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Effects of Harvesting age and Barley varieties on Morphological characteristics, Biomass Yield, Chemical Composition, and Economic benefits under Hydroponic Conditions in Fogera District, Ethiopia

Yeshambel Alemnew

BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF ANIMAL PRODUCTION AND TECHNOLOGY

EFFECTS OF HARVESTING AGE AND BARLEY VARIETIES ON MORPHOLOGICAL CHARACTERISTICS, BIOMASS YIELD, CHEMICAL COMPOSITION, AND ECONOMIC BENEFITS UNDER HYDROPONIC CONDITIONS IN FOGERA DISTRICT, ETHIOPIA

MSc. Thesis

By

YESHAMBEL ALEMNEW NEGASH

December, 2022 G.C

Bahir Dar, Ethiopia

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A Thesis Submitted to College of Agriculture and Environmental Sciences Department of Animal Production and Technology in Partial Fulfillment of the Requirements for the Degree of Master of Science in Animal Production

Program: M.Sc. In Animal Production

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December, 2022 G.C

Bahir Dar, Ethiopia

DECLARATION

This is to certify that this thesis entitled “Effects of Harvesting Age and Barley Varieties on Morphological Characteristics, Biomass Yield, Chemical Composition, and Economic Benefits under Hydroponic Conditions in Fogera District, Ethiopia”. Submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in **Animal Production**, Bahir Dar University, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged

Yeshambel Alemnew Negash	12/12/2022	Fogera
Name of the candidate	Date	Place

BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF ANIMAL PRODUCTION AND TECHNOLOGY

Approval of Thesis for Defense

I hereby certify that I have supervised, read, and evaluated this thesis titled "Effects of Harvesting Age and Barley Varieties on Morphological Characteristics, Biomass Yield, Chemical Composition, and Economic Benefits under Hydroponic Conditions in Fogera District, Ethiopia" by Yeshambel Alemnew Negash prepared under my guidance. I recommend the thesis be submitted for oral defense.

Yeshambel Mekuriaw (PhD)		15/12/2022
Advisors name	Signature	Date
Esubalew Adimasu		15/12/2022
Department Head	Signature	Date

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COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF ANIMAL PRODUCTION AND TECHNOLOGY

Approval of Thesis Defense Result

As members of the board of examiners, we examined this thesis entitled "Effects of Harvesting Age and Barley Varieties on Morphological Characteristics, Biomass Yield, Chemical Composition, and Economic Benefits under Hydroponic Conditions in Fogera District, Ethiopia" by Yeshambel Alemnew Negash. We hereby certify that the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Science (M.Sc.) in Animal Production.

Board of Examiners

Fasil Negusie (PhD)	[signature]	13/12/2022
External Examiner Name	Signature	Date
Shashie Ayele (PhD)	[signature]	14/12/2022
Internal Examiner Name	Signature	Date
Fiseha Mogese	[signature]	14/12/2022
Chairpersons Name	Signature	Date

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ABSTRACT

'EFFECTS OF HARVESTING AGE AND BARLEY VARIETIES ON MORPHOLOGICAL CHARACTERISTICS, BIOMASS YIELD, CHEMICAL COMPOSITION, AND ECONOMIC BENEFITS UNDER HYDROPONIC CONDITIONS IN FOGERA DISTRICT, ETHIOPIA'

Yeshambel Alemnew[1] and Yeshambel Mekuriaw[2]

[1]South Gondar zone Fogera District, Livestock Office, Fogera, Ethiopia.

[2] Colleges of Agriculture and Environmental Sciences, Bahir Dar University, Department of Animal Sciences, P. O. Box 5501, Bahir Dar, Ethiopia

Natural pastures are becoming less productive due to high grazing intensity. To meet the demand for green fodder, hydroponic techniques are alternatives to supplement pasture. A study was conducted in the Fogera district to evaluate the effects of harvesting age and barley varieties on morphological characteristics, biomass yield, chemical composition, and economic benefits under hydroponics. HB-1307, Debark-1, Tila, and Local barley at 6, 8, 10, and 12 harvestings were used. Data were subjected to a GLM analysis of variance procedures SAS version 9.2. All morphological parameters except a number of leaves per plant (NLPP), stem weight (SW), leaf-to-stem ratio (LSR) & all chemical compositions were significantly different (P<0.01) harvesting age (HA) and different barley varieties. Plant height, shoot length, leaf length, and all chemical compositions were significantly different (P<0.01) by the interaction effects. The highest plant height (21.26 cm) and (21.39%) CP were obtained from Debark-1 on the 12 days of harvesting. The highest fresh fodder biomass yield (FFBY) 203.50 t/ha, and dry matter yield (DMY) 36.21 t/ha were obtained at 12 days of harvesting. In the case of harvesting age, all morphological parameters increased in the progress harvesting age, except for LSR. All morphological characteristics were significantly affected (P<0.001) by different barley varieties except for the NLPP, SW, and LSR. The highest net return 2,923,002.25 ETB/ha was obtained from Debark-1 at the 12 days HA and the lowest 941,201.13 ETB/ha was recorded at Tila variety on the 6 days HA. Except for LSR and DM, all morphological and chemical compositions have a positive correlation. From the study, it can be concluded that based on FFBY, DMY, CP, and economic benefits Debark-1 was the recommended variety on the 12 days HA, followed by HB-1307, Local, and Tila investigated in the current study.

Keywords: Dry matter yield, Fresh fodder, Greenhouse, Growth parameters

TABLE OF CONTENTS

CONTENTS **Page**

LIST OF TABLES

Table **Page**

LIST OF FIGURES

Figure **Page**

LIST OF APPENDIX TABLES

Appendix Table **Page**

LIST OF APPENDIX FIGURES

Appendix Figure **Page**

ABBREVIATIONS AND ACRONYMS

ADF	Acid Detergent Fiber
ADL	Acid Detergent Lignin
ANOVA	Analysis of Variance
ANRSLDPA	Amhara National Regional State Livestock Development Promotion Agency
AOAC	Association of Analytical Chemists
CF	Conversion Factor
CP	Crude Protein
CSA	Central Statics Agency
DM	Dry Matter
DMY	Dry Matter Yield
FDCAO	Fogera District Communication Affairs Office
FDLDO	Fogera District Livestock Development Office
FFBY	Fresh Fodder Biomass Yield
FNRRTC	Fogera National Rice Research and Training Center
GDP	Gross Domestic Production
GLM	General Linear Model
GR	Gross Return
Ha	Hectare
HA	Harvested Area
HA	Harvesting Age
LL	Leaf Length
LSD	List Significant Difference
LSR	Leaf-to-Stem Ratio
LW	Leaf Weight
MOA	Ministry of Agriculture
NDF	Neutral Detergent Fiber
NLPP	Number of Leaves per Plant
NR	Net Return
PH	Plant Height

RCBD	Randomized Complete Block Design
RMW	Root Mass Weight
SAS	Statically Analysis System
SL	Shoot Length
SSDW	Sub-Sample Dry Weight
SSFW	Sub-Sample Fresh Weight
SW	Stem Weight
TDN	Total Digestible Nutrient
TFW	Total Fresh Weight
TVC	Total Variable Cost

CHAPTER 1. INTRODUCTION

1.1. Background and Justification

Ethiopia has the largest livestock population in Africa with approximately 70 million cattle, 42.9 million sheep, 52.5 million goats, 2.15 million horses, 10.80 million donkeys, 0.38 million mules, and 8.1 million camels, 57 million poultry (CSA, 2021). The livestock sector has a significant contribution to the Ethiopian economy and the livelihoods of many peoples. Livestock generates income for farmers, provides employment opportunities, and food security provides services and contributes to social, cultural, and environmental values. Over 90% of agriculture in the country is characterized by mixed crop-livestock farming systems. Livestock contributes about 40% of the agricultural GDP, 20% of the national GDP, and 20% of foreign earnings (Zeleke Mekuriaw and Lacey Harris, 2021).

Despite the large number and importance of these animals, their productivity is low due to several factors such as inefficient management, poor infrastructure, poor marketing, and credit facilities, feed shortages both in quality and quantity, and health constraints (Shimelis Mengistu *et al*., 2021). Poor quality and inadequate quantity of feed sources may not provide effective livestock production throughout the year due to low digestibility and low feed intake, resulting in increased weight gain during the rainy season may be loss in whole or in part of the dry season (Kindu Mekonnen *et al*., 2013). According to Adugna Tolera *et al*. (2018), about 60-70% of livestock productivity is affected by feed. Particularly in the Fogera district, the major feeds are communal grazing and rice straw (FDLDO, 2022). But this rice straw has poor nutritional value.

Natural pastures account for about 54.54% of the ruminant feed resources. The availability of hay mainly from natural pastures is inadequate, and farmers do not provide adequate animal care. Ensiling had advantages over hay making due to the preferred mode of green feed conservation methods is not yet available to small-scale farmers (McDonald *et al*., 2010). Green fodder is an essential part of livestock feed, used to improve production and reproduction performance, at a minimum, green fodder supplementation is essential to improve rumen function in cattle, and green feed provides animals with vitamin “K” (McDonald *et al*., 2007).

Livestock holders face various problems in feed production, such as scarcity of land, and water, high labor input, manure required, and characterized by a long growing season (45-60 days), fencing to prevent forage from wild animals, natural climate, etc. is a challenge of forage production (Firehiwot Girma *et al*., 2018). As an alternative, growing hydroponics fodder can have a nutritious green feed and improve livestock performance (Rodriguez *et al*., 2004). To combat livestock feed shortage, hydroponic green fodder production is advisable. Hydroponics is emerging as alternative and advanced technology due to its being environmentally friendly, producing constant feed supply all year round, and supporting commercialization's livestock production (Naik, 2014).

The scarcity of green fodder in most countries (Middle East, Africa, and Asia) has renewed interest in hydroponic technology. Globally, hydroponic forage production started in the 18^{th} century in the Netherlands, Germany, and Australia. Kenya was the first country in Africa to use hydroponics for milk, meat, and poultry production (Kerr *et al*., 2014). Hydroponics is not widely used in our country, but it is used in certain areas of the country, such as Mekelle hydroponics cultivation has a significant impact on animal production and productivity, especially in dairy farming (Naik *et al*., 2011).

Hydroponics technology uses fewer pesticides and chemicals in the form of pesticides is environmentally friendly with less waste, and provides a constant supply of large amounts of feed produced at a reasonable price all year round (Mooney, 2005). In recent years, hydroponics has been growing from different hydroponic crops of barley, oats, wheat, and other cereals (Sharma *et al*., 2019). Hydroponics is used in harsh climates such as desert areas with poor soils, or urban and peri-urban areas (Bakshi *et al*., 2017). Hydroponic forages have a short growing season from 7 to 10 days and do not require crop rotation or high-quality arable land, but hydroponic forages are produced on a small amount of land (Al-Karaki and Al-Momani, 2011).

Hydroponics is an alternative advanced technology in agriculture and it can meet the nutritional needs of growing fodder and ensures stable production of large quantities of green fodder production throughout the year (Bakshi *et al*., 2017). It is a very rich source of β-carotene, a precursor of vitamin "A" and young green crops can contain up to 550 mg/kg of β-carotene (McDonald *et al.*, 2007). The hydroponic feed contains high quality and is rich in proteins, vitamins, and minerals (Lorenz, 1980). Barely seeds have 12% CP, when it is changed to hydroponics the CP increased up to 16% (Cuddeford, 1989). To improve the availability and quality of green feed packs growing hydroponic feeds are required.

1.2. Statement of the Problem

The feed problem is one of the major factors that hinder the development and expansion of livestock production in Ethiopia (Adugna Tolera *et al*. 2018). The feed resources available in smallholder mixed production systems are inadequate in quantity and of poor quality. Livestock production in Ethiopia relies primarily on natural grazing and crop residues. Natural pastures are becoming less productive due to high grazing intensity. Crop residues are of insufficient quantity and poor quality, natural pastures and hay are low in nutritional value and palatability, and their CP, minerals, and vitamins are generally below the minimum requirements for animal production (Ulfina Galmessa *et al*., 2013). The availability of improved feeds, agro-industrial by-products, and green feed production is also limited.

The district's livestock holders (pre-urban, subsistence farmers, females, and youth) who work on poultry, fattening, and dairy production faced a feed problem in cost, quality, and quantity. Also, there is a lack of information on the production and utilization of hydroponic green feed in the study district. Due to the many difficulties of soil-based forage cultivation, experiments have been conducted to test different barley varieties for their hydroponic green fodder potential. Few studies have been conducted recently to assess the effects of harvesting age on the growth parameters, biomass yield, and chemical composition of different barley varieties, but the information is limited. Therefore, this study is one of the efforts to evaluate the effects of harvesting age on morphological characteristics, biomass yield, chemical composition, and economic benefits of different barley (*Hordeum vulgare*) varieties under hydroponic conditions with the following objectives.

1.3. Objectives of the Study

1.3.1. General objective

The general objective of the study is to evaluate the effect of harvesting age and barley varieties on the morphological characteristics, biomass yield, chemical composition, and economic benefits under hydroponic conditions in the Fogera district, Amhara Region.

1.3.2. Specific objectives

The study has the following specific objectives.

- To evaluate the effects of harvesting age and different barley varieties on morphological characteristics and biomass yield.
- To determine the effects of harvesting age and different barley varieties on the chemical composition of hydroponically grown forage.
- To assess the economic benefit of hydroponically grown different barley varieties at different harvesting ages.

1.4. Research Questions

This research focuses on solving the following research questions:

1. Is there a difference in morphological characteristics and biomass yields of hydroponically grown forages between different harvesting ages and different barley varieties?
2. Is there a difference in the chemical composition of hydroponically grown forages between different harvesting ages and different barley varieties?
3. Which harvesting ages and barely varieties are economically feasible under hydroponic techniques?

1.5. Significance of the Study

The study result will be used by the livestock office, planners and researchers, and forage and nutrition experts for improving livestock production by producing quality green hydroponic fodder. The outcome of the study will have contributions to the livestock holder and those who are engaged in selling green fodder. Especially the livestock sector used the finding of the study for the enhancement of hydroponic production techniques by identifying the factors for its effectiveness. Also, the study will be valuable to other people who wish to research related topics, just because they will use the result of the study as a reference when reviewing the literature. It helps agricultural transformation in agriculture, due to its advanced technology.

CHAPTER 2. LITERATURE REVIEW

2.1. Major Livestock Feed Resources in Ethiopia

Urbanization and industrial development lead to a proportionate reduction in grazing, despite the continued reduction of rangeland and forest areas for crop production to feed an ever-growing population (Yeshitila Adimasu *et al*., 2008). Ruminants will continue to rely primarily on forage from natural pastures and crop residues. In Ethiopia, mixed grain agriculture crop residues account for an average of about 50% of total ruminant forage resources, with crop residue contributions reaching up to 80% during the dry season of the year (Adugna Tolera, 2010). Crop residue and natural grazing are of low quality and quantity, which adversely affect livestock productivity (Shapiro *et al., 2017).* So far, great efforts have been made to solve the problem of feed scarcity in Ethiopia to improve the availability of feed and thereby increase the productivity of livestock.

The main fodder for livestock in different parts of the country is from natural pasture and crop residue. Ethiopia's forage resources are categorized into green fodder (grass), crop residues, improved fodder, hay, industrial by-products, and other fodder. Crop residues include harvested by-products such as grain and legume straw and rice husks. The improved feed is like alfalfa. Hay includes all types of grass, clover, and cut and dried fodder. The industrial by-products are such as oil meal, rapeseed meal, nuge meal, sunflower meal, etc. bran and brewer residues (CSA, 2021). The collected information from CSA (2021) on the feed use experience of feeders in rural areas of the country, green feed (grass feed) was the most important feed type (54.54%), with 31.13% of crop residues following it. Hay and by-products were also used as animal feed, accounting for approximately 7.35% and 2.03% of the total feed, respectively. A significant amount of improved feed (only 0.57%) was used as animal feed, and other types of feeds accounting for about 4.38%, were also used.

2.1.1. Natural pasture

Alemayehu Mengistu (2010) estimates that 80-85% of Ethiopian forage originates from natural pastures. In Ethiopia, natural grazing is the main source of livestock feed, but pasture expansion, overgrazing, and degradation are reducing its contribution to livestock feed (CSA, 2021). A vast rangeland availability accounts for about 54.54% of Ethiopia's forage resources. In Ethiopia, research began in the late 1960s on forage species grown in pasture and mixed husbandry (Alemayehu Mengistu, 2006). Grazing lands are the main source of natural land that was degraded for a variety of reasons, including population growth, soil degradation, and conversion of pasture to cropland. Free grazing is the primary method of feeding livestock in most areas of Ethiopia's extensive and smallholder crop-livestock farming areas in Ethiopia.

2.1.2. Crop residues

Crop residue is a roughage that becomes available as animal feed after harvesting. It is a fibrous by-product of the growth of cereals, legumes, oil crops, roots, and tubers and is an important forage resource (Yayneshet Tesfay, 2010). They are critical to filling food gaps when other foods are rapidly becoming scarce. Crop residues resulting from the expansion of food crops increase overall production and contribute to the growth of the country's mixed livestock system and they can make up the most forage resources. A large number of crop residues can explain cattle feeding in Ethiopia at 31.13% (CSA, 2021). Crop residue production is also seasonal, being available in very large quantities immediately after harvesting and no longer available. The feed value of crop residues is limited by their low voluntary uptake and low digestibility. The crop residue has a crude protein content of 2.4 to 7%, which have lower CP contents.

2.1.3. Improved forages

Fodder plays multiple roles in Ethiopian animal husbandry practice. The contribution of improved feed production for livestock is negligible (0.57%), despite the promotion of improved feed production strategies since the 1940s in Ethiopia (CSA, 2021). In particular, the use of improved forage as a cut-and-carry system reduces natural pressures on the land, improves soil fertility and marginal erosion, and improves carbon sequestration to mitigate climate change. This provides important support for the system and natural resources improve system reliability (Etsubdink Tekalign, 2014).

One of the most important factors in determining profitability in livestock production is achieving optimal feeding levels. Improved forage crops were grown and used on state ranches, state farms, farmer demonstration sites, and dairy and fattening areas. Forage crops typically include, a mixture of oats and vetch, forage beets, elephant grass, including a mixture of silatro and desmodium, Rhodos, a mixture of fatalism and Leucaena, and tree alfalfa hedge and hydroponics, most commonly used.

2.1.4. Agro-industrial by-products

Agricultural by-products have a particular value in animal feed, primarily in urban and suburban livestock production systems, and in situations where animal productivity is relatively high and large food supplies are required. The contribution of agro-industrial products as livestock feed resources in Ethiopia is 2.03% (CSA, 2021). The most commonly used concentrate feeds in Ethiopia are wheat bran, oil cakes such as wheat semolina cakes and galette cakes, and agricultural by-products including milling by-products such as cottonseed cakes, peanut cakes, flaxseed cakes, sesame cakes, and sunflower cakes. From sugar mills, peat, bagasse, brewery by-products, and sometimes surplus grain or grain damaged during grain processing.

Agricultural by-products produced in Ethiopia also include by-products from grain mills, sugar mills, petroleum processing plants, slaughterhouses, and breweries. These products are primarily used in dairy, fattening, and commercial poultry production, with limited widespread use by smallholder farmers due to their availability and price (Yoseph Mekasha *et al*., 2010).

2.1.5. Hay

Hay is preserved by drying, and generally as long as it stays dry. However, traditional hay-making methods have some drawbacks, including, loss of feed, low nutrient levels, and unsuitable for transportation and storage. These shortcomings underscore farmers' lack of knowledge about forage conservation, remediation of low-quality forage, and the use of appropriate techniques for hay harvesting and storage. After drying, the hay is collected and piled in loose piles raised above the ground on wooden or stone platforms to avoid contact with the ground and rotting. Ethiopia's hay resources account for 7.35% (CSA, 2021). In some areas, hay is saved inside the shade. Peri-urban and small-scale dairy holders save hay and straw in bales. Fodder conservation as hay used for the dry season is not widely utilized in many parts of the country and wherever it is practiced it is harvested very late after losing its quality (Adugna Tolera, 2007).

2.1.6. Other feed resources

Other feed sources are generally defined as a feed that is not traditionally used as feed and is not used commercially in the manufacture of feed. Non-traditional feed such as vegetable refusals, sugarcane leaves, Enset leaves, fish offal, leftover Enjera and porridge, home waste, and local brewery by-products are used as animal feed in various regions of Ethiopia. It has been used as a supplementary source of forage, farmers also use non-traditional forage resources such as shrubs (trees) and foliage. It can reduce food competition between humans and animals and reduce feed costs. However, non-conventional diets are not widely used and this contribution for livestock feeding as a coping strategy was modest at 4.38% (CSA, 2021).

2.2. Definition, Concept, and History of Hydroponics Feed

2.2.1. Definition, and concept of hydroponics feed

The word hydroponics comes from the two Greek words (hydro means "water" and Ponic means "work"). Hydroponics is a technique for growing plants in greenhouse water or nutrient-rich solutions without soil. Hydroponics is the ‘water culture’ growing of plants without soil. Hydroponic feed is also called sprouted feed, sprouted grains, or alfa culture. Forages made by growing plants in water or nutrient-rich solutions without soil are known as hydroponic forages (Dung *et al*., 2010). The term 'greenhouse' refers to a growing habitat in which environmental conditions are at least partially regulated (Shamshiri *et al*., 2018). Inexpensive greenhouses and shade structures can be made from bamboo, wood, mild steel, galvanized steel, and polyethylene, which can significantly reduce the cost of hydroponic systems (Naik *et al*., 2015). However, the structures must be large enough to allow people to participate in cultural activities (Chandra and Gupta, 2003).

Watering or irrigation can be manual or automatic at short intervals using a knapsack sprayer. Hydroponic green feed production takes very little time to operate in a greenhouse. The fodders produced under hydroponic conditions the green shoots and root mat are palatable and germinated seeds embedded in the root system are consumed with the plant shoots without wasting nutrients (Pandey and Pathak, 1991). Hydroponics grows grain in the absence of the required moisture, nutrients, and solid growth media. The sprouted shoots and root mats are harvested and fed to animals. Hydroponics is considered an alternative to concentrates and forages, lowers production costs, and increases milk and meat production for livestock in areas prone to droughts and where forages are scarce (Indira *et al*., 2020). Hydroponics is now used extensively by commercial growers of fast-growing horticultural and it was originally developed as part of early plant nutrition research.

2.2.2. History of hydroponics feed production

Hydroponics techniques began and have been used in research and business since the 18th century (Kerr *et al*., 2014) during the 'hanging gardens of Babylon' period. It has been adopted in several countries, including Latin America, Australia, Europe, and more recently in the Middle East, where the technique has seen great success. Sneath and McIntosh (2003), provided background on hydroponic forage production. Sachs and Knopp worked independently in England to practice the technique of hydroponics. European dairy farmers fed their cow’s sprouted grain during the winter to maintain milk production and improve fertility (Anonymous, 2008). Greek developed a method of growing plants in nutrient solutions. Leitch reviewed several tests of various livestock and poultry sprouted feeds and concluded that sprouted feeds are commercial exploitation of the hydroponic process of plants to produce livestock feeds (Naik *et al*., 2015).

Sometime later, British scientist Woodward tried to grow plants in different water sources. In the mid-1990s, many units were designed and built to produce hydroponic feed in many countries, including Europe and America. The scientist from South Africa, Harris questioned the economics of hydroponic systems. An attempt was then made to popularize hydroponics technology for feed production in India, and the research was carried out by several workers. Generally, this technology is not widely used in our country, but it is used in certain areas of the country, such as Mekelle Hydroponics Forage Cultivation has a significant impact on animal production and productivity (Naik *et al*., 2011).

2.3. Types of Hydroponic Production Systems

Hydroponic systems are characterized as active or passive. An active hydroponic system actively moves the nutrient solution, usually using a pump. Passive hydroponic systems rely on the capillary action of the growing medium or a wick. The nutrient solution is absorbed by the medium or the wick and passed along to the roots. Passive systems are usually too wet and do not supply enough oxygen to the root system for optimum growth rates (Jensen and M. H, 1997). Hydroponic systems can also be characterized as recovery or non-recovery. Recovery systems or recirculating systems reuse the nutrient solution. Non-recovery means just what it says. The nutrient solution is applied to the growing medium and not recovered (Jensen and M. H, 1997).

2.4. Hydroponic Fodder Crops

The development of hydroponic has made it possible to produce green fresh fodder from barley (*Hordeum vulgare*), oats (*Avina sativa*), wheat (*Triticum aestivum*), alfalfa (*Medicago sativa*), cowpea (*Vigna unguiculata*), sorghum (*Sorghum bicolor*), maize (*Zea mays*), and other cereals (Rodriguez *et al*., 2004). Forage produced in hydroponic systems is used as a supplement for poultry, shout, and lactating cows during the dry season. The choice of seed type used depends on geographic and agro-climatic conditions and seed availability (Naik *et al*., 2013). In India, maize grain is the choice for hydroponic feed due to its easy availability, low cost, high biomass productivity, and fast growth.

For better biomass production, the grain must be clean, healthy, undamaged, untreated, viable, and of high quality. Various types of forage plants are grown barley, oats, and wheat (Snow *et al*., 2008), sorghum, alfalfa, and cowpea (Al-Karaki and Al-Hashimi, 2012). Even though barely, wheat and maize are suitable for hydroponic fodder production in tropical conditions they are used for human consumption in Ethiopia.

2.4.1. Barley

Barley (*Hordeum vulgare*) is a grass of the family Poaceae, the subfamily Pooideae and the tribe triticale (Voltas *et al.*, 1998). Barley is considered to be the best choice for hydroponic feed production due to its low-cost purchase price, low water usage, and ready availability (Al-karakia and Al-Hashimi, 2012). It is almost possible to harvest hydroponically green feed every day of the year. There are many barley varieties in Ethiopia such as (HB-1307, Tila, Abay, Agegnehu, Debark-1, Direbie, Biftu, Dinsho, Etayish, Bent, and local barley). Barley seed has a good biological and chemical reaction and it has a better character to convert simple sugar into utilizable sugar (Cuddeford, 1989).

Barley seeds have 88% DM and 12% protein content, and when they changed to hydroponics the crude protein levels increased by up to 16% (Cuddeford, 1989). Hydroponically grown barley fodder has a high yield, a better digestible, and high nutritional value (Sprouts are rich sources of anti-oxidants in the form of B-carotene, Vitamin C, E, and related trace minerals such as Se and Zn, and have a lower fiber concentration than other small grains). As sprouted grains are rich in enzymes, enzymes, and alkaline (Brink and Marten, 1986).

2.5. Seed Rate, Seed Soaking, and Nutrient Solution for Hydroponic Barley Fodder

2.5.1. Seed rate

Hydroponics forage yields were affected by the seeding rate and seed type. The seeding density of barley (*Hordeum vulgare*) grain corresponds to 4.5 kg/m^2 (Fazaeli *et al.*, 2012). A high seed density increases the potential for microbial contamination in the root mat, affecting shoot growth. These rates were based on seed size and weight to have approximately the same number of plants per tray. It is better to use clean seed helps to achieve high quality and optimum forage production. Hydroponic systems have used the appropriate temperature and humidity levels (Sneath and Mcintosh, 2003).

2.5.2. The nutrient solution for hydroponic barley forage

The nutrient solution consists of a liquid of 13 plant essential solutions. Concentrations of nutrient solution for hydroponics fodder production contained six macronutrients such as Ca, K, **N**, Mg, S, and P, with composition (89.20, 81.90, 75.10, 1.80, 20.80, and 43.20) and seven micronutrients (Zn, Fe, Cl, Cu, Mn, Bo, and Na) at a level (3.20, 1.80, 0.50, 0.40, 0.01, 0.10, and 0.10 ppm) respectively (Dung *et al.*, 2010). It is quite interesting to note that hydroponics forage production requires only about 3-5% of the water needed to produce the same amount of forage produced under field conditions (AI-Karaki and Al-Hashmi, 2012).

A balanced supply of nutrients is a prerequisite for the efficient use of resources and stable pH and oxygen content of solutions. In hydroponics, nutrients are readily available and absorbed by plants. The function of hydroponic nutrient solutions is to supply plant roots with water, oxygen, and essential minerals in soluble form. Nutrient solutions usually contain inorganic icons of soluble salts of essential elements required by plants. The nutrient flow within the hydroponic substrate mechanically stimulates the plants and influences plant contact morphogenesis. Nutrient solutions help plants get essential minerals and this helps plants grow and have proper feed chemical composition (Aires, 2018).

2.5.3. Seed soaking and germination

Soaking the seeds to quickly absorb water is a very important step in hydroponic forage production to promote seed metabolism and utilize reserves for plant growth. According to the report of Morgan *et al*. (1993), a 4-hour water soaking is effective. Seeds were soaked in fresh water for at least 12 hours. After 12 hours remove the water and let it breathe for at least 1 hour without water. According to Egerton University (2008), seeds are disinfected by soaking for two hours in a dilute chlorine solution similar to that used to disinfect drinking water to prevent mold and mildew growth. During soaking the floated debris and broken seeds should be removed. The seeds are then drained and placed in germination trays. Although light is not required for grain germination, a small amount of light during the latter part of the germination stage promotes photosynthesis and the greening of the shoots. Grains germinate in the greenhouse for about 6-10 days (Prafulla *et al*., 2015).

2.6. Physiological Emphasis on Green Fodder Production

In the hydroponic, there are physiological changes in green forage production during germination, and increased metabolic activity of seeds led to the loss of dry matter content. The first germination begins after 1-2 days and roots are visible after 2-3 days (Naik *et al*., 2015). In photosynthesis, light is not required for the germination of grains. Photosynthesis is not important for seedling metabolism until the end of the 5 days when chloroplasts are activated (Sneath and Mcintosh, 2003). If seedlings are grown in no light or low light intensity, photosynthesis is minimized and seedlings must rely on stored starch and fat to meet their energy needs.

2.7. Morphological Characteristics and Yield of Hydroponic Barley

Hydroponics green feeds are grown naturally like other feeds. Plant height in hydroponic barley forages increased gradually as the plants matured in a late harvest. Depending on the crop species, at the end of a germination period of about 8 days, hydroponic forages appear as mats with plant heights of 11–30 cm, and longer harvest times help plants utilize nutrients (Naik, 2014). Fresh mats of barley hydroponic feed reach a height of 19.78 cm in the 12 days of harvesting (Alemayehu G/Mariam, 2020). Plant shoots grown from 5-8 days of harvesting at about 20-25 cm height. Furthermore, shoots grew to a height of 16.2–21.3 cm (Fazaeli *et al*., 2011). Forage consists of roots, seeds, and plant mats approximately 20–30 cm in height (Prafulla *et al*., 2015). Interestingly, fresh green shoots are not affected by the weather and can be grown at any time of the year (Kruglyakov and Y.A., 1989).

The fresh fodder biomass yields of 251.34 t/ha from hydroponically grown barley fodder were reported by (Alemayehu G/Mariam, 2020). The highest fresh biomass yield on the 12 days of harvesting depends on growth parameters (plant height, number of leaves per plant, leaf length, and root mass weight). As the weight of the roots increases, the length and height of the fresh leaves increase. The dry leaf weight of hydroponic barley reported by Bonsa Bulcha *et al*. (2022) on the harvesting days of 6, 8, 10, and 12 were (0.23, 0.34, 0.63, and 1.21 t/ha) respectively.

Fresh fodder biomass yield and dry matter content are critical for successful hydroponic forage production. Longer harvesting times lead to increased biomass production. The increase in forage fresh weight was due to greater water uptake during germination and plant growth seen in green shoots compared to the original grain (Morgan *et al*., 1993). Depending on the type of grain, about 7-9 kg of fresh green feed is equivalent to 0.9 to 1.1 kg DM (Al Ajmi *et al*., 2009).

The average fodder biomass yield at 7 days after germination is 5.21 kg of barley per kg of barley grain (Endalew Mekonen *et al*., 2019). The conversion factor ranges from 6 to 10 times the weight of the harvested forage as compared to the weight of the seed. The DMY depends on the weight of sprouts grown from a given grain weight and the DM% of the sprouts (Sneath and Mcintosh, 2003). During seed germination, the fresh weight increases and DM content decreases. Water absorption (leaching) and enzymatic activity (oxidation) are the causes of DM reduction.

The fresh fodder biomass yield and dry matter content of hydroponic forages are mainly affected by crop type, harvest date, seed type and quality, seed treatment, water quality, and pH value. Also, it is affected by the nutrient solution used, light, growing time, temperature, humidity, cleanliness, and greenhouse hygiene (Sneath and Mcintosh, 2003). The hydroponic fodder yield is affected by grain quality, grain type, temperature, humidity, mold growth, water quality, pH, soaking time, nutrient supply, depth, the density of seed, and the harvesting stage (Sneath and Mcintosh, 2003).

Table 1: Morphological characteristics and biomass yield of hydroponic barley fodder at different harvesting ages

Morphological characteristics	Harvesting Age	Values	Sources
Plant height (cm)	5-8 days	20-25	(Fazaeli *et al*., 2011).
	6 days	19.78	(Alemayehu G/Mariam, 2020)
	8 days	14	(Snow *et al*., 2008)
	8 days	11 - 30	(Naik *et al*., 2014)
	10 days 12 days	7.5 10.6	(Firehiwot Girma *et al*., 2018) oat crop
Shoot length (cm)	12 days	14	(Snow *et al*., 2008)
Fresh fodder biomass yield (t/ha)	6 days 8 days 10 days	41.98 43.8 51.09	(Bonsa Bulcha *et al*., 2022)
	8-10 day	133.2	(Natsheh, 2020)
	12 days	251.34	(Alemayehu G/Mariam, 2020)
Dry matter yield (t/ha)	6 days 8 days 10 days 12 days	24.03 23.14 21.34 13.31	(Bonsa Bulcha *et al*., 2022)

Table 2: Morphological characteristics of hydroponically grown local barley (Landrace) at 12 harvesting age

	Variety		
Parameters	Black barley	Mosno barley	White barley
Plant height (cm)	14.72	18.34	14.76
Fresh yield (t/ha)	68.49	104.77	68.5
Root weight (t/ha)	22.34	16.3	19.02
Leaf weight (t/ha)	0.96	2.48	0.98
DMY (t/ha)	23.3	18.78	19.85

Source (Bonsa Bulcha *et al*., 2022)

2.8. Nutritive Value of Hydroponic Fodders

The nutritional value of hydroponic barley fodder is superior to conventional non-legume feed in terms of crude protein, organic matter, ether extracts, and nitrogen-free extracts. However, during germination, total energy, metabolic energy, and total digestible nutrients are reduced. This is due to the energy absorbed during plant respiration (Fazaeli *et al*., 2011). Conventional feed is less nutritious than hydroponic feed. During germination, there are nutritional fluctuations that increase crude protein, ether extract, and nitrogen-free extract, but decrease crude fiber, total ash, and insoluble ash. Enzyme activity is highest from germination to 7 days after sprout. They are rich in antioxidants, especially in the form of β-carotene (Sneath and Mcintosh, 2003). No nutrients are wasted as the plant's shoots and roots are consumed together by animals. Supplementing dairy cows with hydroponic diets improves feed digestibility (Prafulla *et al*., 2015).

2.8.1. Energy

The energy detailed analysis of the feed provides the most accurate analysis of feed value as compared to alternative feeds. Hydroponic sprouts and processed grains are highly nutritious and highly digestible feeds. During germination, starch is catabolized to soluble sugars to support metabolism, and the growing plant needs the energy it needs to respire and build cell walls, and organic matter decreases. Metabolizable energy and net energy recovery decreased when the grain sprouted or turned green. This is because the energy stored in the grain is used and broken down during the seed germination process. Dry matter without significantly improved digestibility means a significant reduction in total digestible energy (Dung *et al*., 2010). These nutrient changes occur because the energy stored in grains is used for seed germination and consumed in the process (Chavan *et al*., 1989).

2.8.2. Protein

Animal performance is highly dependent on critical elements such as protein. In sprouts, crude protein, ash, and all other minerals except potassium are more concentrated on a dry matter basis than in barley grain. In addition, nutrient intake also accelerates the metabolism of nitrogen compounds, increasing crude protein content. Nutrient solutions improve the crude protein content of hydroponic feeds as compared to using tap water (Dung *et al*., 2010). The cultivation of hydroponic fodder increases the protein content of grains and improves animal performance (Rodriguez *et al*., 2004). Further, a study conducted by Al-Karaki (2010), compared the forage production and water use efficiency of the five forage crops (alfalfa, barley, cowpea, sorghum, and wheat) under hydroponic conditions. The results indicate that barley showed higher feed production and better water use efficiency. This may be due to the uptake of nitrogen compounds (Dung *et al*., 2010). The protein content of sprouted grains increases due to the reduction of other constituents, while the total protein content remains the same (Morgan *et al*., 1993).

2.8.3. Vitamins

During germination vitamin contents especially vitamins B, vitamin E, and β-carotene (Vitamin-A precursor) are increased manyfold (Muhammad Sharif *et al*., 2013). The vitamin content in hydroponic production techniques can be improved by up to 20 times. However, increases in individual vitamins are too small to meet the nutritional needs of grain-based diets for practical use and have little impact on feed values (Sneath and Mcintosh, 2003). The cultivation of hydroponic fodder increases the vitamin content of grains and improves animal performance (Rodriguez *et al*., 2004).

2.8.4. Minerals

In hydroponic fodders production, root growth aids mineral uptake, and ash and protein levels change rapidly from day 4 (Sneath and Mcintosh, 2003). Ingestion also accelerates the metabolism of nitrogen compounds and increases the crude protein content. Morgan *et al*. (1993) found that ash content in shoots increased from the 4 days to accommodate root growth and allow for mineral uptake. Using nutrient solution instead of water increases the ash content of the sprouts, this may be due to mineral uptake by roots (Dung *et al*., 2010).

2.9. Effect of Sprouted Grains on Feed Intake and Digestibility

2.9.1. On feed intake

Feeding sprouted grains for ruminates reduced the other feed intake (Fazaeli *et al.*, 2011). This is due to the increased fiber content of sprouted grains as compared to whole grains. The report of Fayed (2011), showed that the addition of rice straw and Tamarix manifera to germinated barley reduced feed intake in lambs. In contrast, Eshtayeh Adel and Intissar Fayez. (2004) observed no significant effect of sprouted grains on DM uptake. Hamid (2001) reported that the addition of sprouted grains to broiler diets reduced feed consumption. Decreased feed intake is probably due to decreased palatability, taste, or odor. Feeding hens with germinated millet sorghum at 300 g/kg feed reduced feed intake, whereas 150 g/kg feed did not affect intake (Muhammad Sharif *et al*., 2013). The report of Fafiolu *et al*. (2006) showed that feed intake is not affected by the addition of sprouted grains to the poultry diet.

2.9.2. Digestibility

In the rumen, the digestibility of hydroponic barley sprouts is hardly higher than that of grains. However, when comparing the digestibility of shoots and roots, the shoots are easily broken down in the rumen. Germination leads to increased availability of enzymes in the grain. Improved nutrient digestibility may be related to changes in the extent and rate of nutrient digestion. This is complemented by an increased intake of nutrients. During the sprouting process, enzymes are produced that reduce digestive viscosity and improve nutrient digestion and absorption (Annison, 1993). Moghaddam *et al*. (2009) reported that increasing the content of germinated barley enhances nutrient digestibility. The dry matter digestibility in hydroponically grown barley feed decreased with increasing harvest days. This decrease in digestibility was due to changes in the composition of the diet, which decreased non-fibrous carbohydrates but increased fiber levels during growth.

2.9.3. Anti-nutritional factor versus hydroponic fodder

The seed coat and germ of plant seeds contain phytic acid. The main effect of this phytic acid is the formation of insoluble minerals, such as calcium and iron, which disable their absorption into the blood. The phytic acid content decreased with germination. In addition, enzymes eliminate other harmful substances during germination. Barley sprouts contain 100 times more enzymes than fruits, so the bioactivity of vitamins, minerals, and trace elements depends on enzymatic activity. The period from germination to 7 days is the time when the enzymatic activity of the sprouts is at its highest.

If the grain does not germinate, the enzyme remains active due to the inhibitor. These inhibitors prevent seed deterioration for a year. However, inhibitors such as trypsin inhibitors found in soybeans must be heated, boiled, and crushed to inactivate them before being fed to livestock. Sprouting and germination also neutralize inhibitors and boost beneficial plant digestive enzymes (Shipard, 2005). Enzymatic activation of grains hydrolyses proteins, carbohydrates, and lipids into simpler components (Dung *et al*., 2010).

2.10. Effects of Harvesting Age on Yield and Chemical Composition of Hydroponics

2.10.1. Dry matter content and dry matter yield

Dry matter analysis provides a good indicator ability of feed production. Dry matter is the part of the feed that is not water and dry feed is also very important. The dry matter content of hydroponic forage is the percentage of all components such as fiber, protein, ash, water-soluble carbohydrates, and lipids that remain after water is removed. Dry matter yield (DMY) is calculated by multiplying the dry matter content, the fodder yield, and the production area. Moisture content is intended to indicate how the feed is packaged (Schroeder, 2004). Sneath and Mcintosh (2003) report there is an increase in fresh weight and a consequent decrease in DM substance during seed development. This was mainly due to water uptake (filtration) and enzymatic activity (oxidation) in which young plants were not sufficiently replenished by photosynthesis during the short developmental cycle, depleting the nutrient reserves of the seed endosperm.

Higher contents of DM may be due to enhanced photosynthetic activity, but plant developmental fractions organize higher biomass production (Mooney, 2005). The dry matter yield per unit area (DMY) is the most important parameter for forage. The average DM percentages on the 6, 8, 10, and 12 harvesting days were (92.7, 92.21, 91.84, and 91.15 DM%) reported by (Bonsa Bulcha *et al*., 2022). The lower the dry matter content, the higher the forage fresh weight required to achieve the target nutrient intake for hydroponic diets (Valboa *et al*., 2015).

The lower DM content of hydroponic barley fodder may be due to high water intake that initiates an increase in the metabolic activity of dormant seeds, resulting in complete dry matter weight (starch) being lost. Increased photosynthetic activity leads to overall plant maturity, leading to higher biomass production (Mooney, 2005). Nutrient changes in sprouting grains by enhancing the time of sprouting, the higher organic matter, particularly starch consumed to support the metabolism and energy requirement for the growing into leaf part (Chavan *et al*., 1989).

2.10.2. Crude protein

Protein is usually measured as crude protein (CP). The crude protein content is 6.25 times the nitrogen content of the feed. Crude protein is used in the rumen because microorganisms convert non-protein nitrogen into microbial protein, which can be used by animals. However, this value does not apply to non-ruminant animals or high nitrate levels in diets and should be used with caution (Ball *et al*., 2001). The crude protein content is one of the most important criteria for determining the nutritional value of livestock feed. Animal performance is highly dependent on a key component, proteins. Therefore, it is necessary to analyze the feed value of the feed. In sprouts, crude protein, ash, and all other minerals except potassium are more highly concentrated on dry matter bases than barley grains (Eastwood and M.A, 2013).

The increased CP contents also increase the dry matter intake and ruminal microbial growth by livestock (Chanthakhoun *et al*., 2012). The increase in protein content could be attributed to an overall change in forage dry weight and an expansion in protein proportion (Fayed, 2011). The decreased CP content of hydroponic forage is due to the rapid accumulation of cell wall carbohydrates during late growth stages (Van Soest, 1994). Decreased cell solubility is due to increased dietary fiber (cellulose, hemicellulose, lignin), nutrient transfer from leaves to roots, and leaching of cell solubility by dormant rain and snow.

Nutrient changes in hydroponics were due to seed germination. The increase in CP substance may be due to the loss of DM, especially carbohydrates, by respiration during germination, thus, longer growth times may lead to more pronounced problems in DM and increased protein substance. The crude protein content increased from 6 to 12 harvesting days (14.78 -17.9 CP%) with the value significantly reported by (Bonsa Bulcha *et al*., 2022). As stated by different researchers late harvesting age was preferred to obtain better CP contents. Apart from that, nitrate assimilation boosts the digestive system for nitrogen compounds and increases CP levels (Naik *et al*., 2015). Also, the CP content of 13.2% on the 7 days of harvesting age was reported by (Endalew Mekonen *et al*., 2019).

2.10.3. Ash

Mineral (ash) nutrients in feeds play an important role in body function through animal production and productive activities, including skeletal development and maintenance, energy, milk production, and physical function (Rasby *et al*., 2011). The ash content increases in late harvesting of the hydroponic forage. Mineral concentrations in fodders vary according to factors such as plant development stage, morphological compartmentation, and climatic conditions (McDowell and Valle, 2000). A higher ash fraction of 3.6% was reported (Eshtayeh Adel and Intissar Fayez. 2004). The average total ash content (4.98%) of hydroponic barley feed was higher than that of cereals. This may be due to the long harvesting days.

2.10.4. Neutral detergent fiber

Neutral detergent fiber is a good indicator of dietary fiber content and does not measure the digestibility of the fiber, but feed intake is a good indicator of quantity because NDF is 'mass'. The insoluble portion of the feed (neutral detergent fiber) contains cellulose, hemicellulose, lignin, and silica. This is commonly called the cell wall fraction. Neutral detergent fiber is negatively correlated with dry matter intake. Feed intake can be predicted more accurately using neutral detergent fiber. Therefore, better rations can be formulated (Schroeder, 2004).

The effect of the harvesting date on neutral detergent fiber content was significant and increased with the advancing harvesting date. According to Singh and Oosting (1992), forages with NDF values below 45% are classified as high, those with values between 45% - 65% are medium, and those with values above 65% are classified as low. In a report by Fazeli *et al*. (2012) and Naik (2012), more plant cell and wall components are produced during the late harvesting days. On day seven of harvesting 45.6% NDF was reported by (Endalew Mekonen *et al*., 2019).

2.10.5. Acid detergent fiber

Acid detergent fiber is an excellent indicator of digestibility and therefore energy intake (Van Soest, 1994). Acid detergent fiber contains cellulose, lignin, and silica. ADF is important because it has a negative correlation with how easily feed is digested when the livestock is fed. Increasing ADF makes the feed less digestible (Schroeder, 2004). The ADF content of hydroponics hardly increases as it matures. The cell wall cellulose accumulation of ADF percentage was raised due to the increasing growth stage (Fazeli *et al*., 2012). The ADF contents of 34.8% hydroponically grown barley fodder were investigated by (Endalew Mekonen *et al*., 2019). Also, the report of Bonsa Bulcha *et al*. (2022) shows that the ADF content of hydroponically grown barley fodder increased from 14.91% to 24.38% on the 6 to 12 days of harvesting.

The variation in ADF among different hydroponic grains, harvesting ages, and interactions with (harvesting age and different grain) could be due to the differences in the genetic makeup and adaptability of the variety including the harvesting date reported (Bonsa Bulcha *et al*., 2022). The ADF substance of hydroponically developed grain feed was increased from 14.91% on day 6 to 24.38% on the 12-day harvesting. ADF values for grown grain feed extend from (17.58 to 21.02%), with the most elevated ADF recorded for dark grain and the least for white grain.

2.10.6. Acid detergent lignin

Acid Detergent Lignin (ADL) is a major factor affecting the digestibility of plant cell walls and materials. Digestibility, intake, and animal performance usually decrease with increasing lignin levels (Chaves *et al*., 2002). Lignin limits the digestion of cell walls (fibers) by forming a physical barrier to microbial attack, increasing concentrations of both fibers and lignin as the plant matures (Van Soest, 1994). Ruminants can digest the cellulosic and hemicellulose components of fiber, but lignin inhibits the rate and extent of digestion, especially when the proportion of lignin in the fiber begins to increase (Chaves *et al*., 2002).

The mean result of 6.7% ADL content hydroponically grown barley fodders was reported by (Endalew Mekonen *et al*., 2019). The average ADL content (6.49%, 7.11%, and 6.52%) for hydroponically grown fodder of Black, Mosno, and White barely and also the average ADL value from the 6 to 12 days of harvesting was from 3.83% - 9.68% reported by (Bonsa Bulcha *et al*., 2022). The variation in ADL contents might be due to cell wall cellulose accumulation of ADL percentage being raised due to increasing harvesting age (Fazeli *et al*., 2012; Naik, 2012).

2.11. Comparative Advantages of Hydroponic Production over Conventional forage

2.11.1. Water usage

Forage production under hydroponic conditions is a highly efficient process in terms of water conservation compared to field production of forage. Hydroponic feed is grown in sheds and there is little loss of water due to evaporation. Hydroponic fodder production systems are very water-efficient technology. In a farmer's field, the watering interval is usually two hours. Calder (2002) reported that hydroponic systems use some of the water used in traditional agriculture and still provide livestock with high-quality feed. Calder (2002) showed that 80-90 liters of water are required to grow one kg of green grass, while 1-2 liters of water are required to produce one kg of green fodder. However, the main advantage of this technology is its high efficiency in water usage saving about 95-97% of water consumption as compared to traditional farming. Hydroponic forage production requires only about 35% of the amount of water required to produce the same amount of forage under field conditions (Al-Karaki and Al-Hashimi, 2012).

Water that is not used to grow fodder can be reused so that it is not wasted. The remaining water still contains many nutrients and can be reused to irrigate gardens, and vegetable beds (Mooney, 2005). Water is one of the fundamental requirements for seed germination and seedling growth, as it is essential for enzyme activation, reserve reservoir depletion, translocation, and use in seed germination and seedling growth (Copeland and McDonald, 1995). It has been reported that hydroponic forage production requires only about 2-3% of the water used in field conditions to produce the same amount of forage (Al-Karaki and Al-Momani, 2011).

2.11.2. Space requirement

Hydroponic forage production requires minimal land as compared to conventional forage production. Feed is grown by hydroponic tray vertical cultivation, which requires less area (Naik *et al*., 2013). There is great potential in developing hydroponics techniques for forage production. A hydroponic feed can be produced and fed in situations where the plants do not grow enough forage. This technology can also be applied to advanced modern dairy farms producing hydroponic feed for good herds to feed their cows. An area of 50 m^2 under hydroponic forage production can produce approximately 600 kg of forage daily, while approximately one hectare of land is required to produce the same amount of forage (Naik *et al*., 2013).

2.11.3. Constant feed supply

A constant supply of hydroponic green feed production technology eliminates the need for long-term forage shortages. Unfortunately, the hay, silage, and other fodder lose some of their nutritional value during storage. A farmer using this type of forage production can always provide high-quality forage 365 days a year, regardless of rain, hail, sun, or snow (Mooney, 2005). As a result, the farmer knows exactly what forage is available year-round, regardless of seasonal conditions, as they only need 6-8 days to grow the forage from seed to 25 cm tall plants. A constant supply of feed allows farmers to keep inventories and sell when prices are reasonable rather than suffer from low market prices for poor-quality cattle.

2.11.4. Short growth period

Hydroponic plants grow from seed germination to maturity just in 7 days plants have 25-30 cm tall and produce 1 kg of seed and 7-10 kg of edible fodder (Mooney, 2005). The reason for the rapid growth is the nutrient solution. However, with sufficient water for irrigation, growing the same amount of forage in paddock conditions can take up to 12 weeks from seed germination to feeding livestock. This shows that the system is very beneficial for farmers.

2.11.5. Reduced labor requirement

Hydroponic green forage cultivation requires minimal labor per day. Studies show that depending on the size of the shed used, it needs as little as one hour a day to maintain and produce hydroponic feed (Mooney, 2005) as compared to the hours of hard labor required to grow the same amount of fodder as pasture crops. However, depending on the distance traveled, it may take some time to deliver the hydroponic feed to the livestock.

2.11.6. Economic benefit

Hydroponic is a profitable, sustainable agricultural method of growing plants without soil. Hydroponic green fodders are more palatable and digestible and can be grown in a low-cost device with locally home-grown grain. It is advantageous in terms of nutritional benefits and economic value, and constant feed supply year-round. Different studies showed that hydroponic feed production is very cheap and economically feasible because does not require pesticides, fertilizers, machinery, and operating costs for growing and harvesting them. Labor costs of the conventional forage production system are estimated to be ten times higher than hydroponic forages (Resh, 1981).

Hydroponic forage production is very economical, especially from October to June, as no temperature or humidity control is required. This is based on the large amount of fuel required for conventional feed production and transportation. Moreover, in the hydroponic system, it only takes 7-8 days to grow from seed to feeding, as compared to 45-60 days in the conventional system.

Hydroponic barley fodder using locally available materials has the potential to improve the technical and economic feasibility of smallholder farmers. The development of low-cost hydroponic feed production equipment using locally available materials ensures the economic competitiveness of hydroponic feed as compared to alternative feed sources. Hydroponic barley forages are suitable nutritional supplements for poultry production with optimal inclusions to achieve the highest growth rates of 23% of total dry matter intake (Abouelezz *et al*., 2019).

2.11.7. Absence of weeds or pest

Traditional free-range agriculture relies on herbicides, fungicides, and insecticides for optimal production. Grown in a controlled soilless environment, hydroponic feed is less susceptible to soil-borne diseases, pests, fungi, and weeds, and minimizes the use of pesticides, and herbicides. Pest and disease outbreaks in hydroponic feeds can be rapidly controlled by spraying crops with appropriate insecticides and fungicides. Irrigation requires the use of fresh, clean water, as aquatic plant diseases spread rapidly (Bakshi *et al*., 2017).

2.11.8. Completely natural

An important factor in growing this type of feed is that it is a completely natural product. Because hydroponic feed production use only organic fertilizers and produced feed without the use of hormones, synthetic growth promoters, or chemical fertilizers. Hydroponically grown barley fodders are also free of dust and other agricultural pollutants and toxins (Mooney, 2005).

2.11.9. Secure production

According to Mooney (2005), conventional production of forage crops is often avoided for safety reasons. Forage crops that are ready to be harvested are often the victims of theft or simply stolen by other farmers who graze their animals. Additionally, hydroponic forage production takes place in a semi-controlled environment that protects the plants from weather-related disturbances.

Table 3: Comparison of hydroponic green fodder and conventional land cultivation

No.	Parameters	Conventional Fodder Cultivation	Hydroponics System	Source
1.	Area required	One ha. of land to produce 600 kg/day	50 m^2 to produce600 kg/day	(Naik *et al*., 2013)
2.	Fodder production (days)	65-70 days	7 days	(Naik *et al*., 2013)
3.	Water requirement	80-90 litter of water used to produce 1 kg fodder	Minimal at 1-2 litters per kg of green fodder	(Al-Karaki & Al-Hashimi, 2012)
4.	Soil fertility	Essential	Not required	(Naik *et al*., 2013)
5.	Fertilizer application	Required	Not required	(Naik *et al*., 2013)
6.	Fencing and farm protection	Essential	Can be undertaken in a small shed	(Naik *et al*., 2013)
7.	Labor requirement	Intensive for sowing, harvesting, and chafing	Minimal	(Naik *et al*., 2013)

Table 4: Chemical composition of hydroponically grown local barley (Landrace)

Parameters	Variety		
	Black barley	Mosno barley	White barley
DM (%)	91.58	91.52	91.67
Ash (%)	5.24	5.65	4.04
CP (%)	16.07	17.58	15.75
NDF (%)	51.49	46.82	43.54
ADF (%)	21.02	19.7	17.58
ADL (%)	6.49	7.11	6.52

Source: (Bonsa Bulcha *et al*., 2022).

2.11.10. Mold prevention in fodder sheds

Unfortunately, growing forage in a controlled, humid environment presents some minor issues that affect yields, such as molds, bacteria, and fungi. Common species of mold that affect yield is a fungus called Rhizopus that affects crops (Mooney, 2005). Rhizopus is a widespread bread mold found in all grains and soils worldwide to varying degrees. However, when mold spreads quickly during the early growth stages, it can become more dangerous pathogens such as bacteria and aspergillus, causing problems and even death in cattle. Hydroponic seeds are sterilized by soaking in 20% sodium hypochlorite solution for 30 minutes to control mold growth (Ghazi and Al-Hashimi, 2011).

According to Egerton University (2008) seeds are disinfected by soaking in a dilute chlorine solution (similar to that used to disinfect drinking water) for 2 hours to prevent mold growth. Diluting one litter of 4.55% bleach concentrate with 45 liters of clean water provides the concentration needed to disinfect seeds (Jeston, 2016). Mold, fungus, bacteria build-up, and inadequate barn ventilation are other causes. This ensures good ventilation of the shed so that there is constant airflow throughout the greenhouse. Therefore, using the right nutrients and their ratios is very important to achieve high-quality hydroponic forage yields (Mooney, 2005).

2.11.11. Produce quality feed

Barley, wheat, corn, and oats can be used to make a palatable and quality hydroponic feed. Hydroponic green feeds were a natural feed for animals. Barley seeds are particularly preferred with 88% barley DM and 12% protein content but are rarely used in hydroponics, increasing CP levels by up to 16%. In contrast to traditional feed supplement plants, no nutrients are leached out during feed growth and production. Hydroponic forages are rich in energy and vitamins such as beta-caroline, bayotine, free folate hormones, and enzymes. Hydroponic green feeds are highly digestible and have high nutrient content, so animal products perform well. It improves fertility and improves animal health. Easily digestible, all biomass is edible, rich in protein, and reduces daily water intake by up to 15% (Naik *et al*., 2013). Increasing CP content also increases livestock dry matter intake and ruminal microbial growth (Chanthakhoun *et al*., 2012). The composition of hydroponically grown barley sprouts is affected by grain quality, grain type, temperature, humidity, mold growth, water quality, pH, soaking time, nutrient supply, depth, and density of seed (Sneath and Mcintosh, 2003).

Table 5: Chemical composition of hydroponic barley fodder on the 6, 8, 10, and 12 days of harvesting

Parameters	Harvesting Age			
	day 6	day 8	day 10	Day 12
DM (%)	92.7	92.21	91.84	91.15
Ash (%)	3.89	3.91	5.05	5.97
CP (%)	14.78	15.03	16.47	17.9
NDF (%)	42.55	44.7	47.78	52.37
ADF (%)	14.91	15.15	18.75	24.38
ADL (%)	3.83	4.08	6.35	9.68

Source: (Bonsa Bulcha *et al*., 2022).

2.12. Correlation on Morphological Characteristics and Chemical Composition of Hydroponic Barley

Pearson's correlation method is one of the most commonly used methods for numeric values. Assign a value between -1 and 1 that measures the strength and direction of the relationship between two variables (Armstrong, 2019). Zero (0) is no correlation, 1 is an overall positive correlation, and -1 is an overall negative correlation. Correlation confidence is a measure of the linear relationship between two variables. Moreover, root dry weight, root volume, and root surface are positively correlated with plant shoot and dry mass. The fiber content of NDF, ADF, and ADL has a negative correlation with digestibility (Schroeder, 2004). There was a high correlation between the growth parameters of plant height and leaf length observed in elephant grass, not hydroponic cereal (Rambau *et al*., 2016). Dry matter yield has a positive association with some of the morphological parameters of plant height and the number of leaves per plant (Biniyam Mihret *et al*., 2018).

CHAPTER 3. MATERIALS AND METHODS

3.1. Description of the Study Area

The study was conducted in the Fogera district at Fogera National Rice Research and Training Center (FNRRTC), South Gondar Zone, Amhara Region, Ethiopia. The experimental site is geographically located at 13^{o}16^{o}56^{o}7' latitude North and 35^{o}70^{o}74' longitude East, at an altitude of 1811 meters above sea level (FNRRTC, 2022). Fogera is one South Gondar Zone districts. Woreta is the district capital (Fogera) which is located 606 km Northwest of Addis Ababa, 55 km from Bahir Dar city on the way to Gondar, and 42 km southwest of the Zonal capital city of Debre-Tabor. The district has 30 rural and 2 urban Kebele; with a total district area of 102,807 hectares (FDCAO, 2022).

The agroecological zone of the district is locally called 100% Woyina Dega. Geographically the district has 11% mountain, 13% hilly, and 76% leveled area. The farming system is 94% mixed farming (crop and livestock), 0.5% handcraft activity, 0.5% trading, and 5% others including (construction, textile, agro-processing, and daily labor). The highest monthly temperature recorded in April is 27.2°C, the lowest is in July and August at 10.30°C, and the average daily temperature is 18.75°C. The study area receives 1751 mm of average annual rainfall and the minimum and maximum rainfalls are 1103 mm and 2400 mm, respectively. The main soil types in the district are red (12%), black (65%), clay (20%), and grizzle (3%) (FDCAO, 2022).

The land use land cover of the study area is 7,644 hectares of forest, 15,708.19 hectares of grassland, 1,698 hectares marshes, 21,086 hectares water bodies, and 4,375 hectares of non-cultivated land, and the rest of cultivated land. The study district has an estimated population of 250,926 with 127,544 male and 123,382 female residents and the population density is 2.407 people per hectare. The total number of livestock in the district is estimated at 708,277, of which 322,854 cattle, 91,008 sheep, 38,803 goats, 34,233 horses, and 221,379 poultry (FDLDO, 2022).

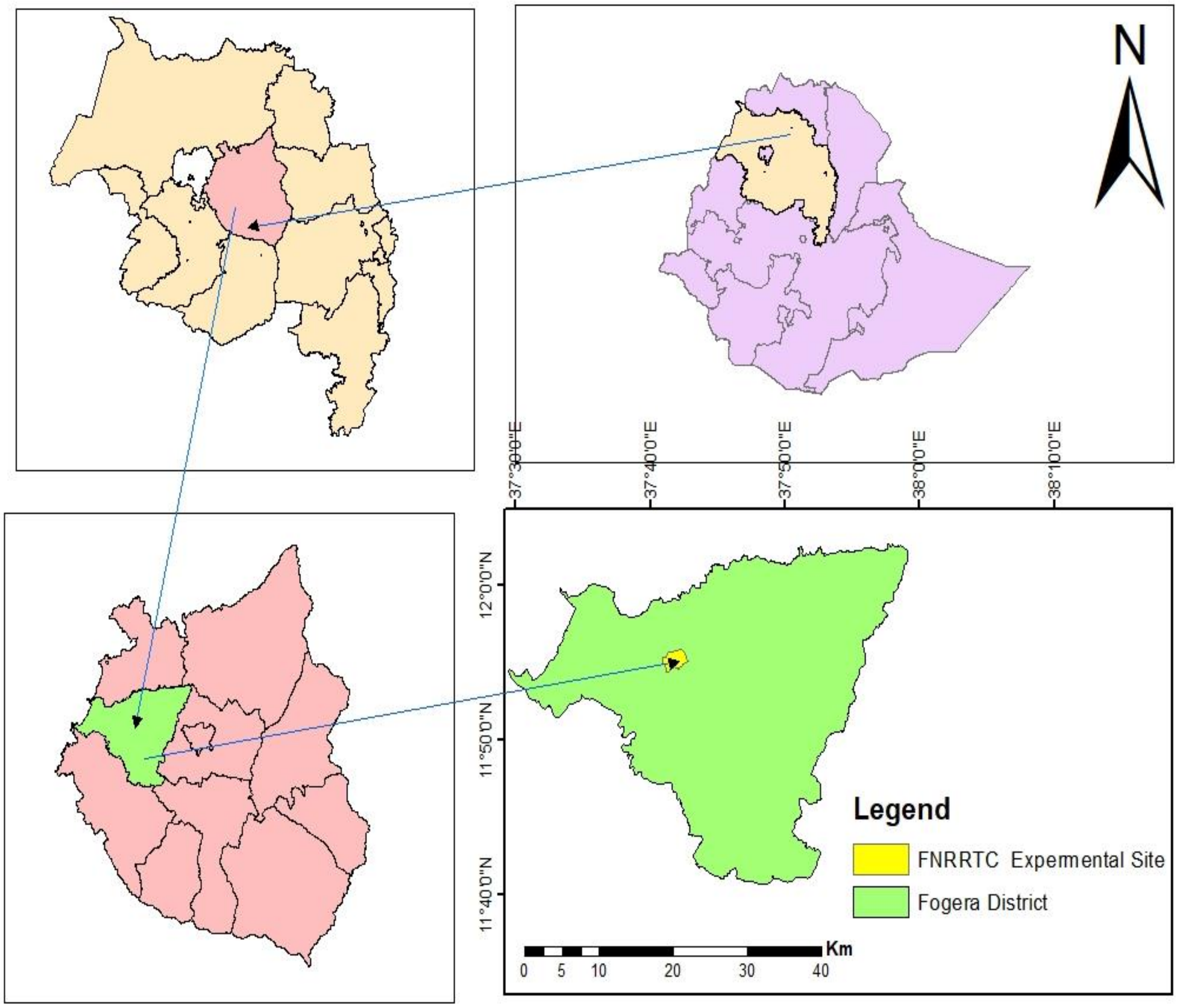

Figure 1: Map of the Study Area

3.2. Description of Experimental Material

Materials used during the experiment were different barley grain, plastic trays, plastic buckets, a hydroponic unit, nutrient solution, scissors, a measuring cylinder, a highland water sprayer, weighing balance, a meter, wood, nail, white plastic, gunny bag, beaker, and mesh. The nutrient solution was obtained from Agricultural Transformation Agency (Bahir Dar). The evaluated barley variety in the current study was HB-1307, Debark-1, Tila, and Local.

Table 6: Barley varieties and their respective origins

No.	Variety	Developed by	Origin
1.	HB-1307	Holetta Agricultural Research Center	Ethiopia
2.	Debark-1	Gondar Agricultural Research Center	Ethiopia
3.	Tila	Adet Agricultural Research Center	Ethiopia
4.	Local	Local (Woreta market)	Ethiopia

3.2.1. Hydroponic shed, shelf, and tray preparation

Green fodder is produced in a hydroponic greenhouse measuring (10 m x 6 m x 3 m) in length, width, and height, respectively. The green fodder shed has 3 meters in height and 10 meters in length. The entire wall of the greenhouse was covered by mesh and white plastic. From the 3-meter high of walls, only a 0.5-meter length is covered by a mesh which is used for ventilation and lighting. The shelf has a 2-3% slope, and there are 8-10 holes on one side the plastic tray has holes of 1.5 mm diameter and 20 mm spacing to allow excess water to drain. The internal shelf structure was made from wooden studs with three shelves in a North-South orientation.

Each shelf has 3.4 meters in length and 1 meter wide. Shelves were arranged vertically to accommodate 48 plastic hydroponic trays. Hydroponics trays (48) were stacked on the 3 shelves. The distance between each shelf and each tray was 50 cm and 10 cm respectively. Each tray has an area of 875 cm^2, (35 cm length, 25 cm wide, and 7 cm deep), which is used to grow seeds for making hydroponic fodder. The Hydroponic trays and plastic sheets were purchased from Bahir Dar city.

3.2.2. Seed collection, treatment, and preparation

Experimental barley seeds (HB-1307 and Debark-1) were obtained from Gondar Agricultural Research Center, the Tila variety from Adet Agricultural Research Center, and Local varieties from the Woreta market in the Fogera district. The germination percentage was calculated as divide the number of germinated seedlings by the total number of seeds in the test and multiplying by 100. Barley seeds with a germination rate of more than 98% were used in the experiment.

After weighing, remove the dirt and other foreign matter from each seed and wash 2-3 times to control mold formation, and remove them with a bucket of fresh water. Also, to prevent mold growth seeds were washed and sterilized by soaking them in a 1% bleach solution (Berekina) for 30 minutes to one hour.

After 2 hours, the seeds were washed twice again. Each seed was soaked in fresh water for 12 hours. After 12 hours, the water was drained and the seeds were left without water for at least one hour. This respiration time, help the seeds to germinate properly. After the respiration time, put the seeds in a gunny bag. The planting tray has been washed and disinfected. Here, all seeds were allowed to germinate properly for 36 hours, after then the germinated seeds were transplanted into trays.

3.2.3. Nutrient solution preparation and application

The hydroponic nutrient solution contained six macronutrients of Ca, K, **N**, Mg, S, and P, with composition (of 89.20, 81.90, 75.10, 1.80, 20.80, and 43.20) and seven micronutrients (Zn, Fe, Cl, Cu, Mn, Bo, and Na) at a level (3.20, 1.80, 0.50, 0.40, 0.01, 0.10, and 0.10 ppm). The nutrient solution was diluted at a ratio of 5 ml of nutrient solution with 10 liters of water (ANRSLDPA, 2020). The nutrient solution was shaken before being used to avoid nutrient sink problems. The diluted nutrient solution contains a mixture of 166.67 ml water and 0.0833 ml nutrient solution 166.75 ml per tray at a time. The tray was irrigated at the affixed rate of 500.025 ml diluted nutrient solution per day containing 500 ml tap water and 0.025 ml nutrient solution 3 times a day (early morning, mid-day, and late afternoon) spraying for 20 seconds. Daily 12 ml of the hydroponic nutrient solution was diluted with 24 liters of water to make 24.012 liters of diluted nutrient solution for 48 trays. To accomplish the experiment 108 ml of nutrient solution and 216 liters of tap water were used.

3.3. Experimental Design and Treatments

The used experimental design was a factorial arrangement in Randomized Complete Block Design (RCBD) with two factors (harvesting age and barley variety) with 3 replicates. The first factor was at the 6-day harvesting age (HA6), the 8-day harvesting age (HA8), the 10-day harvesting age (HA10), and the 12-day harvesting age (HA12). The second factor was the different barley varieties (HB-1307, Debark-1, Tila, and Local). There were 3 blocks (the shelf), each had 16 treatments, with a total of 48 experimental units (trays) having a (4*4) factorial combination. The greenhouse has a total area of 60 m^2, and a treatment area or trays of 875 cm^2 (35 cm in length, and 25 cm in width).

Table 7: Experimental treatment combinations

Variety (V)	Harvesting Age (HA)			
	HA6	HA8	HA10	HA12
HB	HBHA6	HBHA8	HBHA10	HBHA12
T	THA6	THA8	THA10	THA12
D	DHA6	DHA8	DHA10	DHA12
L	LHA6	LHA8	LHA10	LHA12

Where, V=variety; HA= harvesting age; HB= HB-1307; T=Tila; D= Debark-1; L= Local. HA6= (harvested at the 6 days); HA8= (harvested at the 8 days); HA10= (harvested at the 10 days); HA12= (harvested at the 12 days).

3.4. Sowing, Watering, and Harvesting of Hydroponic Barley Fodder

The experimental different barley varieties were sown in trays on 07/02/2022. The barley grains were sown in the planting trays which were lined with plastic sheets. The bottom of the plastic tray has 1.5 mm diameter holes at 20 mm intervals to allow excess water from irrigation to drain. The plastic trays were placed on the shelves and randomly assigned treatments. The seeding rate of barley seed was 4.5 kg/m^2, (Fazaeli *et al*., 2012), and 393.75 grams of barley seeds per tray were sown at 1.5-2 cm seed depth.

All barley seeds started to germinate on day two and finished germination on day four. Excess water was drained using waterproof plastic and collected in plastic buckets placed under each plant shelf. To keep the seedlings moist, a constant watering of 500.25 ml/tray three times a day with a highland sprayer was used. Experimental seed biomass was ready for harvesting at 6, 8, 10, and 12 days after seed germination for each barley variety.

3.5. Data Collection

Data on morphological characteristics and yield parameters were recorded during each harvesting age. During harvesting, approximately 350 grams of green feed and 20 plants per tray randomly were selected and measured the fresh fodder biomass yield (FFBY), plant height (PH), shoot length (SL), leaf length (LL), leaf weight (LW), stem weight (SW), root mass weight (RMW), leaf-to-stem ratio (LSR), the number of leaves per plant (NLPP), and mean values were taken. Harvesting was done manually and scissors were used to separate the plants.

3.5.1. Morphological characteristics

Morphological parameters such as fresh fodder biomass yield (FFBY), plant height (PH), shoot length (SL), leaf length (LL), leaf weight (LW), stem weight (SW), root mass weight (RMW), leaf-to-stem ratio (LSR), number of leaves per plant (NLPP), and conversion factor (CF) were recorded at 6, 8, 10, and 12 days harvesting. Fresh fodder biomass yield was calculated by adding the weight of the forage and the tray and subtracting the weight of the tray.

Plant height (PH): was measured from the tray level to the top of the longest leaf by ruler. Shoot length (SL): was measured from the seed to the top of the longest leaf by a ruler. The number of leaves per plant (NLPP): was manually counted from each tray by hand. Leaf length (LL): was measured from the branch to the tip of the longest leaf. Leaf weight (t/ha): during harvesting, twenty plant leaves were cut with a razor blade and weighting the leaf, the tray, the stem, and the roots. Then calculate the fresh leaf weight obtained on the tray area and convert it to tone/ha.

Stem weight (t/ha): during harvesting, twenty plants' stems were cut with a razor blade and weighting the stem, the leaf, the tray, and the roots. Then calculate the fresh stem weight obtained on the tray area and convert it to tone/ha.

Root mass weight (t/ha): during harvesting, twenty plant roots were cut with a razor blade and weighting the root, the leaf, the stem, and the trays were. Then calculate the fresh root mass weight obtained on the tray area and convert it to tone/ha (Bonsa Bulcha *et al*., 2022). Leaf-to-stem ratio (LSR): from all harvesting ages samples were taken from all trays properly measured and the fresh leaf and stem weights were weighted separately. Then drying and weighing of the leaf and stem and calculated by dividing the leaf's dry weight by to stem dry weight. Leaf and stems were dried by air in shade for 36 hours at 26°C temperature by putting samples on the mats, tables, and floors. The value of conversion factors was the ratio of produced green fodder to the initial planted seed weight.

Dry matter yields (DMY) were calculated by:

DMY (t/ha) = (10*TFW*SSDW) / (HA*SSFW) (James, 2008).

Whereas: 10 = constant for conversion of yields in kg/m^2 to tone /ha;

TFW = total fresh weight from the harvested area (kg);

SSDW = sub-sample dry weight (g)

HA = harvested area (m^2), and

SSFW = sub-sample fresh weight (g).

3.5.2. Chemical composition analysis

Approximately 60 grams of dried representative feed samples were collected at each harvesting age for DM determination and additional feed chemical evaluation. Samples were shade-air dried for 36 hours under natural air flow and at a temperature of 26°C and partial DM for each barley, variety was determined by drying the fodder samples at 65°C in an air-forced oven for 72 hours. Feed chemical composition measurements consisting of DM, CP, and ash were analyzed via means (AOAC, 1990). Nitrogen content and crude protein (CP) were determined using the Kjeldahl approach and were calculated by multiplying by Nx6.25. Ash was determined by igniting at 550°C overnight for 6 hours. Neutral Detergent Fiber, Acid Detergent Fiber, and Acid Detergent Lignin were determined using (Van Soest *et al*., 1991). Dry matter yield was calculated by multiplying the dry matter percentage by the forage yield and the production area. All the feed chemical analyses were done at Bahir Dar University Animal Nutrition Laboratory.

3.6. Economic Analysis

The economic feasibility of different treatments of hydroponically grown barley varieties was determined by a partial budget analysis of the method (Upton, 1979). The partial budget analysis involved the calculation of variable costs and benefits. Economic analysis was performed to determine the most economic harvesting age and different barley varieties. Total variable costs (TVC) included the costs of barley seed, nutrient solution, chemical (detergent), and labor costs for the various treatments. At the end of the study, hydroponically grown barley fodder have been marketed in the DM bases and the sales price of hydroponic feed was taken as gross income. Net return (NR) was calculated as GR–TVC. Net return (NR) was calculated by the difference between gross return (GR) and total variable cost (TVC). The NR = GR–TVC.

3.7. Correlation

Correlation on morphological characteristics, biomass yield, and chemical composition data was subjected to Pearson correlation analysis using the statistical analysis system (SAS, 2008) version 9.2. The correlation analysis deals with the relation among different variables on the harvesting age and different barley varieties.

3.8. Data Analysis

The collected data were managed and organized in Microsoft Excel 2010. Data on morphological characteristics, biomass yield, and chemical composition were subjected to Analysis of Variance (ANOVA) using the General Linear Model (GLM) statistical analysis system (SAS, 2008) version 9.2. Duncan's multiple range test was used for mean comparisons at $\alpha = 0.05$.

Morphological characteristics, biomass yield, and chemical composition were determined using the following model.

- $Yijk = \mu + Bi + HAj + Vk + (Bi * HAj * Vk) + \sum ijk$, where:
- $Yijk =$All dependent variables (morphological characteristics, yield data, and chemical composition)
- $\mu =$ Overall mean
- $Bi =$ Effect of i^{th} block
- $HAj =$ Effect of j^{th} harvesting age (6, 8, 10, and 12 days)
- $Vk =$ Effect of k^{th} varieties (HB, D, T, and L)
- $Bi * HAj * Vk =$ Interaction effect (block, harvesting age, and barley varieties)
- $\sum ijk =$ Random error

CHAPTER 4. RESULTS AND DISCUSSION

4.1. Plant Morphological Characteristics and Biomass Yield of Different Barley Varieties under Hydroponic Conditions

The effect of harvesting age and different barley varieties on morphological characteristics, biomass yield, and dry matter yield of hydroponically grown barley fodders are shown in Table 8. The current study showed that the majority of plant morphological characteristics and DMY were not significantly affected (P>0.05) by the interaction effect (harvesting age, and different barley varieties). But, there was a significant difference (P<0.001) in the interaction effect of plant height, shoot length, and leaf length. In the case of harvesting age, the number of leaves per plant (NLPP), leaf weight (LW), stem weight (SW), root mass weight (RMW), leaf-to-stem ratio (LSR), fresh fodder biomass yield (FFBY), the conversion factor (CF), and dry matter yield (DMY) showed a highly significant difference (P<0.001) to the harvesting age. Hydroponically grown barley fodder harvested on the 12 days had a better yield performance. Different barley varieties showed significant differences (P<0.001) in all growth parameters except NLPP, stem weight, and, leaf to steam ratio.

4.1.1. Plant height

There was a highly significant difference (P<0.001) among harvesting age, barley variety, and their interaction effect (harvesting age and barley variety) on plant height of hydroponically grown barley fodders shown in Table 8. The overall mean observed plant height in the current study was 14.21 cm. A higher plant height was noted in all barley varieties on the 12 days of harvesting and shorter plant heights on the 6 days of harvesting. The current result plant heights of Debark-1, HB-1307, Local and Tila barley varieties in the 12 days of harvesting (21.26, 21.10, 18.33, and 16.63 cm), were above the findings (Bonsa Bulcha *et al*., 2022) a height of 14.72, 18.34, and 14.76 cm for Black, Mosno, and White barley respectively. Plant heights of 9.40, 9.20, 9.13, and 8.43 cm on the 6 days of harvesting for (HB-1307, Debark-1, Tila, and Local barley varieties) were recorded respectively.

Alemayehu G/Mariam (2020) reports that plant height at the 12 days of harvesting (19.78 cm) of wheat crop (relative hydroponic crop) corresponds to the current results (19.33 cm) at a similar harvesting age. The current result of hydroponic barley harvested on the 8 days 12.24 cm plant height was below the report of Snow *et al*. (2008), a plant height of 14.0 cm. Also, the current investigation (12.24 cm) plant height at 8-day harvesting was within the range of 11–30 cm reported by (Naik *et al*., 2011; and Naik, 2014).

Sprout of all barley varieties was well grown on the 12 days of harvesting and had a higher plant height due to increased photosynthesis leading to increased leaf length, stem development, massive root development, and efficient uptake of nutrients, allowing the plant to continue to increase in height of the hydroponic barely forage. The difference in plant height of different barley varieties and harvesting age in the current result and another study may be due to growth stages, genetic makeup, adaptability of different barley varieties to specific environments, temperature, and variations in management during the experiment. Generally, it is possible to conclude that the plant height of hydroponic barley was increasing progressively with increasing plant maturity in all harvesting ages.

4.1.2. Shoot length

The current study result showed that shoot length was very highly significantly influenced ($P<0.001$) by harvesting age, barley variety, and interaction effect (harvesting age and barley varieties) of hydroponically grown barley fodder shown in Table 8. Longer shoot lengths were significantly shown in HB-1307, Debark-1, and Local barley variety on the 12 days of harvesting (17.21, 16.41, and 15.06 cm) respectively. All barley varieties had shorter shoot lengths (7.33, 7.19, 7.16, 6.53 cm) at 6-day harvesting for HB-1307, Debark-1, Tila, and Local barley respectively.

The current study shoot length harvested over 12 days was 15.50 cm was above 14 cm reported by (Snow *et al*., 2008). Differences in the shoot growth potential of different barley varieties may be caused by differences in the growth stage (length of sprouting days), genetic makeup, and management. The later the harvesting age, the more the plant will consume the nutrients in the seed, and the plant will continue to grow the shoot length.

4.1.3. Leaf length

The current study showed that leaf length was highly significantly influenced (P<0.0001) by harvesting age, barley variety, and their interaction effect (harvesting age and barley variety) of hydroponically grown barley fodder as shown in Table 8. In the case of interaction effects, longer leaf lengths of 12.30 cm and 10.63 cm were recorded on HB-1307 and Debark-1 barley varieties at the 12 days of harvesting. The leaf length was increased with the progress of harvesting age. The higher leaf length was recorded on all barley varieties on the 12 days of harvesting than on the 6, 8, and 10 days of harvesting. Whereas the lowest leaf length on the 6-day harvesting for HB-1307, Debark-1 Tila, and Local barley varieties (5.06, 4.93, 4.93, and 4.56 cm) respectively.

Also, the difference in the interaction effects of the different barley varieties and harvesting ages may be due to differences in growth stage, genetic makeup, temperature, and management. In general, the leaf length increased gradually as the hydroponic barley was harvested in progress. This is because, in hydroponics, leaf length is largely influenced by the developmental or vegetative stage of plant growth. The current investigation was similar to those reported by Firehiwot Girma *et al*. (2018) late harvesting ages can produce a longer leaf length.

4.1.4. Number of leaves per plant

The number of leaves per plant didn’t show a significant difference (P>0.05) to the interaction effect (harvesting age and barley varieties), and barley variety. While the NLPP show a very highly significant difference (P<0.0001) among the different harvesting age of hydroponically grown barley fodder shown in Table 8. Overall, there was no significant difference (P>0.05) in the interaction effects among the main variables (harvesting age and barley variety) on the number of leaves per plant of grown hydroponic barley. It is necessary to interpret the main effects of harvesting age. The overall mean number of leaves per plant was 1.35. In the case of harvesting age, the higher number of leaves per plant was obtained at 12 days of harvesting 1.88 leaves and the lowest number of leaves per plant 1 was on the 6 and 8 days of harvesting. The number of leaves per plant at the 6, 8, 10, and 12 harvesting ages was 1.0, 1.0, 1.55, and 1.88 respectively.

The difference in the number of leaves per plant at the harvesting ages may be due to the variation in the growth stage (length of sprouting days), management, and temperature. There is no significant difference (P>0.05) to the NLPP on the 6 and 8-day harvesting. During the early harvesting age on the 6 and 8 days, plants initially develop only shoots and stems, whereas on the 10 and 12 days of harvesting they tend to grow leaves for further photosynthesis.

4.1.5. Leaf weight

Leaf weight was very highly significantly different (P<0.0001) by harvesting age and barley variety. However, no significant differences (P>0.05) were noted in the interaction effects (harvesting age and barley varieties) to the leaf weight of hydroponically grown barley fodder shown in Table 8. Overall, there was no significant difference (P>0.05) in the interaction effects among the main variables (harvesting age and barley variety) on the leaf weight of hydroponically grown barley forage. It is necessary to interpret the main effects of harvesting age and barley varieties. There were highly significant differences (P<0.0001) among treatments in leaf weight as the effect of harvesting age. The current result leaf weight at the 6, 8, 10, and 12 days of harvesting (2.40, 3.72, 4.76, and 6.46 t/ha) respectively which was above the report of Bonsa Bulcha *et al*. (2022) dry leaf weights on the 6, 8, 10, and 12 days harvesting was (0.23, 0.34, 0.63 and 1.21 t/ha) respectively.

The highest leaf weight 6.46 t/ha was obtained on the 12 days of harvesting as compared to the 6, 8, and, 10 days of harvesting which indicate leaf weight increases as the age of plants increases. As harvesting age increases photosynthesis continued and the growth of plant leaf weight also increased. This implies a longer harvesting age may bring a higher plant leaf growth and higher leaf weight was recorded on the 12 days of harvesting and becomes about appeared that the leaf weight was increased. The reason for harvesting age having a significant difference (P<0.0001) in leaf weight outcome is due to the increment within the plant's leaf length, leaf development, and management.

In the current study, barley varieties showed a very highly significant difference (P<0.0001) by leaf weight. Higher leaf weights (4.89, and 4.66 t/ha) were obtained at Debark-1, and HB-1307 varieties, and a lower leaf weight (3.75 t/ha) were recorded in the Tila barley variety. There is no significant difference (P>0.05) in leaf weight between HB-1307 and Debark-1 barley varieties, and also Tila and Local barley varieties did not show a significant difference (P>0.05), due to the barley variety's similar tendency of leaf weight development. Current results different barley variety's leaf weight of HB-1307, Debark-1, Tila, and Local barley (4.66, 4.89, 3.75, 4.04 t/ha), which was higher than the reports (Bonsa Bulcha *et al*., 2022) for Black barley, Mosno and White barely leave weights (0.96, 2.48, and 0.98 t/ha), respectively. The variation in leaf weight among the different barley varieties could be due to the differences in the genetic makeup, management, and temperature.

4.1.6. Stem weight

The stem weight was not significantly different (P>0.05) by interaction effects (harvesting age and barley variety), and also by the barley variety. While the stem weight was a very highly significant difference (P<0.0001) by harvesting age on the hydroponically grown barley fodder shown in Table 8. Overall, there was no significant difference (P>0.05) in interaction effects among the main variables (harvesting age and barley variety) on the stem weight of hydroponic barley. It is necessary to interpret the main effects of harvesting age. In the current study, harvesting age has a significant difference (P<0.0001) to the stem weight.

On the 6, 8, 10, and 12 harvesting ages, the mean dry stem weights 0.91, 1.65, 2.36, and, 3.56 t/ha were obtained respectively. For all harvesting ages, the average dry stem weight of 2.12 t/ha was recorded. A variation in stem weight at different harvesting ages might be to the plant stem growth stage (length of sprouting days), management, and temperature during the experiment. The longer harvesting age will help the plant use nutrients in the seed of barley and the plant continues to increase in stem weight. In the current study, the barley variety did not show a significant difference (P>0.05) in the stem weight might be due to different barley varieties having a similar ability of stem growth and stem weight on this technology and an equal increase in the plant's stem maturation.

4.1.7. Root mass weight

Root mass weight was significantly different (P<0.01) by harvesting age and different barley varieties. However, no significant differences (P>0.05) were noted in the interaction effects (harvesting age and barley varieties) on the hydroponically grown barley fodder shown in Table 8. Overall, there was no significant difference (P>0.05) in the interaction effects among the main variables (harvesting age and barley variety) on the root mass weight of hydroponic barley. It is necessary to interpret the main effects of harvesting age and different barley varieties.

There were significant differences (P<0.01) among treatments in root mass weight as the effect of harvesting age. The current study result of root mass weight on the 6, 8, 10, and 12 days of harvesting (21.80, 24.87, 25.73, and 26.18 t/ha) which was above the report of Bonsa Bulcha *et al*. (2022) on the harvesting age of the 6, 8, 10, and 12 days were (21.80, 24.87, 25.11, and 26.19 t/ha) respectively. The highest (26.18 t/ha) root mass weight was obtained on the 12-day harvesting as compared to the 6, 8, and 10 harvesting ages which indicates root mass weight increases as the ages of plants increases due to the root development leads to absorption of water and mineral from the nutrient solution.

In the current study, different barley varieties show a very highly significant difference (P<0.0001) by root mass weight. However, no significant difference (P>0.05) was noted between HB-1307, Debark-1, and the Local barley variety. A higher root mass weight (27.27 t/ha) in the Debark-1 varieties and a lower root mass weight (21.20 t/ha) were recorded in the Tila variety. The root mass weight of HB-1307, Debark-1, Tila, and Local (25.05, 27.27, 21.20, and 25.07 t/ha) which was above the reports (Bonsa Bulcha *et al*., 2022) for Black barley, Mosno and White barely leaf weight (22.34, 16.30, and 19.02 t/ha), respectively. Hydroponically grown barely fodder after 6 days of harvesting most of the weight was the root seed mass. The variations in root mass weights by harvesting age and the different barley varieties might be due to growth stage, genetic makeup, management, and temperature during the experiment.

4.1.8. Leaf-to-stem ratio

In the current study, the leaf-to-stem ratio was not significantly different (P>0.05) by the interaction effects (harvesting age and barley variety) and also, by the different barley varieties. Whereas harvesting age shows a significant difference (P<0.01) effect on the leaf-to-stem ratio of hydroponically grown barley fodder in Table 8. Overall, there was no significant difference (P>0.05) interaction among the effects of the main variables (harvesting age and barley variety) on the leaf-to-stem ratio of hydroponic barley fodder. It is necessary to interpret the main effects of harvesting age. In the case of harvesting age, the highest (2.63 t/ha) leaf-to-stem ratio was recorded on the 6 days of harvesting and the lowest (1.93 t/ha) leaf-to-stem ratio was recorded on the 12 days of harvesting.

The leaf-to-stem ratio on the 6, 8, 10, and 12 days of harvesting (2.63, 2.21, 2.01, and 1.93 t/ha) was recorded. For all harvesting ages, the mean leaf-to-stem ratio was 2.2. There is no significant difference (P>0.05) in the leaf-to-stem ratio on the 8, 10, and 12 days of harvesting. As the harvesting age increased the LSR decreased due to the development and maturation of the stem more than the leaf. Therefore, plants harvested in 12 days will have a lower LSR than the other three harvesting ages. It can be concluded that LSR declined sharply as the harvesting ages increased. Also, the decrease in leaf-to-stem ratio with increasing harvesting age could be attributed to the accumulation of more cell wall components in plant tissues as a result of stem development with increasing maturity. The leaf-to-stem ratio difference in the case of harvesting age might be the growth stage, management, and temperature in the greenhouse.

4.1.9. Fresh fodder biomass yield

Fresh fodder biomass yield was very highly significantly influenced (P<0.0001) by the different barley varieties, and harvesting age. However, no significant differences (P>0.05) were noted by the interaction effects (harvesting age and barley variety) on the fresh fodder biomass yield of hydroponically grown barley fodder in Table 8. Overall, there was no significant difference (P>0.05) in the interaction effect among the main variables (harvesting age and barley variety) on the fresh fodder biomass yield of hydroponic barley. It is necessary to interpret the main effect of harvesting age and different barley varieties. The overall mean fresh fodder produced in the current study was 170.99 t/ha. The mean fresh fodder biomass yield on the 6, 8, 10, and 12 days of harvesting (137.97, 163.26, 179.25, and 203.50 t/ha), were above the work of (Bonsa Bulcha *et al*., 2022) on the 6, 8, 10, and 12 days of harvesting (41.98, 43.80, 51.09, and 61.88 t/ha), respectively.

Natsheh (2020) reported the fresh fodder biomass yield of 133.2 t/ha from 8 to 10 days of harvesting was below the current findings (163.26 to 179.25 t/ha). The current study's lowest fresh fodder biomass yield (137.97 t/ha) on the 6 days of harvesting indicates no full growth of leaf, stem, and root while the highest FFBY (203.50 t/ha) at the 12 days of harvesting was below Alemayehu G/Mariam (2020) who reported (251.34 t/ha). The highest fresh fodder biomass yield on the 12 days of harvesting depends on growth parameters of plant height, stem development, number of leaves per plant, leaf length, and root development.

The increase of forage fresh weight in later harvesting age was due to greater water uptake during germination and plant growth seen in green shoots as compared to the original grain (Morgan *et al*., 1993). Also, the variation of FFBY among the different harvesting ages might be the difference in the growth stage of leaf stem and root, management, and temperature during the experiment. This increment within the new weight of green feed could be credited to the absorption of water amid the germination and the development of the plants. There was a significant difference (P<0.0001) between FFBY of the hydroponic different barley varieties. In the current study, Debark-1 had the highest fresh forage yield (187.15 t/ha) as compared to the other three experimental barley varieties. The current results of average green fodder yield to the HB-1307, Debark-1, Tila, and Local barley (177.53, 187.15, 148.42, and 170.87 t/ha) were above the report (Bonsa Bulcha *et al*., 2022) to the FFBY of 68.49, 104.77, and 68.50 t/ha for Black, Mosno, and White barley respectively.

The current study result agreed with the finding of FFBY difference might be due to different barley varieties, harvesting date, light, temperature, moisture, and growth rate of leaf-stem ratio, barley seed size, (Dung *et al*., 2010; Fazaeli *et al*., 2011; and Naik *et al*., 2013). Higher fresh fodders biomass yield at Debark-1 may be due to the relatively small size of the seed, which helps to obtain a much number of plants per hectare. This indicates that the Debark-1 barley variety was preferred for hydroponic forage production. Al-Karaki and Al-Momani (2011) report that Local, ACSAD176 and Rum barley hydroponic feed on the 10 days of harvesting produce (281, 222, and 236 t/ha) was above the current investigation for HB-1307, Debark-1, Tila, and Local barley varieties harvested on the 10 days 181.84, 192.93, 157.71, and 184.51 t/ha FFBY respectively.

4.1.10. Conversion factor

The conversion factor had a very highly significant difference (P<0.0001) to the harvesting age and different barley varieties but was not significantly influenced (P>0.05) by the interaction effects (harvesting age and barley variety) of hydroponically grown barley fodder in Table 8. Overall, there were no significant differences (P>0.05) in interaction effects among the main variables (harvesting age and barley variety) to the conversion factor of hydroponic barley. It is necessary to interpret the main effects of harvesting age and different barley varieties. A higher conversion factor obtained at the 12 days of harvesting (4.51%) and a lower conversion factor at the 6 days of harvesting (3.05%) were recorded. A higher conversion factor in the current study at the 12 days of harvesting indicates the increment of the fresh biomass yield to grain seed ratio with increasing harvesting days.

The increase in fresh weights of green fodder was due to the higher water uptake during germination. The current finding of one kg barley seed produces 3.05, 3.62, 3.97, and 4.51 kg fresh sprouts in the 6, 8, 10, and 12 days of harvesting respectively are relatively similar to the result of Natsheh (2020) that one kg barley produces 4.49 kg fresh fodder in the 12 days of harvesting. The current results are also comparable to Al-Ajmi *et al.* (2009) and Al-Hashmi (2008) who reported 2.76 to 3 times green fodder per kg of barley seed at 6-days harvesting. Ghazi and Al-Hashimi report that (2011) there was a 4.5 times increment in the new weight of green grain after growing grain on the 6 days of harvesting was over than the current result (3.05%) times the first seed.

Current studies have shown that the conversion factor was very highly significantly influenced (P<0.0001) by barley variety. The Debark-1 barley has more conversion factors (4.15%) than HB-1307, Local, and Tila, at (3.94, 3.28, and 3.78%). The current finding of conversion factors is consistent with reports by Abd Rahim *et al*. (2015) due to different seed varieties, and differences in light intensity, water quality (pH), seeding density, and temperature. The current finding of the conversion factor is also in agreement with the report of Mooney (2005), that the conversion factor ratio variation depended on management, quality of grain, amount and frequency of irrigation, the nutritious solution used, temperature, humidity, density, and position of lights, and the number of seeds on each tray.

4.1.11. Dry matter yield

Dry matter yield (DMY) very highly significant difference (P<0.0001) by harvesting age and barley variety. However, no significant differences (P>0.05) were noted in the interaction effects (harvesting age and barley variety) in the dry matter yield of hydroponically grown barley fodder shown in Table 8. There were no significant differences (P>0.05) in the interaction effects among the main variables (harvesting age and barley variety) on the dry matter yield of hydroponic barley. It is necessary to interpret the main effect of harvesting age and different barley varieties. The current studies show that there is a significant difference in harvesting ages for the dry matter yield. The overall mean DMY produced in the current study was 31.11 t/ha. The mean DMY results of the current study on the 6, 8, 10, and 12 days of harvesting (25.12, 30.25, 32.86, and 36.21 t/ha) respectively above the report (Bonsa Bulcha *et al*., 2022) reports (24.03, 23.14, 21.34, and 13.31 t/ha) dry matter yield.

The current result showed that the longer the harvest time, the higher the FFBY, DM, and dry fodder yields were produced. The dry matter yield from 7 to 9 kg of fresh forage corresponding to 0.9 to 1.1 kg of dry matter (Al-Ajmi *et al*., 2009) was below the current finding of 7- 9 kg of green fodder producing (1.26 -1.62 kg) dry matter. The lower DMY result on the 6-day of harvesting (25.12 t/ha) and (30.25 t/ha) on the 8-day harvesting may be due to the activation of chloroplasts for photosynthesis which in turn reduces the accumulation of DM because photosynthesis commences around day 5 (Dung *et al*., 2010).

The current study result (36.21 t/ha) DMY of hydroponic barley forage on the 12 days of harvesting was relatively lower than the report of Alemayehu G/Mariam (2020) who reported a dry matter yield of 37.33 t/ha on wheat seeds (relative hydroponic crop) have been reported at the same age. In the current study, DMY increases within late harvesting due to hydroponics being less likely to mature, the rapid increase in plant tissue, the development of additional leaf formation, leaf elongation, and stem development increase forage yields as plants in late harvesting age. The result showed that as the harvesting age increased photosynthesis continued until nutrients in the seed were lost. As photosynthesis continued growth of plant leaves also increased. Variations of DMY in the case of harvesting age were due to the difference in FFBY produced, growth stage (length of sprouting days), management, and temperature during the study.

Different barley varieties show a very highly significant difference ($P<0.0001$) to the dry matter yield. The mean DMY (32.01, 34.32, 26.82, and 31.29 t/ha) for HB-1307, Debark-1, Tila, and local, respectively, which was higher than the work of Bonsa Bulcha *et al*. (2022) for Black, Mosno, and White barley were (23.30, 18.78, and 19.85 t/ha). The reason might be genetic makeup, management, and quantity of fresh fodder biomass yield produced. The higher dry matter yields of the Debark-1 barley variety may be due to the high fresh biomass yields.

Table 8: Effect of harvesting age, barley variety, and their interaction on the morphological characteristic and yield of hydroponic barley

Factors HA		PH (cm)	SL (cm)	LL (cm)	NLPP (count)	LW (t/ha)	SW (t/ha)	RMW (t/ha)	LSR (t/ha)	FFBY (t/ha)	CF (%)	DMY (t/ha)
6		9.04^{d}	7.06^{d}	4.87^{d}	1.00^{c}	2.40^{d}	0.91^{d}	21.80^{b}	2.63^{a}	137.97^{d}	3.05^{d}	25.12^{d}
8		12.24^{c}	10.35^{c}	7.11^{c}	1.00^{c}	3.72^{c}	1.65^{c}	24.87^{a}	2.21^{b}	163.26^{c}	3.62^{c}	30.25^{c}
10		16.26^{b}	13.07^{b}	8.61^{b}	1.55^{b}	4.76^{b}	2.36^{b}	25.73^{a}	2.01^{b}	179.25^{b}	3.97^{b}	32.86^{b}
12		19.33^{a}	15.50^{a}	10.42^{a}	1.85^{a}	6.46^{a}	3.56^{a}	26.18^{a}	1.93^{b}	203.50^{a}	4.51^{a}	36.21^{a}
Sig		***	***	****	****	***	***	**	**	***	***	***
Variety												
HB		14.17^{b}	11.27^{b}	8.03^{ab}	1.37	4.66^{a}	2.3	25.05^{a}	2.18	177.53^{ab}	3.94^{ab}	32.01^{ab}
D		15.66^{a}	12.61^{a}	8.47^{a}	1.33	4.89^{a}	2.16	27.27^{a}	2.46	187.15^{a}	4.15^{a}	34.32^{a}
T		12.99^{c}	10.34^{c}	6.96^{c}	1.38	3.75^{b}	1.86	21.20^{b}	2.08	148.42^{c}	3.28^{c}	26.82^{c}
L		14.06^{b}	11.74^{ab}	7.55^{b}	1.3	4.04^{b}	2.17	25.07^{a}	2.06	170.87^{b}	3.78^{b}	31.29^{b}
Sig		***	****	***	ns	***	ns	***	ns	***	***	***
HA*V												
6 day	HB	9.4^{g}	7.33^{j}	5.06^{fg}	1	2.77	1.08	21.58	2.57	139.24	3.08	25.44
	D	9.2^{g}	7.19^{j}	4.93^{g}	1	2.63	0.95	24.47	2.75	153.91	3.41	28.05
	T	9.13^{g}	7.16^{j}	4.93^{g}	1	2.38	0.92	19.72	2.6	123.02	2.71	23.04
	L	8.43^{g}	6.53^{j}	4.56^{g}	1	1.83	0.7	21.43	2.62	135.71	2.99	23.96
8 day	HB	12.06^{f}	9.55^{hi}	6.99^{de}	1	3.99	1.74	24.39	2.35	165.96	3.68	30.12
	D	14.73^{e}	12.26^{ef}	9.25^{c}	1	4.35	1.78	27.42	2.66	179.8	3.99	33.57
	T	10.83^{f}	9.18^{i}	6.03^{ef}	1	3.2	1.35	21.18	2.05	140.95	3.12	25.73
	L	11.33^{f}	10.4^{ghi}	6.33^{e}	1	3.35	1.74	26.5	2	166.32	3.69	31.6
10 day	HB	14.1^{e}	10.96^{bcd}	7.76^{d}	1.68	5.36	2.62	24.85	2.06	181.84	4.02	32.83
	D	17.43^{bc}	14.58^{cd}	9.25^{c}	1.58	5.17	2.57	27.88	2.43	192.93	4.25	35.62
	T	15.36^{de}	11.75^{efg}	7.81^{d}	1.61	3.9	2.01	22.5	1.92	157.71	3.49	28.42
	L	18.13^{b}	14.96^{bcd}	9.6^{c}	1.35	4.63	2.25	27.68	2.06	184.51	4.09	34.56
12 day	HB	21.1^{a}	17.21^{a}	12.3^{a}	1.83	6.52	3.75	29.38	1.73	223.1	4.95	39.65
	D	21.26^{a}	16.41^{ab}	10.63^{b}	1.76	7.4	3.34	29.3	2.01	221.97	4.93	40.05
	T	16.63^{cd}	13.28^{de}	9.06^{c}	1.91	5.53	3.14	21.4	1.76	172	3.8	30.08
	L	18.33^{b}	15.06^{bc}	$9.7b^{c}$	1.88	6.37	4.02	24.66	1.59	196.95	4.37	35.05
Overall Mean		14.21	11.49	7.75	1.35	4.34	2.12	24.64	2.2	170.99	3.78	31.11
SEM		0.82	1.06	0.59	0.12	0.56	0.49	2.74	0.47	12.13	0.26	2.94
R^2		0.97	0.94	0.95	0.93	0.92	0.87	0.67	0.5	0.9	0.9	0.83
CV		5.82	9.28	7.67	9.53	12.99	23.02	11.15	21.51	7.09	7.05	9.47
HA*V		***	***	***	ns	ns	ns	ns	ns	ns	ns	ns

Where: HA= harvesting age;V= variety; PH= plant height, SL= shoot length; LL= leaf length; NLPP= number of leaf per plant; LW= leaf weight; SW= stem weight; RMW= root mass weight; LSR= leaf to stem ratio; FFBY= fresh fodder biomass yield; CF= conversion factor; CV= coefficient of variance SEM= standard error of mean; DMY= dry matter yield, HB= HB-1307; D= Debark-1; T= Tila; L= Local; a b c means followed by different superscript letters within a row/treatments differ at P<0.05; ns= not significant; **= significant at P<0.01; *** = significant at P<0.001.

4.2. Chemical Composition of Different Barley Varieties under Hydroponic Condition

The interaction effect of different harvesting ages and barley varieties on the chemical composition was significantly different ($P<0.01$) by the hydroponically grown barley forage as shown in Table 9. In the current study, there was a significant interaction effect between the effects of harvesting age and the different barley varieties on the chemical composition of hydroponically grown barley fodder. For a clear understanding of the dependent variable factors, each of the chemical composition parameters DM, CP, Ash, NDF, ADF, and ADL are presented and discussed separately in the following sections.

4.2.1. Dry matter percentage

Dry matter content was significantly influenced ($P<0.05$) by the interaction effect of harvesting age and different barley varieties. Dry matter content was also significantly influenced ($P<0.01$) by harvesting age and different barley varieties of the hydroponically grown barley shown in Table 9. The overall mean dry matter percentage for the interaction effect was 92.19%. The higher dry matter content 92.81%, 92.73%, and 92.70 was recorded at Debark-1, Tila, and HB-1307 barley varieties on the 6-day harvesting respectively. The lower DM contents of 90.86%, 91.56%, and 91.87% were obtained at the Local, Tila, and HB-1307 barely variety on the 12 days of harvesting.

The decrease in DM contents with late harvesting age may be due to the reduction in moisture content of the forage with progress harvesting age. Also, the reduction in DM content during the 12 days of harvesting might be due to the diminishing of the starch substance since, amid growing, starch is catabolized to solvent sugars for supporting the digestion system and vitality prerequisite of the developing plants for breath (Fazaeli *et al*., 2012; Naik, 2012; and Naik, 2014). Sneath and Mcintosh (2003) reported the new weight increased as seeds matured, resulting in a decrease in DM material was comparable to the current study.

Water absorption (leaching) and enzymatic activity are the causes of DM reduction. The loss of DM, mainly in the form of carbohydrates, is due to respiration during sprouting. The status could be understood when the amount of digestible organic matter obtained from green forage per unit of barley grain used was reduced (Chavan *et al*., 1989). The difference in DM content of the interaction effect (different barley varieties and harvesting age) in the current result might be due to growth stages (length of sprouting days), genetic makeup, temperature, and management during the experiment.

4.2.2. Ash content

In the current study, ash content was a highly significant difference between ($P<0.0001$) harvesting age, barley variety, and their interaction effect (harvesting age and barley variety) of hydroponically grown barley fodders shown in Table 9. The current investigation noted that there was a highly significant difference ($P<0.0001$) in the interaction effect of ash contents. The overall mean ash content in the current study was 4.24%. At all harvesting ages, the Tila variety has higher ash content as compared to the other three experimental barley varieties, while Debark-1 has lower ash content except at the 6-day harvesting.

Higher ash fractions (5.06, 4.60, and 4.58%) for the Tila variety at the 12-day harvesting, Tila at the 10-day harvesting, and HB-1307 at the 10 days harvesting were obtained. The lower (3.47, 3.79, and 3.88%) ash contents were recorded for Local, Debark-1, and HB-1307 on the 6 days of harvesting. The current result highest ash (5.06%) at Tila on the 12-day harvesting exceeded from 3.6% ash contents reported by (Eshtayeh Adel and Intissar Fayez. 2004).

Ash contents of hydroponic barley fodders were increased due to the progress of harvesting ages. This was supported by a report by Naik *et al*. (2012) that ash content increased during growth. This may be related to the depletion of organic matter for giving vitality to growing, in other terms the modifications are based on changes within the extent of the organic matter and the mineral (ash) substance (Chavan *et al*., 1989). The ash content of hydroponic barley fodder was increased in the late harvesting ages. Higher ash levels were obtained on the 12 days of harvesting, indicating higher mineral content as compared to the other three harvesting ages.

Also, the current study result of 3.47% ash content in Local barley at the 6 days of harvesting agreed with the ash content of 3.4% reported by (Eshtayeh Adel and Intissar Fayez. 2004).

The ash content of hydroponic barley increased with the maturation of fodders. The mineral content of hydroponically grown different barley varieties according to factors such as plant development stage (length of sprouting days), morphological development, and climatic conditions (McDowell and Valle, 2000) was agreed upon within the current study. The current results were similar to those reported by Morgan *et al*. (1993) who found that root elongation increased the ash content of sprouts with increasing harvesting age, allowing for mineral uptake. Differences in ash content of the current investigation on the interaction effect of harvesting age and different barley varieties may be due to the genetic makeup of variety, management, temperature, and level of harvesting stages during the study.

4.2.3. Crude protein content

The current investigation showed that there was a highly significant difference ($P<0.001$) between harvesting age, different barley variety, and their interaction effect (harvesting age and barley variety) on the crude protein content of hydroponically grown barley fodders shown in Table 9. The overall mean CP content in the current study was 18.03%. The highest CP contents were recorded on the 12 and 10 days harvesting for Debark-1, and also for HB-1307 and, Tila at the 12-day harvesting, (21.39, 21.09, 19.90, and 19.80 CP%) respectively. While the lowest CP content was recorded at Tila, HB-1307, and local varieties on the 6 days of harvesting (14.99, 15.78, and 16.15 CP%) respectively. Crude protein content increased in late harvesting, but there is no significant difference in CP content between the 10 and 12 days of harvesting. The current result of the increased CP content during germination was comparable to the study by (Fazeli *et al*., 2012). The average CP value for all barley varieties was 18.03%. The results showed that hydroponic cultivation of barley improved the CP content of the fodders.

Snow *et al*. (2008) report that 16.3% of CP content was below the current study (18.84%) at the 10 days of harvesting. Crude protein levels increased from the 6 days of harvesting (14.99 CP%) for the Tila variety and on the 12 days of harvesting (21.39

CP%) for Debark-1. An increase in protein content could be due to a complete conversion of dry weight to herbage and an increasing proportion of protein percentage (Fayed, 2011). The present results are also consistent with the findings of Tudor *et al*. (2004) and Fazeli *et al*. (2012) who reported an increase in seed CP contents during growth or sprouting. This may be due to a decrease in DM substances during growth, as reported by Lorenz (1980), who is known to have increased concentrations of supplements during germination associated with a relative decrease in DM contents.

The current result was consistent with the report of Hande *et al*. (2014), and Flynn and O'Kiely (1986) the CP levels increased with increasing harvesting ages. Increasing the CP content also increases livestock dry matter intake and ruminal microbial growth (Chanthakhoun *et al*., 2012). In general, CP content serves as an important indicator of feed quality (Lim *et al*., 2022). Differences in the interaction effect of harvesting age and barley variety in protein content of hydroponic barley fodders may be due to differences in genetic composition, harvesting stage, adaptability to hydroponic feed production, management, and temperature during the study. The crude protein levels can be influenced by growing conditions (Sneath and Mcintosh, 2003) which was in line with the current study result.

4.2.4. Neutral detergent fiber content

In the current investigation, the neutral detergent fiber content was significantly influenced ($P<0.05$) by the interaction effect (harvest age and barley variety). NDF content was very highly significantly affected ($P<0.0001$) by the harvesting age and barley varieties of hydroponically grown barley fodder shown in Table 9. The overall mean NDF content in the current study was 43.68%. For the interaction effects, the highest neutral detergent fiber contents for all different barley varieties were measured during the 12 days of harvesting. The higher (51.70%) neutral detergent fiber was recorded on the Local barley varieties at the 12-day harvesting whereas the lower neutral detergent fiber content was recorded for HB-1307, Debark-1, Tila, and Local barley varieties at the 6-day harvesting (38.39, 37, 38, and 38.5% NDF). However, no significant difference was observed between all barley varieties at the 6-day harvesting to the NDF content.

According to Singh and Oosting (1992) feeds with a neutral detergent fiber value of less than 45% are classified as high, feeds with a neutral detergent fiber value between 45% and 65% are classified as medium, and feeds with a neutral detergent fiber value of more than 65% are classified as low. The current study NDF content on the 6, 8, and 10 days harvesting (37.9, 42.71, and 45.44% NDF) are of high quality, while all varieties on the 12 days harvesting the NDF are of medium quality. In the current study, the mean NDF content for all barley varieties meets the high-quality feed standards of less than 45%. This confirms that the hydroponic barley feed produced in the current study is classified as high to medium-quality fodder and is expected to be high in animal intake.

The accumulation of neutral detergent fiber-like cell wall cellulose increased with increasing growth stage (Hoffman *et al*., 2003). The current study result was consistent with the report by Fazeli *et al*. (2012) that the fiber content of the neutral detergent increased with delayed harvesting age that plant cell wall components increased as the harvesting age progressed. The higher neutral detergent fiber content for the interaction effects may be due to higher structural elements (more cell wall component formation of plant structural carbohydrates) at late harvesting. Variations in neutral detergent fiber contents may be less succulent as a result of less solution absorption capacity and seed rate. Neutral detergent fiber concentration is the most component consistently associated with forage intake (Van Soest, 1994). The difference in NDF contents of different barley varieties and harvesting age in the current result and another study may be due to growth stage, genetic makeup, temperatures, and variations in management during the experiment.

4.2.5. Acid detergent fiber content

The current investigation showed that there was a highly significant difference (P<0.0001) between harvesting age, barley variety, and their interaction effect (harvesting age and barley variety) on the acid detergent fiber content of hydroponically grown barley fodders shown in Table 9. In the current investigation, ADF contents were significantly (P<0.0001) influenced by the interaction effects. The overall mean ADF content in the current study was 17.42%. Tila barley variety has the highest ADF values at all harvesting ages and Debark-1 has the lowest ADF content at all harvesting ages except at the 8 days of harvesting. Higher ADF content was recorded in Tila and Local barley variety at the12 days of harvesting (23.36 and 23.25 ADF%), and the lowest ADF content in Debark-1 and HB-1307 at the 6 days of harvesting (12.84, and 13.25 ADF%) were recorded.

According to Owens (2009), ADF values in the range of 17–32% are classified as high-quality feed. Therefore, from 14.26 - 22.29% ADF results in the current study indicate high-quality hydroponic green feed. The cell wall cellulose accumulation of ADF percentage was raised due to the increasing growth stage (Fazeli *et al.*, 2012) reported that was in line with the current investigation. In the current study, the mean ADF content of different barley varieties (17.42%) was lower than the 18.3% reported by (Bonsa Bulcha *et al*., 2022). The acid detergent fiber content increased in the late harvesting age due to the increase in structural components of the cell wall as the plant matured.

In the late harvesting age, ADF content was increased due to the structural cell wall components increasing as the plant gets matured because photosynthesis components are converted to structural components at the expense of soluble carbohydrates (Bouajila *et al*., 2020). Higher ADF content in the hydroponic feed results in a reduced digestibility of dry matter as a consequence of increased lignification of cellulose in the latter stage harvesting age of the plants (Depeters, 1993). Variations in ADF between interactions may be due to differences in the genetic makeup, management, temperature, and harvesting stage (length of sprouting days). The ADF value was also less than 39.9%, which was consistent with the current result of 22.29% ADF contents.

4.2.6. Acid detergent lignin content

The current study result showed that acid detergent lignin content was highly significantly influenced (P<0.0001) by harvesting age, barley variety, and their interaction effects (harvest age and different barley varieties) of hydroponically grown barley fodder shown in Table 9. There were highly significant differences (P<0.0001) among treatments in ADL content on the interaction effect. The overall mean ADL content in the current study was 5.85%. In the current study, the highest ADL content was recorded in Local barley at the 12 days harvesting (8.44%), whereas the lowest average ADL content in HB-1307 at the 6-day harvesting (3.97%).

Significantly a higher ADL means the content was recorded in the 12 days of harvesting than in other harvesting ages. However, no significant difference (P>0.05) was found between the 6 and 8 days of harvesting. The ADL levels current results of Local barley on the 6 days of harvesting (3.97%) and HB-1307 on the12 days of harvesting (8.44 ADL%), were over the report of Bonsa Bulcha *et al*. (2022) ADL contents on the 6 and 12 days of harvesting (3.83–9.68%). Variation in the ADL content may be due to the differences in genetic makeup, management, and different harvesting age, accumulation of cellulose in the cell wall, and the ADL percentage reported by Fazeli *et al*. (2012) increased with increased harvesting age. The results showed that there was an increase in ADL with increasing harvesting age.

Table 9: Effect of harvesting age, barley variety, and their interaction on the chemical composition of hydroponically grown barley

Factors		DM (%)	Ash (%)	CP (%)	NDF (%)	ADF (%)	ADL (%)
HA	V						
6 day	HB	92.70[ab]	3.88[gh]	15.78[hi]	38.39[e]	13.25[g]	3.97[h]
	D	92.81[a]	3.79[h]	17.15[ef]	37[e]	12.84[g]	5.21[efg]
	T	92.73[a]	4.57[b]	14.99[i]	38[e]	15.85[e]	5.36[def]
	L	92.36[abcd]	3.47[i]	16.15[gh]	38.5[e]	15.1[ef]	6.08[cd]
8 day	HB	92.46[abc]	4.32[cde]	17.63[de]	41.6[d]	15.05[ef]	4.80[fg]
	D	92.13[cde]	3.75[h]	18.66[c]	41.5[d]	14.65[f]	6.02[cd]
	T	92.49[abc]	4.44[bcd]	16.59[fgh]	42.75[d]	15.75[e]	4.99[fg]
	L	92.47[abc]	4.33[cde]	16.76[efg]	45[bc]	14.46[f]	4.78[fg]
10 day	HB	92.25[bcde]	4.58[b]	18.82[c]	46.1[b]	17.25[d]	4.53[gh]
	D	92.36[abcd]	4.11[ef]	21.09[a]	43.3[cd]	18.7[c]	5.25[efg]
	T	92.11[cde]	4.60[b]	18.85[c]	46.18[b]	19.5[c]	7.33[b]
	L	91.89[ef]	4.24[def]	16.60[fgh]	45.9[b]	17.15[d]	7.22[b]
12 day	HB	91.87[ef]	4.28[cdef]	19.90[b]	47.15[b]	21.3[b]	6.29[c]
	D	91.96[def]	4.06[fg]	21.39[a]	45.5[bc]	21.25[b]	5.94[cde]
	T	91.56[f]	5.06[a]	19.80[b]	50[a]	23.36[a]	7.44[b]
	L	90.86[g]	4.47[bc]	18.37[cd]	51.7[a]	23.25[a]	8.44[a]
Over mean		92.19	4.24	18.03	43.68	17.42	5.85
SEM		0.27	0.13	0.56	1.31	0.6	0.45
R^2		0.82	0.92	0.94	0.94	0.97	0.91
CV		0.3	3.22	3.11	3.01	3.46	7.69
HA*V		*	***	***	*	***	***

Where: DM= dry matter%; Ash= ash%; CP= crude protein%; NDF= neutral detergent fiber%; ADF= acid detergent fiber%; ADL= acid detergent lignin%; V= variety; HA= harvesting age; HB= HB-1307; D= Debark-1; T= Tila; L= Local; CV= coefficient of variance; SEM= standard error of mean; a b c means followed by different superscript letters within a row/treatments differ at $P<0.05$; * = significant at $P<0.05$; ** = significant at $P<0.01$*** = significant at $P<0.001$;

4.3. Economic Analysis

A partial budget analysis of different barley varieties grown under the hydroponic condition at different harvesting ages and their interaction were presented in table 10. The total variable cost including the purchase price of barley seed, nutrient solution, detergent (chemicals), and labor cost was recorded during the experiment. Finally, the produced hydroponic barley feeds were sold and obtained gross income in (ETB), calculating the net return as follows.

Table 10: Economic analysis of hydroponically grown barley fodder as affected by interaction effect (harvesting age and barley varieties)

Variety (V)	Parameters	Harvesting Age (HA)			
		HA6	HA8	HA10	HA12
HB	TVC	901,998.88	961,998.50	1,021,998.13	1,081,997.75
	Gross return	2,544,000.00	3,012,000.00	3,283,000.00	3,965,000.00
	Net return	1,642,001.13	2,050,001.50	2,261,001.88	2,883,002.25
D	TVC	901,998.88	961,998.50	1,021,998.13	1,081,997.75
	Gross return	2,805,000.00	3,357,000.00	3,562,000.00	4,005,000.00
	Net return	1,903,001.13	2,395,001.50	2,540,001.88	2,923,002.25
T	TVC	901,998.88	961,998.50	1,021,998.13	1,081,997.75
	Gross return	1,843,200.00	2,058,400.00	2,273,600.00	2,406,400.00
	Net return	941,201.13	1,096,401.50	1,251,601.88	1,324,402.25
L	TVC	901,998.88	961,998.50	1,021,998.13	1,081,997.75
	Gross return	2,396,000.00	3,160,000.00	3,456,000.00	3,505,000.00
	Net return	1,494,001.13	2,198,001.50	2,434,001.88	2,423,002.25

Where: V= varieties; HA= harvesting age; HB= HB-1307; D= Debark-1; T= Tila; L= Local; TVC= total variable cost; TC= total cost; GR= gross return; NR= net return; ETB= Ethiopian birr.

The partial budget analysis was used to evaluate the economic advantage of different barley varieties, harvesting ages, and their interaction effects in forage production under hydroponic conditions. The partial budget analysis involves tabulating the costs and benefits of different barley varieties of hydroponic production. An economic analysis of the current study showed that the net benefits gained from Debark-1 at 12 days of harvesting were higher than that of other varieties and harvesting age. In the current study, the Debark-1 barley variety at the 12 days of harvesting achieved the highest net return (2,923,002.25 ETB/ha) followed by HB-1307 at 12 days of harvesting with a net return (2,883,002.25 ETB/ha). On the other hand, the Tila barley variety at 6 days of harvesting has the lowest net benefits (1,494,001.13 ETB/ha).

Based on the above results, 5 ml nutrient solution was diluted with 10 liters of water, and 500ml of water and 0.025ml of the nutrient solution was diluted to form (500.025 ml/tray/day) by irrigating 3 times a day (early morning, mid-day, and late afternoon) throughout the growing season. The 12 days harvesting age was appropriate to be economically and affordable for future hydroponically grown barley green fodder production in this technology.

4.4. Correlation among Morphological Characteristics, Biomass Yield, and Chemical Composition of Hydroponic Barley

The correlation among morphological characteristics, biomass yield, and chemical composition parameters of hydroponically grown barley fodders is presented in Table 11. In the current finding, plant height had a strong positive correlation ($P<0.001$) to most morphological and chemical composition parameters. The analysis showed that plant height positively correlated to shoot length, leaf length, NLPP, leaf weight, stem weight, root mass weight, FFBY, conversion factor, DMY, CP, NDF, ADF, and ADL content. This is because growth parameters play a vital role in enhancing fodder yield (Imran *et al*., 2007).

Plant height was highly negatively correlated with LSR and DM. Fresh fodder biomass yield has a strong positive correlation ($P<0.001$) with PH, SL, LL, LW, SW, RMW, CF, DMY, CP, NDF, ADF, and ADL. Also, the fresh fodder biomass yield has a moderately negative correlation with LSR and DM contents. In the current study, DMY has a strong positive correlation ($P<0.001$) with PH, SL, LL, LW, SW, RMW, FFBY, CP, NDF, and ADF. The crude protein content has a strong positive correlation ($P<0.001$) with PH, SL, LL, NLPP, LW, SW, RMW, FFBY, CF, DMY, NDF, and ADF. LSR negatively correlates with all chemical composition and agronomic parameters except DM content.All morphological characteristics and chemical composition were negatively correlated to the dry matter content and LSR. The fiber contents of NDF, ADF, and ADL were positively correlated ($P<0.01$) to PH, SL, LL, NLPP, LW, SW, FFBY, and CF. Also, the fiber content of NDF, ADF, and ADL was negatively correlated with leaf-to-stem ratio and DM. The ash content negatively correlated with LSR. The root mass weight has a strong positive correlation ($P<0.001$) to the PH, SL, LL, LW, SW, FFBY, CF, DMY, and CP contents. The positive association of DMY with some of the morphological parameters of plant height and the number of leaves per plant has a similar result (Biniyam Mihret *et al*., 2018). The number of leaves per plant (NLPP) is strongly positively correlated ($P<0.001$) for plant height, shoot length, leaf length, LW, SW, CF, DMY, Ash, CP, NDF, ADF, and, ADL contents. Except for DM and LSR both leaf weight and stem weight are positively correlated ($P<0.001$) to all morphological characteristics and chemical composition parameters.

Table 11: Correlation between morphological characteristics, biomass yield, and chemical composition of hydroponically grown barley

	PH	SL	LL	NLPP	LW	SW	RMW	LSR	FFBY	CF	DMY	DM	Ash	CP	NDF	ADF	ADL
PH	1																
SL	0.98***	1															
LL	0.97***	0.96***	1														
NLPP	0.79***	0.74***	0.73***	1													
LW	0.88***	0.84***	0.85***	0.80***	1												
SW	0.83***	0.81***	0.80***	0.84***	0.90***	1											
RMW	0.55***	0.57***	0.57***	0.33*	0.54***	0.43***	1										
LSR	-0.37**	-0.40**	-0.35*	-0.44**	-0.30*	-0.64***	-0.05ns	1									
FFBY	0.85***	0.84***	0.84***	0.64***	0.85***	0.80***	0.76***	-0.33*	1								
CF	0.85***	0.84***	0.84***	0.64***	0.86***	0.80***	0.76***	-0.32*	0.99***	1							
DMY	0.79***	0.79***	0.78***	0.62***	0.83***	0.75***	0.91***	-0.24ns	0.91***	0.91***	1						
DM	-0.64***	-0.64***	-0.62***	-0.66***	-0.60***	-0.69***	-0.20ns	0.46***	-0.49***	-0.49***	-0.44**	1					
Ash	0.28*	0.28*	0.26ns	0.47***	0.34*	0.41**	-0.17ns	-0.42**	0.08ns	0.08ns	0.06ns	-0.34*	1				
CP	0.75***	0.71***	0.72***	0.72***	0.78***	0.69***	0.44**	-0.23ns	0.75***	0.75***	0.66***	-0.28ns	0.17ns	1			
NDF	0.74**	0.74***	0.72***	0.78***	0.72***	0.78***	0.27ns	-0.52***	0.61***	0.61***	0.54***	-0.63***	0.63***	0.54***	1		
ADF	0.79***	0.75***	0.74***	0.89***	0.77***	0.82***	0.20ns	-0.46***	0.60***	0.60***	0.51***	-0.63***	0.54***	0.64***	0.83***	1	
ADL	0.54***	0.52***	0.49***	0.54***	0.42**	0.52***	0.06ns	-0.35*	0.32*	0.32*	0.26ns	-0.68***	0.26ns	0.27ns	0.60***	0.69***	1

Where: PH= plant height, SL= shoot length; LL= leaf length; NLPP= number of leaves per plant; LW= leaf weight; SW= stem weight; RMW= root mass weight; LSR= leaf to stem ratio; FFBY= fresh fodder biomass yield; CF= conversion factor; DMY= dry matter yield; DM= dry matter; Ash= ash; CP= crude protein; NDF= neutral detergent fiber; ADF= acid detergent fiber; ADL= acid detergent lignin; ***= Significant at ($P<0.001$); ** = significant at ($P<0.01$); *= significant at ($P<0.05$);ns=notsignificant.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

There was a biomass yield and chemical composition difference among different barley varieties. Hydroponic barley produces fresh fodder biomass yield from 137.97-203.50 t/ha, DMY 25.12-36.21 t/ha, and an average of 18.03 CP%, indicating that it can be used to supplement low-protein feeds such as crop residues and natural pastures. Fiber content such as NDF (37-51.70%), ADF (12.84-23.36%), and ADL (3.97-8.44%) showed that hydroponic barley fodder is in the high to the medium quality range. Hydroponically grown barely feed fiber contents (NDF, ADF, and ADL) increased with increasing harvest age. The growth parameters of plant height, shoot length, leaf length, and overall chemical composition were significantly influenced ($P<0.05$) by the interaction effects of harvesting age and barley variety. All morphological characteristics were significantly different ($P<0.01$) among harvesting ages and the stem weight, LSR, and NLPP are not significantly influenced ($P<0.05$) by the different barley varieties.

Results showed that the highest PH, SL, LL, NLPP, LW, SW, RMW, FFBY, DMY, CP, and fiber content were recorded on 12 days of harvesting. Debark-1 barley varieties have higher PH, LW, FFBY, and DMY. The 12 days harvesting was identified as the optimal harvesting age for better hydroponic forage yields. The FFBY, DMY, and CP were strongly positively correlated to PH, SL, LL, NLPP, LW, SW, RMW, FFBY, CF, DMY, CP, and all fiber contents, while it has a negative correlation to LSR and DM contents. Current studies showed that different barley varieties and proper harvesting ages are important parameters to maximize the yield and quality of the hydroponic forage. The economic analysis of the hydroponic barley showed higher net benefits were gained from Debark-1, HB-1307, Local, and Tila barley varieties respectively at the 12 days of harvesting. There for, it can be concluded that growing hydroponically green barley fodder improves nutrient values such as CP along with increased green fresh fodder, DMY, and have better economic returns.

5.2. Recommendations

- The following recommendations were forwarded based on the results of the study:-
  - ✓ Due to the lack of pastures and the high cost of fodder, it is possible to produce alternative fodders with low cost and high nutritive value.
  - ✓ Urban, peri-urban, and rural youth and females who work on poultry can produce alternatives (cheaper and nutritious green feed).
- In addition, further research can be conducted to fill the gaps in this study.

- Based on this finding, it is also very important to undertake feeding experiments to evaluate animal performances.
- Harvesting hydroponic forage after 12 days to check the biomass yield and CP content increment in the late harvesting.
- Comparative evaluation of hydroponic fodder production with nutrient solution and without using the nutrient solution.

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7. APPENDICES

7.1. Appendix Table

Appendix Table 1: Summary Analysis of Variance (ANOVA) on morphological characteristics and biomass yield of hydroponic barley

Parameters	DF	Sum Squares	Mean Square	F Value	Pr > F	SL	R-Square	Coeff Variance	Root MSE	Mean
PH	17	838.78	49.34	72.01	<0.0001	***	0.97	5.82	0.82	14.21
SL	17	556.46	32.73	28.77	<0.001	***	0.94	9.28	1.06	11.49
LL	17	242.89	14.28	40.31	<0.0001	***	0.95	7.67	0.59	7.75
NLPP	17	6.69	0.39	23.66	<0.0001	***	0.93	9.53	0.12	1.35
LW	17	122.44	7.20	22.68	<0.0001	***	0.92	12.99	0.92	4.34
SW	17	49.82	2.93	12.23	<0.0001	***	0.87	23.02	0.87	2.12
RMW	17	466.16	27.42	3.63	0.001	***	0.67	11.15	2.74	24.64
LSR	17	6.77	0.39	1.78	0.0819	ns	0.50	21.51	0.47	2.20
FFBY	17	39881	2345.9	15.92	<0.0001	***	0.90	7.09	12.13	170.99
CF	17	19.87	1.16	16.36	<0.0001	***	0.90	7.05	0.26	3.78
DMY	17	1282.7	75.45	8.68	<0.0001	***	0.83	9.47	2.94	31.11

Where: DF= degree of freedom; PH= plant height, SL= shoot length; LL= leaf length; NLPP= number of leaf per plant; LW= leaf weight; SW= stem weight; RMW= root mass weight; LSR= leaf to stem ratio; FFBY= fresh fodder biomass yield; CF= conversion factor; DMY= dry matter yield, SL= significance level; ns= not significant; *** = significant at P<0.001

Appendix Table 2: Summary Analysis of Variance (ANOVA) mean squares for morphological characteristics of hydroponic barley influenced by harvesting age and variety

parameters	Mean square for morphological characteristics														
	DF			Source of Variation			F value			Pr > F			SL		
	V	HA	V*HA	V	HA	V*HA	V	HA	V*HA	V	HA	V*HA	V	HA	V*HA
PH	3	3	9	14.42	244.12	6.88	21.06	356.29	10.05	<0.0001	<0.0001	<0.0001	***	***	***
SL	3	3	9	10.75	157.94	5.41	9.45	138.8	4.76	0.0001	<0.0001	0.0006	***	***	***
LL	3	3	9	5.03	66.28	3.12	14.21	187	8.81	<0.0001	<0.0001	<0.0001	***	***	***
NLPP	3	3	9	0.015	2.15	0.02	0.9	19.46	1.21	0.4418	<0.0001	0.3243	ns	***	ns
LW	3	3	9	3.33	35.21	0.37	10.50	110.92	1.16	<0.0001	<0.0001	0.3521	***	***	ns
SW	3	3	9	0.42	15.24	0.16	1.76	63.63	0.68	0.1763	<0.0001	0.7190	ns	***	ns
RMW	3	3	9	76.31	46.67	7.69	10.10	6.18	1.02	0.0001	0.0021	0.4480	***	**	ns
LSR	3	3	9	0.40	1.17	0.16	1.79	5.26	0.73	0.1702	0.0049	0.6790	ns	**	ns
FFBY	3	3	9	3253.2	9101.1	154.92	22.08	61.77	1.05	<0.0001	<0.0001	0.4247	***	***	ns
CF	3	3	9	1.62	4.51	0.07	22.75	63.21	1.11	<0.0001	<0.0001	0.3831	***	***	ns
DMY	3	3	9	118.40	262.53	8.33	13.63	30.22	0.96	<0.0001	<0.0001	0.4911	***	***	ns

Where: DF= degree of freedom; PH= Plant height, SL= Shoot length; LL= Leaf length; NLPP= Number of leaves per plant; LW= leaf weight; SW= stem weight; RMW= root mass weight; LSR= leaf to stem ratio; FFBY= fresh fodder biomass yield; CF= conversion factor; DMY=dry matter yield; V= variety; HA= harvesting age; SL= significance level; ns= not significant; ** = significant at P<0.01; *** = significant at P<0.001.

Appendix Table 3: Summary Analysis of Variance (ANOVA) for the chemical composition of hydroponic barley fodder

Parameters	DF	Sum Squares	Mean Square	F value	Pr > F	SL	R-Square	Coefficient Variance	Root MSE	Mean
DM (%)	17	11.04	0.64	8.43	<0.0001	***	0.82	0.30	0.27	92.19
Ash (%)	17	7.11	0.41	22.33	<0.0001	***	0.92	3.22	0.13	4.24
CP (%)	17	162.12	9.53	30.19	<0.001	***	0.94	3.11	0.56	18.03
NDF (%)	17	842.16	49.53	28.59	<0.0001	***	0.94	3.01	1.31	43.68
ADF (%)	17	528.72	31.10	85.14	0.0001	***	0.97	3.46	0.60	17.42
ADL (%)	17	69.09	4.06	20.01	<0.0001	***	0.91	7.69	0.45	5.85

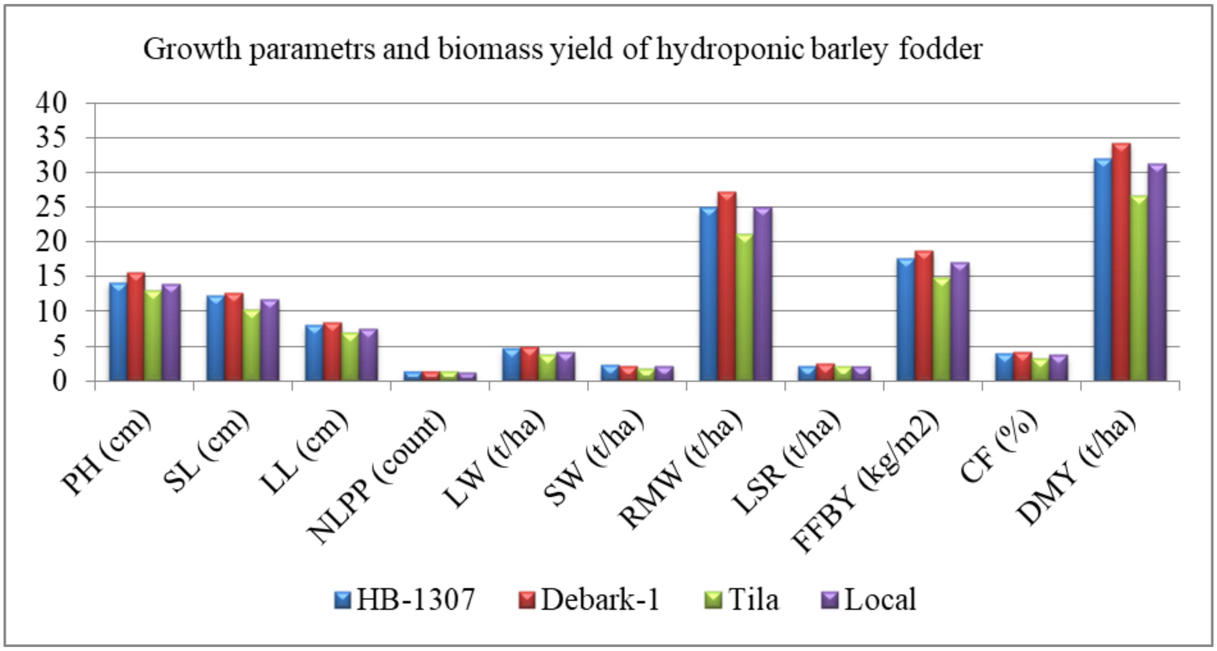
Where, DF= degree of freedom; DM= dry matter%; Ash= ash%; CP= crude protein%; NDF= neutral detergent fiber%; ADF= acid detergent fiber%; ADL= acid detergent lignin%; SL= significant level; *** = significant at P<0.001

Appendix Table 4: Analysis of Variance (ANOVA) showing mean squares to the chemical composition of hydroponic barley as influenced by harvesting age and variety

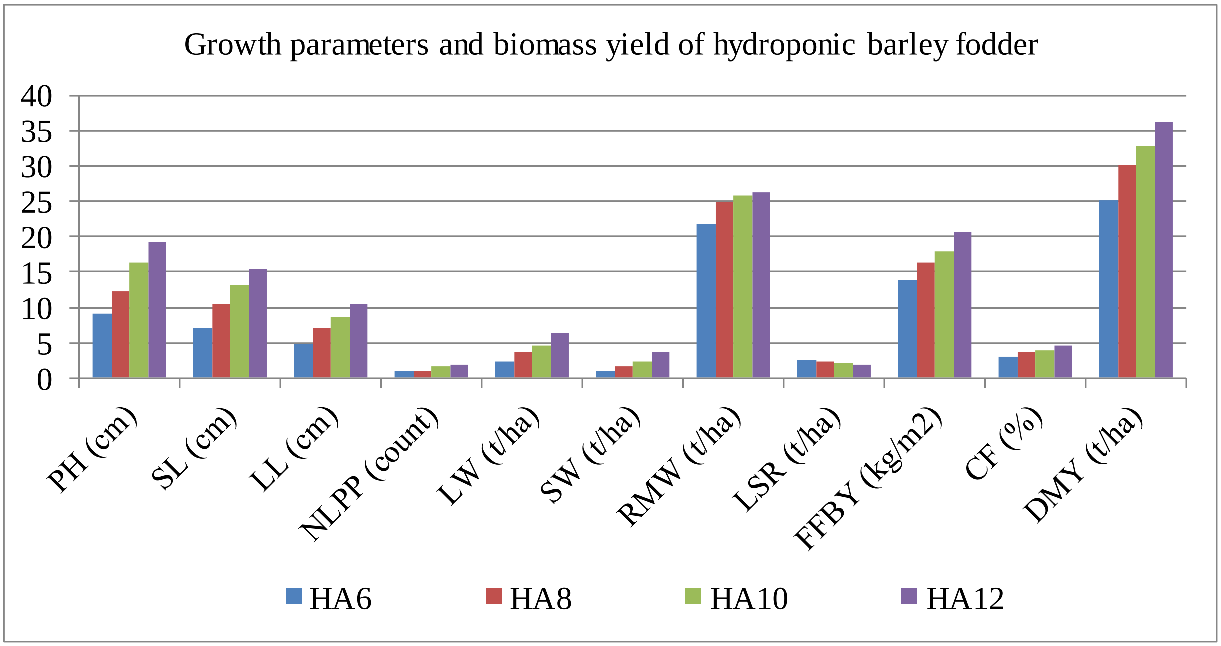
Parameters	Mean square for the chemical composition														
	DF			Source of Variation			F value			Pr > F			SL		
	V	HA	V*HA	V	HA	V*HA	V	HA	V*HA	V	HA	V*HA	V	HA	V*HA
DM (%)	3	3	9	0.48	2.56	0.19	6.25	33.36	2.57	0.002	<0.0001	0.0253	**	***	*
Ash (%)	3	3	9	1.17	0.68	0.16	62.61	36.75	8.79	<0.0001	<0.0001	<0.0001	***	***	***
CP (%)	3	3	9	14.91	33.84	1.61	47.22	107.15	5.13	<0.0001	<0.0001	0.0003	***	***	***
NDF (%)	3	3	9	24.61	242.78	4.19	14.21	140.13	2.42	<0.0001	<0.0001	0.0333	***	***	*
ADF (%)	3	3	9	9.00	160.90	2.10	24.65	440.46	5.77	<0.0001	<0.0001	0.0001	***	***	***
ADL (%)	3	3	9	7.04	9.68	2.04	34.68	47.71	10.09	<0.0001	<0.0001	<0.0001	***	***	***

Where, DF= degree of freedom; DM= dry matter%; Ash= Ash%; CP= crude protein%; NDF= neutral detergent fiber%; ADF= acid detergent fiber%; ADL= acid detergent lignin%; V= variety; HA= harvesting age; SL= significant level; * = significant at P< 0.05; ** = significant at P<0.01 *** = significant at P<0.001.

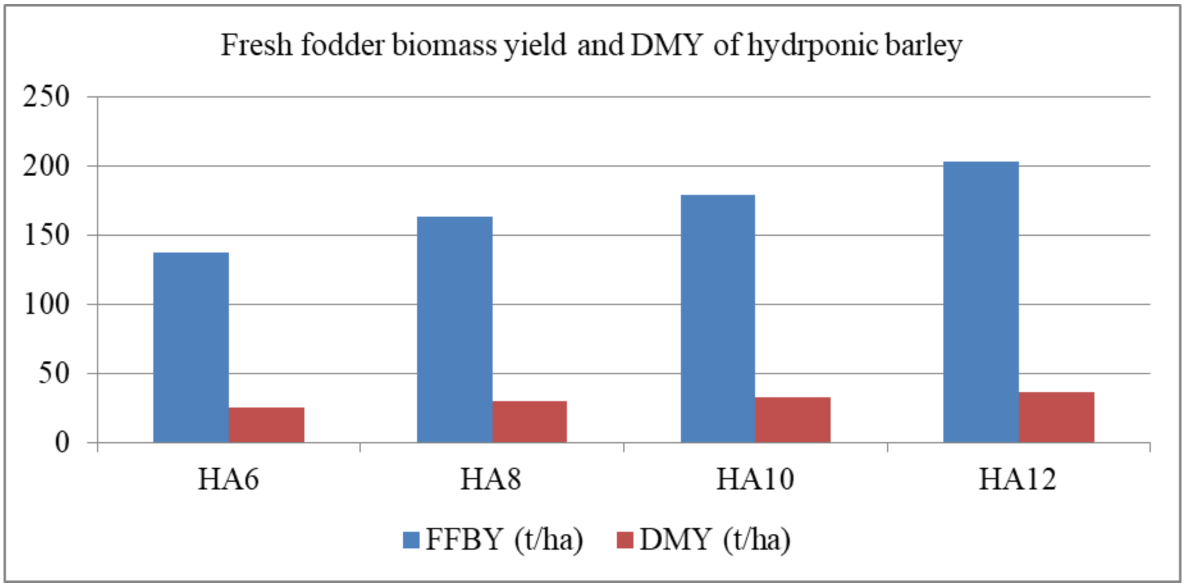
7.2. Appendix Figure



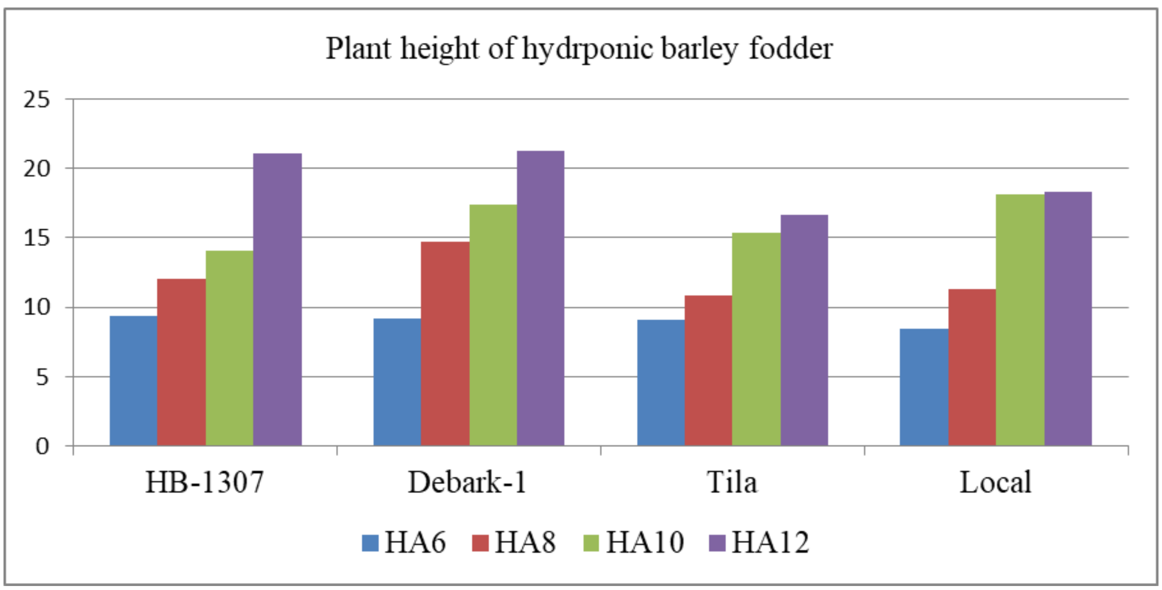
Appendix figure 1: Effect of different barley varieties on morphological characteristics and biomass yield of hydroponic barley



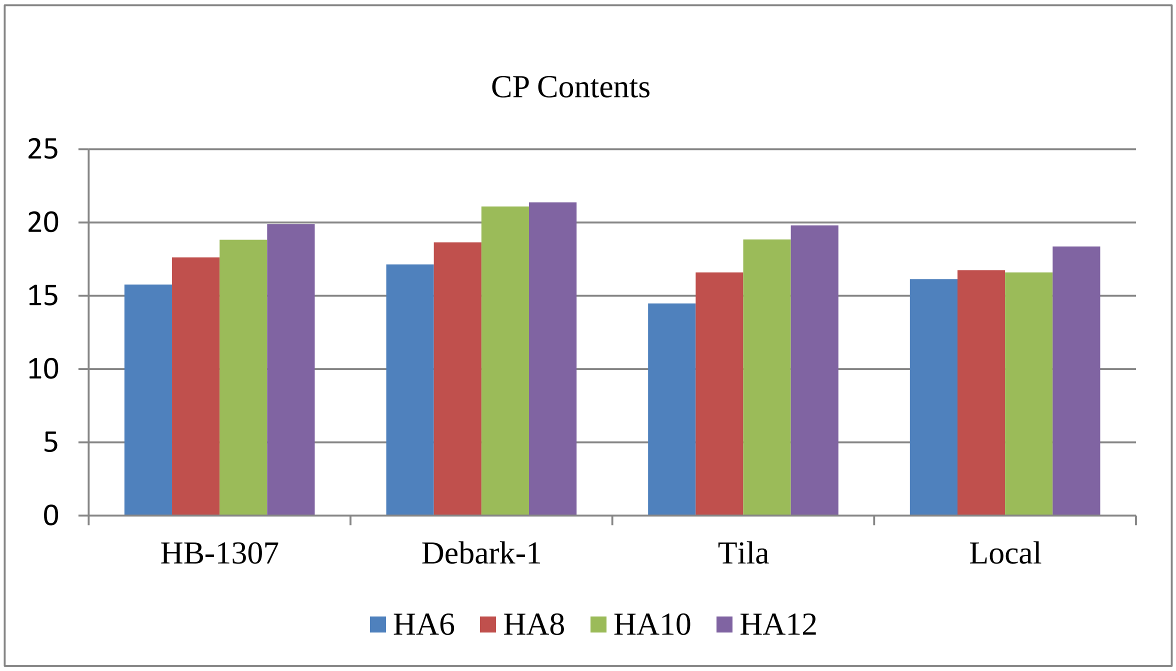
Appendix figure 2: Effect of harvesting age on growth parameters and biomass yield of hydroponic barley



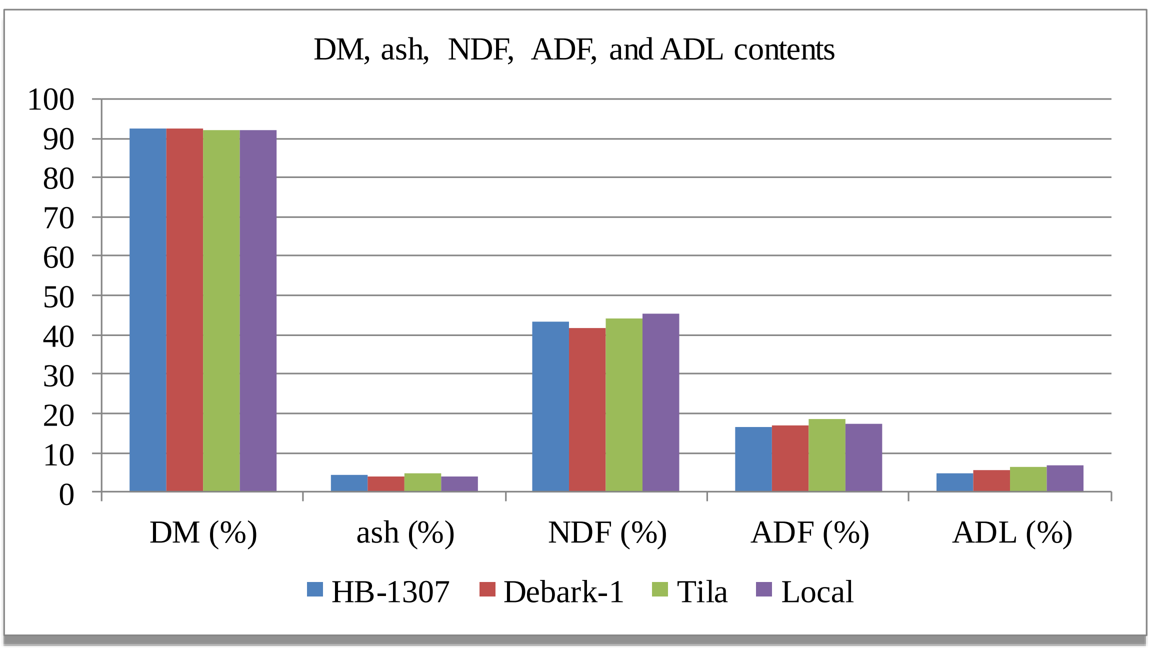
Appendix figure 3: Effect of harvesting age on fresh fodder biomass yield and DMY of hydroponic barley



Appendix figure 4: Interaction effect of harvesting age and barley variety on plant height (cm)



Appendix figure 5: Interaction effect of harvesting age and barley variety on CP contents



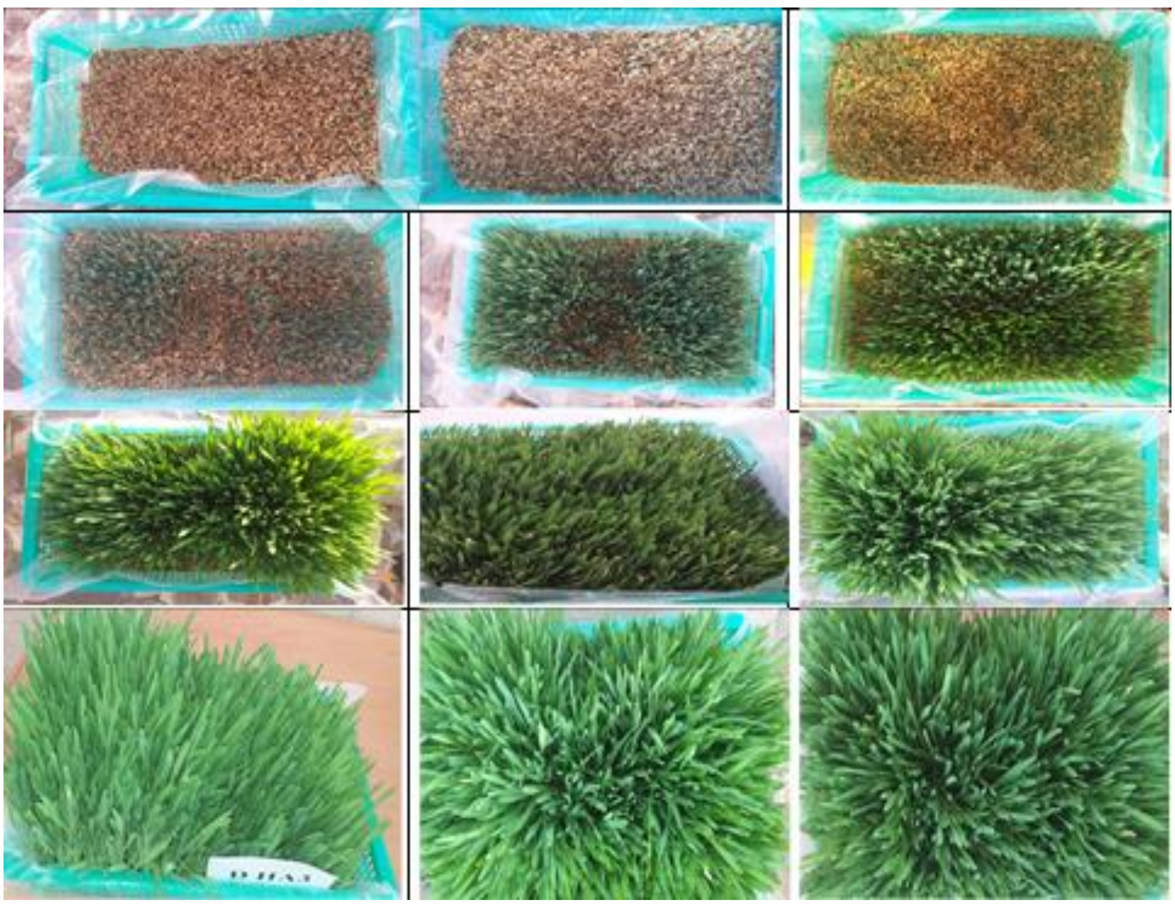
Appendix figure 6: DM, ash, NDF, ADF, and ADL influenced by the effect of barley variety

Appendix figure 7: External and internal view of the hydroponic shed

Appendix figure 8: Seed treatment, soaking, and tray cleaning


Appendix figure 9: Growth performance of hydroponic barley on the 6, 8, 10, and 12 days

Appendix figure 10: Morphological data collection on hydroponically grown barley



Appendix figure 11: Growth performance of hydroponic barley fodder from 1-12 days

BIOGRAPHICAL SKETCH

The author, Yeshambel Alemnew Negash was born on May 1, 1990, in Fogera District, Amhara Region. He completed his elementary education at Meneguzer primary school and completed his secondary school at education at Woreta town. In September 2007, he received an honors Diploma in Animal Science from Burie ATVET College. Soon after graduating, he joined the Department of Agriculture office and worked as an Animal production expert for ten years and as a livestock production and feed development team leader for four months in Quara district, Weast Gondar Zone, Amhara region. Also, in June 2013 he entered the University of Debretabor and in July 2017 received a bachelor's degree in animal production. Finally, he joined the Livestock and Fishery Sector Development Project (LFSDP) as a coordinator in the Fogera district, Amhara Region. He has been working for 4 years and 4 months since August 2018. He then returned to Bahir Dar University in 2020 to complete his M.Sc. study in the field of Animal Production and Technology.