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ENVIRONMENTAL AND ECONOMIC ASPECTS OF HYDROPONIC FODDER PRODUCTION, A COMPREHENSIVE REVIEW

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Summary

Livestock is one of the major sources of economy, livelihood, cultural and social values of Ethiopians. However, its productivity is extremely low mainly due to shortage of feed. Conventional fodder cultivation relies heavily on arable land, large volumes of water, and seasonal stability, making it increasingly unsustainable. Shrinkage of land, recurrent droughts and the irreversible impact of climate change is threatening conventional rain-fed fodder production exacerbating the existing feed shortage. Hydroponic fodder production has emerged as an innovative solution to these constraints, enabling the growth of nutrient-rich green feed in controlled environments using water-efficient, soil-less techniques. Hydroponic fodder production is a technique in which seeds are germinated into a high quality, nutritious, disease free animal food in a hygienic and controlled environment. This review examines the environmental and economic dimensions of hydroponic fodder production system, highlighting its ability to significantly reduce water consumption, minimize the size of land requirement, lower application of agrochemicals, and ensure year-round fodder availability. The economic feasibility of hydroponic fodder production is ensured by its high nutritional value, low production cost and higher production efficiency. It is resilient to climatic change and does not require fertile land. Such integration and its short production cycle ensure year-round feed availability and enhance its application at all feed production levels. Collectively, the adoption of hydroponic fodder production presents a transformative opportunity to realize feasible livestock system, enhance rural livelihoods, and promote sustainable agricultural transitions under the changing climatic and economic conditions.

Keywords: climate change; conventional farming; green fodder; livestock; sustainable agriculture.

1. Introduction

Livestock is one of the major sources of economy, livelihood, cultural and social values of Ethiopians (Asresie *et al*., 2015). However, its productivity is extremely low mainly due to shortage of feed. Feed shortage in Ethiopia is originated from shrinkage of land, recurrent droughts exacerbated by the irreversible effect of climate change (Sintayehu *et al*., 2025). With its numerous economic and environmental benefits, hydroponic technology is emerging as a viable alternative to traditional fodder production methods, transforming the industry in the twenty-first century by promoting vertical farming (Ahamed *et al*., 2023). The only way to produce year-round green fodder anywhere is by using a hydroponic system, which requires little space and a few litres of water in a regulated growth environment (Hughes, 2017). Hydroponic fodder production does not require cultural operations like land preparation, cultivation, crop rotation and fertile soil (Nguyen *et al*., 2016), (Al-Karaki & Al-Hashimi, 2012).

The absence of green forage in livestock diets adversely affects the productive and reproductive performance of the animals (Kumar *et al*., 2018). Green fodder of barley, wheat, maize, alfalfa, oats, millets, rye, sunflower seeds, lentil, and other crops can be grown in an environmentally controlled system (Ahamed *et al*., 2023). According to commercial hydroponic fodder firms, 1.0 kg of grain can generate roughly 6–10 kg of fresh fodder in 7–10 days under hydroponic techniques in controlled environments with optimum growing temperature, humidity, and light (Dogrusoz, 2022); Wotton-Beard, 2019). In 1969, Woodward, an English scientist, made attempt to grow plants in various sources of water.

During the 1970s, many units were designed and manufactured in different countries including those in Europe and the USA to produce hydroponic fodder (Naik et al, 2015). In 1973, Harris from South Africa questioned the economic feasibility of the hydroponic system, and several researchers conducted research in the late 1980s in an effort to encourage hydroponic technology for forage production in India (Ningoji et al., 2021). In the 21st, hydroponic technology has revolutionized the production of green fodder (Shit, 2019). Today, hydroponic feed systems are promoted as a low-cost feed supplement, a potential solution to drought condition, and an effective way to reach nutritional burdens of livestock (Pierce et al., 2024).

Lack of green fodder for livestock production in regions with water scarcity and extreme climates has ignited an interest in controlled environments for fodder production (Ahamed *et al*., 2023). Furthermore, due to recurring droughts and a lack of water for irrigation in Middle Eastern, African, and Asian countries are severely in short of livestock feed (Al-Karaki & Al-Hashimi, 2012). According to a warning from the Food and Agriculture Organization of the United Nations, conventional production alone will not be sufficient to fulfil the increased food demand in 2050, which requires a 60–70% rise in global food production from current levels (Eitzinger *et al*., 2010). The livestock sector has made significant contributions to ensure global food security (Falvey, 2015), (Rosegrant *et al*., 2002). Under a hydroponic system, green fodder can be produced in six to ten days in a controlled agriculture in the presence of proper temperature, relative humidity, water, and light (solar radiation) (Ahamed *et al*., 2023).

An innovative method of fodder production (hydroponic technology) could have significant potential in reducing the competition of land between livestock feed and human food production. Fodder production on agricultural land is a critically conflicting issue to ensure the food security of the increased human population (Ahamed *et al*., 2023). The scarcity of green fodder has sparked a renewed interest in hydroponic fodder production, a rudimentary method that dates back to the 1800s or earlier (Bakshi *et al*., 2017). Green fodder production in the 21st century has been transformed by hydroponic technology after it was realized that there was a significant discrepancy between supply and demand (Shit, 2019).

Land scarcity brought on by urbanization and population growth, as well as climate change, it is currently difficult to produce animal feed in the required amount and quality (Canton, 2021). Consequently, Millions of herders have been left without assets as a result of the loss of millions of sheep, putting them at risk for psychological distress and starvation-related deaths (Maria Luisa *et al*., 2025). However, it is possible to save the lives of livestock by adopting hydroponic fodder production technology. Therefore, the general objective of this paper is to review and summarize the global experience of hydroponic fodder production and its feed value to livestock with the specific objectives: (a) to review the principles, procedures and methods of hydroponic fodder production; and (b) to review the economic and environmental advantages of hydroponic fodder production.

2. Materials and Methods

This paper implemented a narrative review approach to organize the current global knowledge from different sources of scientific information on the environmental and economic aspects of hydroponic fodder production at different levels (low-cost and high-tech). Published and grey literatures from widely used databases, including Scopus, Web of Science, Science-Direct, PubMed, and Google Scholar were reviewed. Similarly, institutional reports and periodicals related to the contents of this paper from international organizations like FAO and World Food Program were also referred to enrich this review

3. Production Principle and Economic Advantages of Hydroponic Fodder

3.1. Production principles

The fundamental idea behind the hydroponic fodder production system is that forage seeds respond to water or nutrient-rich solutions (containing nitrogen, phosphorus, potassium, sulfur, and magnesium) to germinate and grow into green plants in as little as six to ten days (Farghaly *et al*., 2019); (Wang *et al*., 2019).The detail procedure of hydroponic fodder production involves cleaning seeds from debris and other foreign materials and washing them thoroughly with tap water till all dirt and poor-quality seeds are removed.

The seeds are sterilized by dipping in a 1.5% sodium hypochlorite solution (household bleach) for 45 minutes to control the formation of moulds during germination and growth periods as recommended by (Pattanaik *et al*., 2015). The planting trays also be cleaned and disinfected with the same solution. Finally, the seeds will be again washed well from the bleach and soaked in tap water for12-24 hours depending on the type of seeds, hardness of the seed coat (Jeton, 2016); (Brownin, 2017). The seeds were incubated in buckets to be sprouted overnight. After 12 hours, seeds with emerged radicles will be spread uniformly on plastic or aluminum trays with few holes at one side of the trays to facilitate the drainage of excess water/nutrient solution, which can be collected in a tank and recycled (Sing *et al*., 2017). The sprouts are allowed to grow for 6-10 days through the application of tap water or nutrient solution at various hour intervals (Farghaly *et al*., 2019). On the 10th day, the fodder mat is harvested from the tray and feeds to the livestock. The trays are disinfected with hypochlorite solution and washed with clean water before they are reused for the next planting cycle (Shit, 2019).

3.2. Economic advantages of hydroponic fodder

3. 2.1. Low input requirement and high production output

Globally, hydroponic agricultural production has grown dramatically in recent years because of its reliable control to adverse climatic and insect damages, as well as enabling efficient use of land, water, and fertilizers (Woznicki *et al*., 2021). Additionally, hydroponic farming boosts agricultural output and quality, which raises economic earnings and competitiveness (Trejo-Téllez and Gomez-Merino, 2012). The major economic and environmental advantages of hydroponic fodder production briefly elaborated in the following sub-topics in comparison with the conventional farming system (**Table 1**).

Table 1: Input requirements of conventional and hydroponic fodder production systems

Parameter	**Conventional farming system**	**Hydroponic System**
Area required	1 ha land to produce 600kg/day	50 m^2 to produce 600kg/day
Fodder production in days	65-70 days	7-10 days
Water requirement	Very high (30 liters/ kg of green fodder)	Minimal (1.5 to 3 liter/ kg of green fodder)
Soil fertility	Essential	Not required
Fertilizer application	Required	Not essential
Fodder yield	Depends on environment, cultivation practices, etc.	Controlled conditions
Labour requirement	Intensive land preparation sowing, field management harvesting, transport, etc.	Minimal
Fencing and farm protection	Essential	Not required (undertaken in small shed or even under shade net
Green fodder utilization	Significant wastage	Almost no wastage

Source: (Ramteke *et al*., 2019)

3.2.2. Reduce land requirement

Hydroponic fodder production technology involves an intensive method of quality fodder production in less space and in a shorter duration (Upreti *et al*., 2022). Using hydroponic technology, 600-1000 kg of fresh fodder can be produced in 7-8 days growth cycle, on only 45-50 m^2 area compared to 1 hectare required in traditional farming (conventional production system) (Naik *et al*., 2013; Musa *et al*., 2024). Moreover, hydroponic technology requires 480 square feet area to produce 1000 kg green fodder every day against 5 - 30 acres of land under conventional system (Musa *et al*., 2024). According to (Ramteke *et al*., 2019) only 10 m by 5 m area is required to produce 600-650 kg of fodder per day whereas to produce the same quantity, one hectare of land is required under conventional cultivation system where 20-25 adult cattle can be fed for one year.

3.2.3. Efficient water use

It has been reported that about 1.5-2 liters of water is needed to produce 1 kg of green fodder hydroponically in comparison with 160 liters to produce 1 kg of green fodder of Rhodes grass under field conditions. Under hydroponic systems this equates to only 2-5% of water used in traditional fodder production ((Naik, 2014); Musa *et al*., 2024).

3.2.4. Improvement of nutritional content

Green fodder is always considered an inevitable, continuous, and economical source of nutrients for livestock from normal production perspectives (Ahamed *et al*., 2023). Compared with other available dry roughages, hydroponic fodder is a natural, highly palatable, and digestible feed enriched with micronutrients resulting in improved nutrient digestibility, health, and performance of animals (Jemimah *et al*., 2018). Green fodder is the primary and the only source of vitamin A for lactating animals (Mohini *et al*., 2007).

In addition to being a strong supply of minerals, thiamine, riboflavin, free folic acid, biotin, and vitamins A, E, and C, the hydroponic feed is also high in antioxidants, β-carotene, and chlorophyll pigments (Fazaeli *et al*., 2012). Dry matter consumption of dairy cows, milk production, and reproductive health are all enhanced by feeding them highly palatable and nutritious hydroponic fodder (Chethan *et al*., 2022). Another advantage of hydroponic fodder reported by (Kaouche-Adjlanea *et al*., 2016) is that replacing 10 kg of oat hay with 10 kg hydroponic barley fodder increased the milk yield of Cross-Breed Holstein cows by 4.7% compared to their control groups. On the other hand, replacing Napier grass with hydroponic maize fodder resulted in 13.7% increase of milk production (Naik *et al*., 2014). Sprouted hydroponic grain is a great source of basic nutrients and juice components with a constant pH that stimulates the appetite of the ruminant and nourishes microorganisms in the rumen capable of accelerating feed digestion and improving animal productivity (Farghaly *et al*., 2019). Moreover, adding hydroponic feed to beef cattle diets increased the concentration of ω-3 fatty acid and vitamins of meat while enriching milk of cows with ω-3 and ω-6(Ahamed *et al*., 2023). The comparative nutritional content of hydroponic and conventional fodder is shown in **Table 2**.

Table 2: Nutrient composition of seed, hydroponic and conventionally grown maize fodder

No.	Nutrient Composition (%)	Maize seed	Hydroponic Maize at			Conventional forage of 60 days
			6 days	7days	8days	
1	CP	9.10	12.46	13.64	14.64	9.34
2	EE	3.01	3.54	3.90	4.61	2.16
3	CF	2.59	8.43	9.53	11.46	25.24
4	NFE	83.97	73.58	70.15	65.60	54.41
5	Total Ash	1.34	1.99	2.78	3.69	8.84
6	NDF	39.64	40.81	41.94	42.43	59.96
7	ADF	10.80	12.46	14.63	18.71	31.24

Source: (Borah *et al*., 2023)

3.2.5. Palatability of hydroponic fodder

The hydroponic fodder is more nutritious and palatable than the conventional fodder and preferred by cattle, horses and young growing calve due to its softness and palatability (Shit, 2019). The germinated seeds embedded in the root system are consumed along with the shoots of the plants, with no nutrient wasting (Ramteke *et al*., 2019). The greater palatability response of hydroponic fodder recorded for Cattle, Buffalo, Sheep, Goat, Pigs, Rabbit, and Chicken was 15 kg, 15 kg, 1 kg, 2 kg, 2 kg, 150 g, and 50 g, respectively compared to their conventional feed types (Musa *et al*., 2024).

3.2.6. High nutrient use efficiency

Hydroponic is a method of growing plants without soil using water or a mineral nutrient solution that allows nutrient uptake more efficiently than plants grown in soil medium (Ghorbel & Koşum, 2022). Due to fast growing industrialization and urbanization, there is not only lack of cultivable land, but the conventional farming techniques have negative impact on the environment. As a result, soilless agriculture is successfully advocating as an alternative option for cultivating nutritious healthy vegetables and crops (Sharma *et al*., 2018).

3.2.7. Reduction of growth period and rate of production

Hydroponic system takes only 6-10 days to develop from seed to fodder while it takes at least 45-60 days under traditional production system (Bakshi *et al*., 2017), (Naik *et al*., 2013). Fodder production is accelerated by as much as 25% by bringing the nutrients directly to the plants, without developing large root systems to seek out food (Shit, 2019). Plants grow 40-50 times faster under a hydroponic (Akkenapally and Lekkala, 2021) and more evenly than the conventional soil based production system (Bakshi *et al*., 2017). Moreover, hydroponic system gives 20-25% more yield than the conventional methods of fodder production (Monisha *et al*., 2023) (**Table 3**).

3.3. Innovative feed production system

Approximately, 70% of agricultural land wo rldwide is currently used for the livestock se ctor (Eitzinger *et al*., 2010). Furthermore, the expected increase in demand for animal source foods will further intensify global pressure on land. An increased pressure on land amplifies the risk of converting forests, wetlands or natural grasslands into agricultural land, resulting in emission of greenhouse gases and the loss of biodiversity and other important ecosystem services (Godfray *et al*., 2010);(Foley *et al*., 2011). To limit land conversion into forage farm, it is essential to improve land use efficiency (Zante *et al*., 2015) through adopting an emerging forage production technologies like hydroponic.

Hydroponic green fodder is a living fodder with high digestibility and nutritional quality of animal feed (Naik *et al*., 2020). It is rich in protein and energy, easily digestible (El-Morsy *et al*., 2013). Moreover, feeding ruminant is incomplete without including green fodder in their daily diet (Naik *et al*., 2020). In many livestock production areas, there is major problem of low quality crop residues for forage requirement of livestock which is not enough for maintenance of animal health and productivity. Green forage availability is very important to maintain livestock health and productivity in general and particularly essential in dairy entrepreneurship where consistent and regular supply of green fodder is essential to sustain milk production (Gupta *et al*., 2019).

Hydroponic fodder increased animal performance and product quality by improving digestibility and efficient use of the nutrients (Ahamed *et al*., 2023). Hydroponic fodder production system helps to get regular green fodder to supplement the crop residues and improve its feeding value while it capably used to replace the expensive concentrate feeds contributing to the reduction of the existing cost of milk production (Upreti *et al*., 2022).

Table 3: Biomass production of cereal forage crops under conventional and hydroponic systems

Crop	Fresh yield (kg m^{-2}tray)		Length of growing period		Remark
	Conventional	Hydroponic	Conventional	Hydroponic	
Maize (*Zea mays L.)*	3.5(Rathod & Dixit, 2019)	28.2(Rachel Jemimah *et al*., 2020)	60-75 days		judicious use of fertilizers
Sorghum (*Sorghum bicolor (L.) Moench*)	3.75 (Rathod & Dixit, 2019)	30.95 (Chrisdiana, 2018)	60-75 days		Multi-cuttings
Pearl millet (*Pennisetumglaucum L.*)	2.75(Rathod & Dixit, 2019)		40-45 days		
Hyb. Napier grass (*P.purpureum x P.glaucum*)	25-30(Rathod & Dixit, 2019)	-	50-75 days		6-8 cuttings
Guinea grass (*Panicum maximum Jacq*.)	18-22(Rathod & Dixit, 2019)	-	70-75 days		7-8 cuttings
Rhodes grass (*Chlorisgayana L*.)	4-5(Rathod & Dixit, 2019)	-	90 days		
Brachiaria (*Brachiariamutica L*)	4-5(Rathod & Dixit, 2019)	-	70-80 days		
Buffel grass (*Cenchrusciliaris L*)	3-4(Rathod & Dixit, 2019)	-	70-75 days		
Barley(*Hordiumvulgare L*)	2.84 (Meena *et al*, 2017)	20.35 (Alemnew & Mekuriaw, 2023)	60 days	7-10 days	The HFP is produced only by water
Wheat (*Triticumastivum L*.)	1.23 (Sharma *et al*., 2019)	13.1(Al-Karaki and Al-Hashimi, 2011)	50-75days		
Oat (*Avena sativa L*.)	3.75 (Rathod & Dixit, 2019)	25 (Rivero *et al*., 2016)	60-70 days		
Rice (*Oriza sativa L*.)	0.35 (Usman, 2007)		50 DAT		

DAT= days after transplanting; HFP= hydroponic fodder production.

3.4. Global experiences of hydroponic fodder production

Feed quality is a critical factor in livestock management which directly influences health, growth, and the productivity of animals (Baris, 2023). Traditional green fodder production is constrained by rapid urbanization, land fragmentation, water scarcity, labour shortage, more growth time, requirement of manure and fertilizer, uncertain rainfall and natural calamities (Akkenapally and Lekkala, 2021). Globally, declining resources caused by climate change and a growing population is challenging traditional agricultural systems (Saha *et al*., 2016).

Therefore, scientists are forced to look for alternatives to address these challenges (Sekhon, 2014). To meet the increasing demand for green fodder, one of the best alternatives is hydroponic technique to supplement the meager pasture resource and crop residues *(Bakshi et al*., 2017). Hydroponic technology is emerged to grow fodder as an alternative to conventional method of fodder cultivation that has many constraints (Naik *et al*., 2014); Naik *et al*. 2015).

Hydroponic green fodder can be produced both in simple or large, sophisticated, and automated commercial systems under controlled environment, or in low cost systems, where the ambient environment is suitable for fodder production (Ningoji *et al*., 2021). Hydroponic fodder production is best-suited to semi-arid, arid, and drought-prone regions of the world, suffering from chronic water shortages or in areas where irrigation infrastructure does not exist (Bakshi *et al*., 2017).

Hydroponics is a successful growing technique that offers a constant supply of green fodder all year round, even in all sorts of worse climatic conditions for sustainable livestock production (Ahamed *et al*., 2023). Fully automated shipping container type system is becoming popular for growing fodder under extreme climates. Many companies in many countries are marketing the shipping containers type systems with a production capacity range of 50-2,500 kg per day (Ahamed *et al*., 2023) depending on the size of the units (**Table 4**). Similar models have been introduced in Peru, Jordan, Sudan, Kenya and Namibia (Mekouar, 2018).

In developing countries, the expensive, hi-tech commercial hydroponic fodder production systems are being replaced by low cost hydroponic systems made up of locally available materials (Bakshi *et al*., 2017). The cost of such systems depends upon the type of construction materials used. Any type of shelter, garage, basement, room or low density plastic sheets, greenhouse or poly-hut with solid floor of compacted earth, concrete, cobblestone and others (Kerr *et al*., 2014); (Jeton, 2016), where the temperature, humidity and light can be controlled are used for hydroponic fodder production. Bamboos were used for the construction of shelf racks (Sinsinwar *et al*., 2012); (Kide *et al*., 2015). Today, The Netherlands, Australia, France, England, Israel, Canada, and the United States are among the world leaders in hydroponic technology (Monisha *et al*., 2023).

Table 4: Major commercial hydroponic fodder production companies of different countries

Company name	Country	hydroponic systems	Capacity
Agritom	Australia/ Turkey	Shipping container, stackable vertical farming system.	Varies based on size and types
Greentech	Gujarat, India	Shipping container growing volume:12-70.8 m^3	130-900 kg/ day
FodderTech	Utah, USA	Shipping container, stackable vertical farming system	Varies based on size and types
Fodder solutions	Queensland, Australia	Shipping container Growing volume: 33-55 m^3	600-900 kg/ day
H_2O Farm	Berkshire UK	Stackable vertical farming system in warehouse	
Eleusis International	Madrid, Spain	Shipping container type vertical farming system Growing area: 50 m^2	Up to 1,000 kg/ day
Nature-Hydro	Shanghai, China	Shipping container, stackable tray system for buildings, and greenhouse	Varies based on size and types

Source: (Ahamed *et al*., 2023)

3.5. Potentials of hydroponic fodder production for large-scale livestock farming

Livestock production provides access to animal-based food products for populations as well as source of livelihood for many resource-poor farmers in developing nations (Makkar, 2006). In many parts of the world, production of sufficient green fodder to feed the livestock population has become a big challenge mainly due to shortage of land, fertilizer, lack of irrigation facilities, and natural calamity resulted from climate change (Amanuel, 2019). Moreover, due to increasing pressure of the human population, more arable land is used for food and cash crops with little chance of having large land size for fodder production (Naik *et al*., 2015). Consequently, there is a large gap between feed supply and demand (Akkenapally and Lekkala, 2021). To overcome this challenge, hydroponic fodder production technology is emerged as alternative to grow sufficient quality fodder and to cover some parts of concentrate in livestock rations (Shit, 2019).

Livestock production in most regions of the world is limited due to poor production and pricy imported green fodder (Akkenapally and Lekkala, 2021). Today, land scarcity presents an important limit towards forage production for animals especially sheep, goats and cattle as these groups cannot solely depend on cereal grains like that of mono-gastric animals (Ghorbel & Koşum, 2022). That’s why, as an alternative technology, hydroponic forage production becomes an alternative solution for sustainable and year round forage production depending on the size of livestock to be fed. The use of this technology improves the long-term economic development of the livestock industry (Masud & Bhowmik, 2018).

Commercial hydroponic farms were developed in Abu Dhabi, Arizona, Belgium, California, Denmark, German, Holland, Iran, Italy, Japan, Russian Federation and other countries. At the end of 1980s, many automated and computerized hydroponic fodder farms were established around the world (Surve and Kamble, 2021).This technology has been tested on various crops such as Maize, Sorghum, Barley, and Oats to produce high-quality, nutritious green fodder for dairy animals (Swain & Sahoo, 2020).

3.6. Ecological conservation of hydroponic fodder production

Conventionally grown forages are associated with heavy external inputs of nutrients, fossil fuels, water, and land consumption, and as demand for animal products increase on a global scale, the environmental impacts of feed crop farming become substantial (McAlpine *et al*., 2009). Through many and repeated efforts of agricultural scientists, the development of agricultural technologies for the advancement of feed production is currently in use to reduce greenhouse gas emissions of livestock sector. These technologies have the potential to address climate change focusing on indoor production facilities that advocates vertical(intensive) farming where the environment factors can be manipulated for crop specific (Gnauer *et al*., 2019). Space can be used much more efficiently resulting in higher yields with lower water and nutrient consumption (Marchant and Tosunoglu, 2017). Currently, hydroponic fodder production has been announced extensively to produce feed for ruminants all over the world renewing the interest of livestock farmers and researchers as well (Prakash, 2017).

Hydroponic fodder technology enables the production of a larger volume of nutritious feed in a relatively small space and with significantly higher reductions in farming inputs (e.g., pesticides, water, and fertilizer) directly saving more land space for ecological reserves (von Wehrden *et al*., 2014); (Jiren *et al*., 2018) and thus contributing to climate mitigation objectives through carbon sequestration and storage benefits associated with habitat conservation (Sollmann *et al*., 2017); (Spencer *et al*., 2017). Hydroponic is a successful growing technique that offers a constant supply of green fodder all year round, even in all sorts of worse climatic conditions for sustainable livestock production (El-Morsy *et al*., 2013).

3.7. Hydroponic: climate smart fodder production system

Global warming and its associated changes in climate variability affect feed and water resources as well as animal health and production (Godde *et al*., 2021) threatening the ability of the current livestock systems to support livelihoods and meet the increasing demand for livestock products (Godde *et al*., 2021). Natural water resources are affected by global climate change so food production and sustainability are endangered (Falkenmark, 2007). It’s expected that the global climate change cause negative impact on the grazing lands in arid and semi-arid regions (Hoffman & Vogel, 2008). The rain fall is reduced while environmental temperature is increased, so the grassland yields decrease and range and meadow deteriorated over the time. Natural water resources are affected by global climate change so food production and sustainability are endangered (Falkenmark, 2007). However, hydroponic allows higher productivity and yield without any constrains of climate and weather conditions (Saha, 2017).

Hydroponic system is one of the components of climate-smart crop production where forage can be produced in 6-10 days under controlled environment like greenhouses where the direct impacts of climate changes can be modified (Mekouar, 2018). It is largely reported that climate change does not impose significant effects on the plants produced under hydroponic system which ensures its sustainability and reliability for year round production regardless of the weather conditions (Lee and Lee, 2015). It is a type of fodder production conducted in a semi-controlled environment making the crop safe from failure due to weather elements (Jeton, 2016).The availability of low-tech hydroponic unit enables fodder growth in arid environments. It is an alternative livelihood for herders and cost-efficient solution that uses up to 90% less water and 75% less space (Mekouar, 2018). A case study carried out under the H2 Grow project (WFP) of the Sahrawi refugees in the Algerian Sahara desert have tested and ensured low-cost hydroponic forage production unit to supply green fodder for their livestock year round (Mekouar, 2018).

Hydroponic or soilless agriculture belongs to the category of controlled environment agriculture (CEA), where production is managed regardless of climate conditions (Sardare & Admane, 2013); a shift in forage agriculture toward novel feed production approach to mitigate environmental impacts and meet at least the green feed requirement of the ruminant livestock (Giovannucci *et al*., 2012). Moreover, a research result reported by (Newell *et al*., 2021) clearly indicated that hydroponic fodder production has the potential to reduce GHG emissions and provides greater carbon sequestration opportunities than conventional forage production system. Other rrecent researches showed that hydroponic fodder production in a shipping container could reduce greenhouse gas emissions (per nutrient mass) by 7.4% compared with the conventional farming of fodder production (Ahamed *et al*., 2023).

3.8. Comparison of traditional and hydroponic fodder production systems

Long growth period, requirement of fertilizer, unavailability of good quality fodder round the year, water scarcity, the uncertain rain fall and natural calamities due to climate change are the key constraints for conventional forage production (Naik *et al*., 2013).

Conventional forage production requires substantial investment in agricultural implements and infrastructure including: machinery and equipment for land preparation, field management activities, harvesting, post-harvest handling and transportation, storage and irrigation facilities (Shit, 2019). Whereas, hydroponic production requires substantially less investment in fixed assets and the required equipment and facilities can be manufactured locally from available materials when compared to the machinery, equipment and facilities needed for conventional fodder production (Jeton, 2016). Low cost hydroponic systems can be developed by using locally available infrastructure where there is an acute shortage of fodder and water; irrigation systems are not well established; transportation and fuel costs are high; and seasonal variations of fodder prices are extreme (Bakshi *et al*., 2017).

In such circumstances, hydroponic fodder pr oduction is frequently preferred over other st ructures, and it emerges as the most viable o ption for sustainable livestock production (S hit, 2019). Hydroponic system ensures regular green fodder supply to supplement crop residues and improve feeding value of the ruminant diets (Ghorbel and Koşum, 2022); while capable of replacing the expensive concentrate thus reducing cost of milk production (Upreti *et al*., 2022).

Fertilizer requirement of hydroponic fodder production is extremely low (ppm) compared to the conventional farming while its utilization efficiency is by far higher under hydroponic system (Dung *et al*., 2010). Similarly, it was reported that hydroponic fodder production guaranteed high nutritional content of the fodder produced with less water, on less space and is cost effective (Gebremedhin, 2015).

4. Major Constraints of Hydroponic Fodder Production

During sprouting of the seeds, there is an increase in the fresh weight and a consequent decrease in the dry matter content which is mainly attributed to the imbibition of water (leaching) and enzymatic activities (oxidation) that depletes the food reserves of the seed endosperm without any adequate replenishment from photosynthesis by the young plant during short growing cycle (Sneath & McIntosh, 2003). A number of studies reported that sprouting resulted in 7- 47% loss in dry matter from the original seed after sprouting for a period of 6-7 days of growth, mainly due to respiration process (Fazaeli *et al*., 2012; (Putnam *et al*., 2013). Seed soaking activates enzymes that convert starch stored in endosperm to a simple sugar, which produces energy and gives off carbon dioxide and water, leading to loss of dry matter with a shift from starch in the seed to fiber and pectin in the roots and green shoots of the fodder (Bakshi *et al*., 2017). There is general consensus that there is no significant gain in fodder dry matter increase through sprouting grain and producing hydroponic fodder. Grain usually contains around 85-87% dry matter while hydroponic fodder usually contains 80-85% water (Jeton, 2016). In developed countries, where there is no dearth of quality feed and fodder, the technology may be less competitive than conventional fodder production on per kg dry matter basis (Shit, 2019).

5. CONCLUSION

The conventional production of green fodder (the natural diet for livestock) to meet the current demand has become the greatest challenge mainly due to shortage of land and the adverse effect of climate change. Hydroponic fodder production, taking all factors into account is best suited for producing supplementary fodder for feeding livestock including poultry and high value breeding animals.

In the history of agricultural development no innovative forages production technologies emerged so far to complement or replace the conventional farming system except hydroponic technology with its high productivity potential per a unit of inputs (land water and fertilizer).

The economic importance of hydroponic fodder lies in its ability to enhance livestock productivity, optimize resource use, and provide sustainable solutions to feed challenges, making it a viable option for modern agriculture.

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