fodder

It is shown in table 4.1.3 that the highest root and shoot length at 5th day was found in T₅ (21.60 ± 0.035 cm) and the lowest one was in T₃ (12.10 ± 0.37 cm) which was significantly ($p < 0.001$) affected. Similar trend was found in case of 7th day. The highest root and shoot length at 9th day were found in T₅ (31.48 ± 0.47 cm) and the lowest one was in T₁ (25.71 ± 0.93 cm) which was significantly ($p < 0.001$) affected. In a study it is found that the root and shoot length of wheat fodder at 8th day was partially matched with present study (Bari *et al.*, 2022). The highest root and shoot length at 11th day were found in T₄ (34.70 ± 0.79 cm) and the lowest one was in T₃ (31.09 ± 0.78 cm) which had significant effect ($p < 0.001$).

Table 4.1.3 Root and shoot length of hydroponic wheat fodder

Treatment	Root and shoot length at 5 th day (cm)	Root and shoot length at 7 th day (cm)	Root and shoot length at 9 th day (cm)	Root and shoot length at 11 th day (cm)
T ₁	12.89 ^b ± 0.17	18.39 ^b ± 0.30	25.71 ^b ± 0.93	33.01 ± 1.17
T ₂	12.55 ^b ± 0.41	18.63 ^b ± 0.78	27.31 ^b ± 0.32	33.13 ± 0.80
T ₃	12.10 ^b ± 0.37	17.89 ^b ± 0.59	26.19 ^b ± 0.48	31.09 ± 0.78
T ₄	21.47 ^a ± 0.21	25.58 ^a ± 0.17	30.66 ^a ± 0.18	34.70 ± 0.79
T ₅	21.60 ^a ± 0.35	25.95 ^a ± 0.46	31.48 ^a ± 0.47	34.21 ± 0.42
CV (%)	3.41	4.07	3.28	4.31
P value	***	***	***	NS

T₁ = Tap water; T₂ = Borehole water; T₃ = Pond water; T₄ = River water; T₅ = Sewage water
*NS=non-significant, Means with different superscripts in a column differ significantly; ***= $p < 0.001$, **= $p < 0.01$, *= $p < 0.05$*

4.1.4 Association of germination and growth parameters of hydroponic wheat fodder

The results of Pearson's correlation co-efficient analysis among the germination and root and shoot length of BARI ghom-30 are presented in Table 4.1.4 Highly significant ($p < 0.001$) association was found between root and shoot length at 5th day and root and shoot length at 7th day ($r = 0.98$), at 9th day ($r = 0.92$), at 11th day ($r = 0.61$), root and shoot length at 7th day and root and shoot length at 9th day ($r = 0.91$).

Table 4.1.4 Correlation matrix of agronomic parameters

Parameters	Germination	Root and shoot length at 5 th day	Root and shoot length at 7 th day	Root and shoot length at 9 th day	Root and shoot length at 11 th day
Germination	1				
Root and shoot length at 5 th day	-0.14	1			
Root and shoot length at 7 th day	-0.29	0.98***	1		
Root and shoot length at 9 th day	-0.11	0.92***	0.91***	1	
Root and shoot length at 11 th day	0.11	0.61**	0.59*	0.57*	1

NS=non-significant, ***= $p < 0.001$, **= $p < 0.01$, *= $p < 0.05$

4.1.5 Leaf chlorophyll content index of hydroponic wheat fodder

It is shown in table 4.1.5 that the highest chlorophyll index at 7th day was found in T₄ (17.37 ± 0.66) and the lowest one was in T₁ (9.08 ± 0.23) which had highly significant effect ($p < 0.001$). Similar trend was found in the 9th day of the experiment. In a study it is found that the highest chlorophyll content of wheat fodder at 10th day was 24.62 (Jolad *et al.*, 2020) which is partially matched with present study and in the case of maize fodder, 24.87 (Jolad *et al.*, 2020) was found which supports the present result. The highest chlorophyll index at 11th day was found in T₅ (29.47 ± 0.90) and the lowest one was in T₁ (27.36 ± 1.17) which had highly significant effect ($p < 0.001$).

Table 4.1.5 Leaf chlorophyll content index of hydroponic wheat fodder

Treatment	Chlorophyll at 7 th day	Chlorophyll at 9 th day	Chlorophyll at 11 th day
T ₁	$9.08^c \pm 0.23$	25.41 ± 0.78	$27.36^b \pm 1.17$
T ₂	$11.69^b \pm 0.53$	25.65 ± 0.41	$28.27^{ab} \pm 0.96$
T ₃	$11.19^b \pm 0.46$	24.05 ± 0.22	$28.03^{ab} \pm 0.57$
T ₄	$17.37^a \pm 0.66$	26.37 ± 0.54	$27.95^{ab} \pm 0.46$
T ₅	$16.94^a \pm 0.30$	25.63 ± 0.67	$29.47^a \pm 0.90$
CV (%)	6.05	3.81	3.34
P value	***	NS	NS

T₁ = Tap water; T₂ = Borehole water; T₃ = Pond water; T₄ = River water; T₅ = Sewage water
*NS=non-significant, Means with different superscripts in a column differ significantly; ***= $p < 0.001$, **= $p < 0.01$, *= $p < 0.05$*

4.1.6 Association of growth parameters of hydroponic wheat fodder

The results of Pearson's correlation co-efficient analysis among the plant height and chlorophyll index of BARI ghom-30 are presented in Table 4.1.6 Highly significant ($p < 0.001$) association was found plant height at 5th day and chlorophyll index at 7th day ($r = 0.91$), plant height at 7th day and chlorophyll index at 7th day ($r = 0.92$), plant height at 9th day and chlorophyll index at 9th day ($r = 0.93$), plant height at 11th day and chlorophyll index at 7th day ($r = 0.82$).

Table 4.1.6 Correlation matrix of plant height and chlorophyll index of hydroponic wheat fodder

Parameters	Plant height at 5 th day	Plant height at 7 th day	Plant height at 9 th day	Plant height at 11 th day	Chlorophyll at 7 th day	Chlorophyll at 9 th day	Chlorophyll at 11 th day
Plant height at 5 th day	1						
Plant height at 7 th day	0.98***	1					
Plant height at 9 th day	0.94***	0.94***	1				
Plant height at 11 th day	0.84***	0.85***	0.86***	1			
Chlorophyll at 7 th day	0.91***	0.92***	0.93***	0.82***	1		
Chlorophyll at 9 th day	0.46*	0.40 ^{NS}	0.30 ^{NS}	0.31 ^{NS}	0.43 ^{NS}	1	
Chlorophyll at 11 th day	0.42 ^{NS}	0.44*	0.40 ^{NS}	0.43 ^{NS}	0.41 ^{NS}	0.11 ^{NS}	1

*NS=non-significant, ***= $p < 0.001$, **= $p < 0.01$, *= $p < 0.05$*

4.1.7 Total water use and water use efficiency of hydroponic wheat fodder

It is shown in table 4.1.7 that the highest water use (liter/tray) was found in T₄ (2.20 ± 0.06 liter) and the lowest one was in T₃ (1.98 ± 0.05 liter). There was no significant effect on total water use among all the treatments. In a study it is found that the total water use of wheat fodder was 4.1 liter (Al-Karaki *et al.*, 2012) which is partially agreed with present study. The highest water use (liter/kg fresh matter) was found in T₅ (3.26 ± 0.07 liter) and the lowest one was in T₁ (2.74 ± 0.11 liter). All the treatment had highly significant effect ($p < 0.001$) on total water use at liter/kg fresh matter. In a study it is found that the total water use of wheat fodder was 1.80 liter/kg fresh matter (Al-Karaki *et al.*, 2012) which is partially consistent with present study. The highest water use efficiency (kg fresh matter/m³) was found in T₁ (392.79 ± 4.77 kg) and the lowest one was in T₅ (358.56 ± 4.77 kg). All the treatments had highly significant effect ($p < 0.001$) on water use efficiency at kg fresh matter/m³. The highest water use efficiency (kg dry matter/m³) was found in T₅ (3.68 ± 0.18 kg) and the lowest one was in T₂ (2.85 ± 0.27 kg). All the treatment had significant effect ($p < 0.05$) on water use efficiency at kg dry matter/m³.

Table 4.1.7 Total water use and water use efficiency of hydroponic wheat fodder

Treatment	Total water use		Water use efficiency	
	Liter tray ⁻¹	Liter kg ⁻¹ fresh matter	kg fresh matter m ⁻³	kg dry matter m ⁻³
T ₁	1.99 ± 0.09	$2.74^c \pm 0.11$	$392.79^a \pm 4.77$	$3.04^{bc} \pm 0.22$
T ₂	2.05 ± 0.08	$2.93^{bc} \pm 0.08$	$378.38^b \pm 3.12$	$2.85^c \pm 0.27$
T ₃	1.98 ± 0.05	$2.83^c \pm 0.06$	$378.38^b \pm 3.12$	$3.11^{abc} \pm 0.17$
T ₄	2.20 ± 0.06	$3.18^{ab} \pm 0.09$	$374.77^b \pm 1.80$	$3.48^{ab} \pm 0.04$
T ₅	2.16 ± 0.05	$3.26^a \pm 0.07$	$358.56^c \pm 4.77$	$3.68^a \pm 0.18$
CV (%)	5.46	4.97	1.70	10.26
P value	NS	***	***	*

T₁ = Tap water; T₂ = Borehole water; T₃ = Pond water; T₄ = River water; T₅ = Sewage water
 NS=non-significant, Means with different superscripts in a column differ significantly; ***= $p < 0.001$, **= $p < 0.01$, *= $p < 0.05$

4.1.8 Yield, cost and biomass of hydroponic wheat fodder

It is shown in table 4.1.8 that the highest yield/tray was found in T₁ (726.67 ± 8.82 gm) and the lowest one was in T₅ (663.33 ± 8.82 gm) which had highly significant effect ($p < 0.001$). In a study it is found that the yield of wheat fodder within 10 days was 543 gm and 551 gm (Lamnganbi *et al.*, 2017), within 11 days was 688 gm (Mohapatra *et al.*, 2019) which is consistent with present study and in the case of maize fodder yield, 672 gm (Lamnganbi *et al.*, 2017) was found which also supports the present result. The highest biomass was found in T₁ (39.11 ± 0.48 t ha⁻¹) and the lowest one was in T₅ (35.70 ± 0.48 t ha⁻¹). Treatment had highly significant effect ($p < 0.001$) on biomass. In a study it is found that the biomass of wheat fodder was 37.9 t ha⁻¹ (Al-Karaki, 2011) which is agreed with present findings and in the case of barley fodder biomass, 34 t ha⁻¹ (Al-Karaki *et al.*, 2012) was found which supports the present result. The highest cost of production/ton was found in T₅ (30161 ± 398.40 BDT.) and the lowest one was in T₁ (26154 ± 319.58 BDT.). All the treatment had highly significant effect ($p < 0.001$) on cost of production/ton.

Table 4.1.8 Yield, cost and biomass of hydroponic wheat fodder

Treatment	Yield tray ⁻¹ (g)	Fresh Biomass (t ha ⁻¹)	Cost of production ton ⁻¹ (BDT.)
T ₁	726.67 ^a ± 8.82	39.11 ^a ± 0.48	26154 ^c ± 319.58
T ₂	700 ^b ± 5.77	37.67 ^b ± 0.31	26432 ^c ± 217.96
T ₃	700 ^b ± 5.77	37.67 ^b ± 0.31	26432 ^c ± 217.96
T ₄	693.33 ^b ± 3.33	37.32 ^b ± 0.18	28126 ^b ± 134.33
T ₅	663.33 ^c ± 8.82	35.70 ^c ± 0.48	30161 ^a ± 398.40
CV (%)	1.70	1.70	1.72
P value	***	***	***

T₁ = Tap water; T₂ = Borehole water; T₃ = Pond water; T₄ = River water; T₅ = Sewage water
NS=non-significant, Means with different superscripts in a column differ significantly; ***= $p < 0.001$, **= $p < 0.01$, *= $p < 0.05$

4.1.9 Association of biomass and water uses efficiency of hydroponic wheat fodder

The results of Pearson's correlation co-efficient analysis among the biomass, total water use, yield, cost of BARI ghom-30 are presented in Table 4.1.9 Highly significant ($p < 0.001$) association was found between biomass and water use efficiency ($r = -0.66$), biomass and cost ($r = -0.89$), water use efficiency and cost ($r = 0.76$), yield and cost ($r = 0.76$).

Table 4.1.9 Correlation matrix of biomass, water use efficiency, yield and cost of hydroponic wheat fodder

Parameters	Biomass	Total water use (liter tray ⁻¹)	Water use efficiency (kg fresh matter m ⁻³)	Water use efficiency (kg DM m ⁻³)	Yield (g)	Cost (BDT t ⁻¹)
Biomass	1					
Total water use (liter tray ⁻¹)	-0.31	1				
Water use efficiency (kg fresh matter m ⁻³)	1***	-0.31	1			
water use efficiency (kg DM m ⁻³)	-0.66***	0.09 ^{NS}	-0.66**	1		
Yield (g)	1***	-0.31	1***	-0.66**	1	
Cost (BDT t ⁻¹)	-0.89***	0.48*	-0.89***	0.76***	-0.89**	1

*NS=non-significant, ***= $p < 0.001$, **= $p < 0.01$, *= $p < 0.05$*

4.2 Nutritional Parameter of Hydroponic Wheat Fodder

4.2.1 Nutritional composition of hydroponic wheat fodder

It is shown in table 4.2.1 that the highest dry matter was found in T₅ (7.94 ± 0.21) and the lowest one was in T₂ (5.81 ± 0.43) which had highly significant effect ($p < 0.001$). In a study it is found that the dry matter of wheat fodder was 8.64 (Yurina *et al.*, 2019) which is partially consistent with present findings and in the case of maize fodder the dry matter, 14.79 (Natsheh, 2020) was also found. The highest crude protein was found in T₅ (19.73 ± 0.73) and the lowest one was in T₁ (16.91 ± 0.69) which had highly significant effect ($p < 0.05$). The crude protein content of wheat fodder was 18.10 (Yurina *et al.*, 2019) which is partially agreed with present results. The highest crude fiber was found in T₄ (9.02 ± 0.51) and the lowest one was in T₃ (7.83 ± 0.51). There was no significant effect on crude fiber among all the treatments. The crude fiber of wheat fodder was 3.40 (Yurina *et al.*, 2019) and in maize fodder the crude fiber, 5.30 (Natsheh, 2020) was found. The highest ether extract was found in T₅ (5.27 ± 0.37) and the lowest one was in T₁ (4.14 ± 0.16). There was no significant effect on ether extract among all the treatments. The highest ash was found in T₅ (4.32 ± 0.22) and the lowest one was in T₁ (3.50 ± 0.30). There was no significant effect on ash among all the treatments. In a study it is found that the ash of wheat fodder was 4.09 (Yurina *et al.*, 2019) which is consistent with present study and in the case of maize fodder the ash, 2.50 (Natsheh, 2020) was found which supports the present result. The highest nitrogen free extract was found in T₁ (67.06 ± 0.96) and the lowest one was in T₅ (61.98 ± 1.01). All the treatment had significant effect ($p < 0.05$) on nitrogen free extract. In a study it is found that the nitrogen free extract of wheat fodder was 71.12 (Yurina *et al.*, 2019) which is partially agreed with present study and in the case of maize fodder the nitrogen free extract, 78.34 (Natsheh, 2020) was found which also supports the present result. The highest gross energy was found in T₅ (232.76 ± 2.62 kcal) and the lowest one was in T₁ (210.72 ± 3.98 kcal). All the treatment had highly significant effect ($p < 0.01$) on gross energy.



Table 4.2.1 Nutritional composition of hydroponic wheat fodder

Treatment	DM (%)	CP (%)	CF (%)	EE (%)	ASH (%)	NFE (%)	GE (kcal/kg)
T ₁	6.01 ^b ±0.17	16.91 ^b ±0.69	8.39±0.33	4.14±0.16	3.50±0.30	67.06 ^a ±0.96	210.72 ^c ±3.98
T ₂	5.81 ^b ±0.43	17.16 ^b ±0.91	8.30±0.29	4.57±0.39	3.56±0.04	66.42 ^{ab} ±0.82	215.53 ^{bc} ±3.72
T ₃	6.15 ^b ±0.20	17.41 ^{ab} ±0.49	7.83±0.51	4.34±0.44	4.28±0.42	66.14 ^{ab} ±1.45	214 ^{bc} ± 4.34
T ₄	7.65 ^a ±0.12	19.18 ^{ab} ±0.91	9.02±0.51	4.39±0.27	4.23±0.24	63.18 ^{bc} ±1.41	222.83 ^{ab} ±3.64
T ₅	7.94 ^a ±0.21	19.73 ^a ± 0.73	8.68±0.51	5.27±0.37	4.32±0.22	61.98 ^c ± 1.01	232.76 ^a ± 2.62
CV (%)	6.46	7.31	8.38	12.98	11.93	3.09	2.93
P value	***	*	NS	NS	NS	*	**

T₁ = Tap water; T₂ = Borehole water; T₃ = Pond water; T₄ = River water; T₅ = Sewage water

NS=non-significant, Means with different superscripts in a column differ significantly; ***= $p<0.001$, **= $p<0.01$, *= $p<0.05$

4.2.2 Association of nutritional parameters of hydroponic wheat fodder

The results of Pearson's correlation co-efficient analysis among the DM, CP, CF, EE, Ash, NFE, GE of BARI ghom-30 are presented in Table 4.2.2. Highly significant ($p<0.001$) association was found between DM and CP ($r=0.75$), DM and NFE ($r=-0.78$), DM and GE ($r=0.81$), CP and NFE ($r=-0.89$), CP and GE ($r=0.85$), CF and NFE ($r=-0.72$), Ash and NFE ($r=-0.74$).

Table 4.2.2 Correlation matrix of nutritional parameter of hydroponic wheat fodder

Parameters	DM	CP	CF	EE	Ash	NFE	GE
DM	1						
CP	0.75***	1					
CF	0.45*	0.53*	1				
EE	0.45*	0.17 ^{NS}	0.15 ^{NS}	1			
Ash	0.45*	0.46*	0.53*	0.46*	1		
NFE	-0.78***	-0.89***	-0.72***	-0.49*	-0.74***	1	
GE	0.81***	0.85***	0.47*	0.66**	0.56*	-0.92***	1

DM = Dry Matter; CP = Crude Protein; CF = Crude Fiber; EE = Ether Extract; NFE = Nitrogen-Free-Extract; GE = Gross Energy

*NS=non-significant, ***= $p<0.001$, **= $p<0.01$, *= $p<0.05$*



CHAPTER V

SUMMARY AND CONCLUSION

5.1 Summary

Hydroponics green fodder is a viable option for fodder scarcity reduction and is a very promising technology for sustainable livestock production. Hydroponic technology is an agro-technology that can be put to practice locally with low-cost materials to provide nutritious, palatable, and digestible fodder for livestock. Certainly, this technology is less competitive than traditional fodder production in areas that doesn't lack quality green fodder, but it always stays as a smart alternative technology against land scarcity and hindering climate changes in different agro-climatic regions in the world. The study was conducted at the small part of the underground basement of Acharya Jagadish Chandra Bose Academic Building (academic building-2) Khulna University, Khulna. The experiment was conducted using CRD with five treatments having three replications. The irrigation applied with tap water, pond water, borehole water, river water and sewage water for BARI ghom-30 (*Triticum aestivum*) to measure yield, fodder quality, and water use efficiency under hydroponic conditions. The fodder was harvested at 11th day.

In this study, the plant height and chlorophyll content were highest in T₅, the root length and yield were highest in T₁. In nutritional data, the dry matter, crude protein, ether extract and gross energy was highest in T₅. Plant height, root length, root and shoot length, water use efficiency, yield and biomass shown the highly significant effect ($p < 0.001$).

Pond water promoted good growth due to organic matter. The findings of the study revealed that highest plant height, root length, root and shoot length and biomass were 21.35 cm, 15.15 cm, 34.70 cm and 39.11 t ha⁻¹, respectively obtained with the treatment effect of T₁ and T₅. Treatments has a significant effect on dry matter and crude protein.

5.2 Conclusion

In this study, the performance of hydroponic wheat fodder was found high in tap and sewage water. In case of agronomic growth parameters, the performance of hydroponic wheat fodder was higher in tap water but in case of nutritional parameters the results were high in sewage water, this might be due to availability of nutrients in sewage water which help to accumulate nutrients in plant system. So, it can be concluded that sewage water or tap water may be a good source for hydroponic fodder cultivation.

CHAPTER VI

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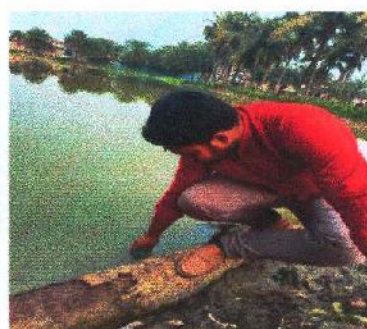
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APPENDIX



Water collection



Seed weight

pH estimation



Day-1



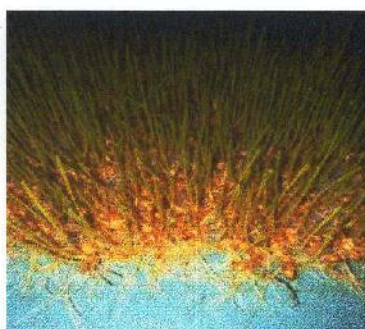
Day-2



Day-3



Day-4



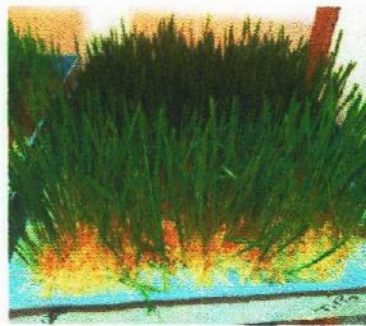
Day-5



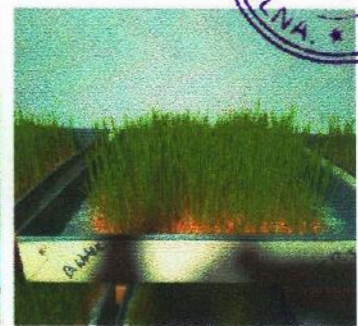
Day-6



Day-7



Day-8



Day-9



Day-10



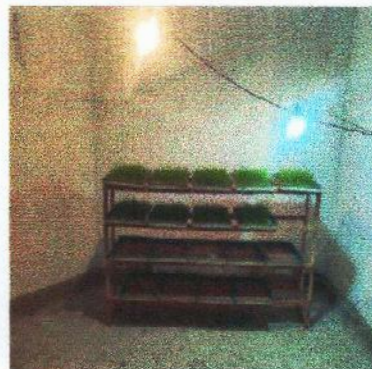
Day-11



Final Production



Artificial light



Cultivation shelf



Plant height measurement



Plant height measurement



Water treatments/Irrigation





Chlorophyll reading count



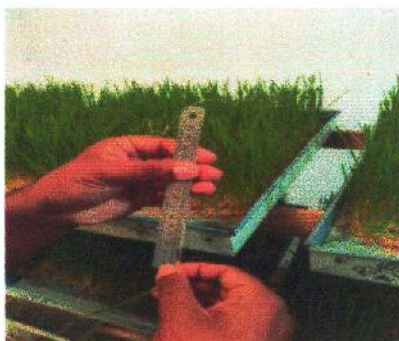
Free of Fungus



Root length estimation



Final Biomass weight



Root and shoot length estimation



1st day on tray



Different treatment shelf



Artificial lighting management