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Review

Hydroponic Feed and Quality in Sustainable Dairy Animal Production

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Abstract: Hydroponic feed production has emerged as an innovative and sustainable approach to address the growing demand for high-quality animal feed while minimizing the environmental impact of traditional agriculture. This paper explores the key principles, and outcomes associated with hydroponic feed production, focusing on its potential to enhance the nutritional quality, sustainability, and safety of livestock diets, as well as milk production and quality. In conclusion, this paper underscores the potential of hydroponic feed production as a sustainable and efficient solution to address the challenges of conventional feed production. By optimizing feed quality and reducing the environmental footprint of livestock and aquaculture industries, hydroponics offers promising prospects for meeting the increasing global demand for high-quality animal nutrition while promoting sustainable agricultural practices.

Keywords: Hydroponic feed; cow nutrition; sustainability; soilless cultivation; livestock; environmental impact.

1. Introduction

Sustainable dairy animal production has become an imperative in the 21st century as the global demand for high-quality dairy products continues to rise. The dairy industry faces the dual challenge of meeting this increasing demand while minimizing its environmental impact [1,2]. A critical component of sustainable dairy farming is the optimization of feed production and quality, which not only plays a pivotal role in ensuring the health and productivity of dairy animals but also affects the overall ecological footprint of the industry [3]. Traditional approaches to feed production have often relied on resource-intensive methods, involving extensive land use, water consumption, and chemical inputs [4]. These practices contribute to land degradation, water pollution, and greenhouse gas emissions, posing significant environmental challenges.

In contrast, hydroponic feed production represents a promising and innovative solution for sustainable dairy animal production [5]. Hydroponics is a soilless agriculture system that involves growing plants in nutrient-rich water solutions, eliminating the need for traditional soil [6]. Hydroponic systems offer precise control over environmental factors such as temperature, light, humidity, and nutrient levels, which can result in highly efficient and sustainable crop production. Hydroponic feed production systems provide an opportunity to cultivate high-quality, nutrient-rich forage crops in a controlled environment, offering several advantages over traditional methods [7].

The adoption of hydroponic feed production systems is founded on the principles of precision agriculture, resource optimization, and ecological responsibility [8]. By exploring the underlying scientific principles, methodologies, and technologies of hydroponic systems, we can gain insights into their potential to transform feed production in the dairy sector [9]. These systems allow for efficient resource utilization, requiring less land and water while minimizing the use of chemical fertilizers, thus reducing the ecological footprint of feed production. Furthermore, hydroponic crops are often cultivated in a controlled environment, free from soil-borne diseases and pests, leading to cleaner and healthier feed options for dairy animals [10].

The advantages of hydroponic feed production are multifaceted. Besides improved feed quality and resource efficiency, hydroponic systems also offer year-round production possibilities, reducing the need for season-dependent forage crops [11]. Additionally, they can be integrated into a broader circular agriculture model, where waste products from dairy farming can be utilized as nutrient inputs for hydroponic systems, promoting a closed-loop approach to resource management [12].

As we progress towards a more sustainable future, a deep understanding of the scientific foundations of hydroponic feed production is vital for dairy farmers, researchers, policymakers, and all stakeholders in the dairy industry [13]. Through the adoption and refinement of hydroponic feed production techniques, the dairy sector can take significant steps towards achieving environmental responsibility and economic viability, ensuring the long-term sustainability of dairy animal production [11].

This review paper aims to comprehensively assess the advantages and challenges associated with hydroponic feed production, providing a balanced perspective on its role in sustainable dairy animal production.

2. Definition of hydroponic feed for dairy animal production

Hydroponic feed for dairy animal production refers to a specialized system of growing and providing nutrient-rich, water-cultivated plants to dairy cattle or other dairy animals as a primary or supplementary source of nutrition [14]. This innovative agricultural approach involves cultivating crops, typically forage or fodder plants, without soil, relying instead on nutrient-rich water solutions to provide essential minerals and nutrients to the plants.

In a hydroponic feed system for dairy animal production, plant roots are directly exposed to a carefully balanced nutrient solution that provides the necessary macronutrients (such as nitrogen, phosphorus, and potassium) and micronutrients (such as iron, calcium, and magnesium) [15,16]. These hydroponically grown crops are then harvested and fed to dairy animals to meet their dietary requirements for essential nutrients [17].

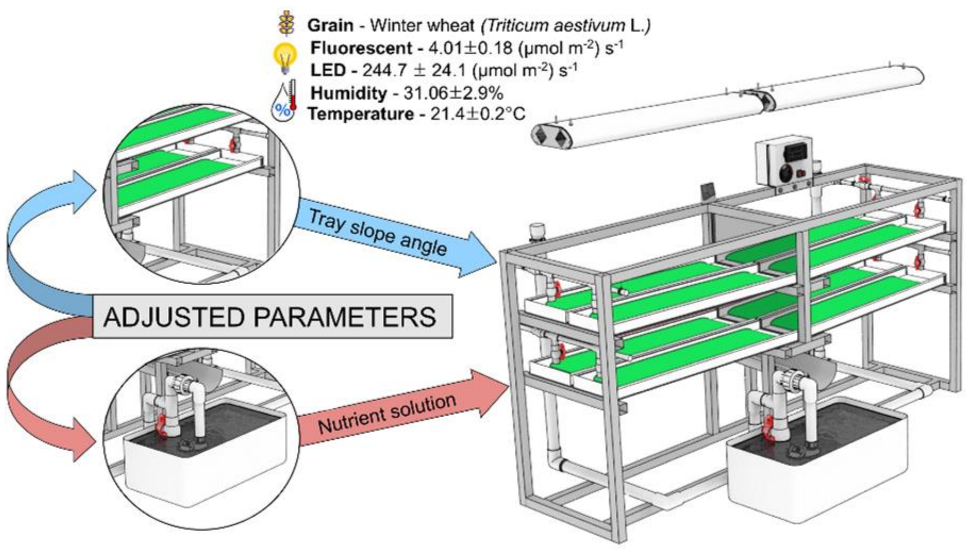
The advantages of hydroponic feed in dairy animal production include precise control over nutrient content, reduced water usage, enhanced crop yields, and potentially improved feed quality [18]. This approach is particularly beneficial in regions with limited arable land or water resources and can contribute to sustainable and efficient dairy farming practices.

3. Principles of hydroponic fodder production

Hydroponics is the growing of cereal grains with necessary moisture, nutrients, and absence of solid growing medium [19]. The sprouted shoot and root mat is harvested and fed to animals. Germination is a response to the supplied moisture and nutrient and produces 200 to 300mm long forage green shoot with interwoven roots within 7 to 10 days [20]. The principles of hydroponic fodder production are grounded in the science of plant growth and nutrition. Table 1 represents the key scientific principles involved in hydroponic fodder production. While Pictures 1 and 2 show structural and technological parameters of hydroponic fodder [21].

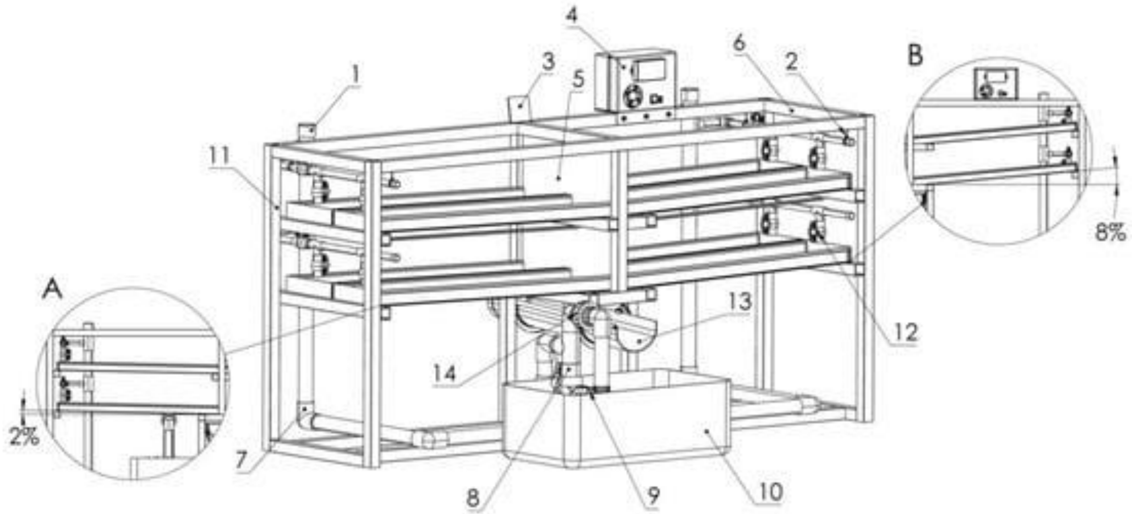
Table 1. The principles of hydroponic fodder production [22–24].

Hydroponic system design	Hydroponic fodder production systems are designed to provide a controlled environment for plant growth. This includes structures that facilitate the optimal distribution of water, nutrients, and light to the growing crops.
Controlled environment	Maintaining a controlled environment is crucial to hydroponic fodder production. Factors such as temperature, humidity, and light intensity are carefully managed to ensure optimal growth conditions for the plants.
Nutrient solution	Hydroponic systems rely on a precisely formulated nutrient solution that contains essential macro and micronutrients required for plant growth. These nutrients include nitrogen, phosphorus, potassium, calcium, magnesium, and trace elements like iron.
Water management	Efficient water management is essential in hydroponic systems. Water is recirculated, and excess runoff is minimized to conserve resources and prevent nutrient loss.
Seed selection	The selection of appropriate seeds for hydroponic fodder production is critical. Varieties that are well-suited to rapid growth in hydroponic systems are chosen. These seeds should also be free from contaminants and diseases.
Germination	Seeds are germinated in a controlled environment, often on trays or shelves, with precise temperature and moisture conditions to promote rapid and uniform sprouting.
Growth period	During the growth period, the crops are exposed to light, usually through artificial lighting systems, to ensure photosynthesis and steady plant development. The duration of the growth period is typically short, ranging from 7 to 10 days.
Harvesting	Fodder is harvested when it reaches the desired height and nutritional value. The timing of harvesting is crucial to maximize nutrient content and digestibility for livestock.
Nutrient recycling	Nutrient recycling is a key principle in hydroponic fodder production. Nutrient-rich runoff is captured and reused in the system to minimize waste and resource consumption.
Quality control	Regular monitoring and quality control assessments are conducted to ensure that the hydroponically grown fodder meets the nutritional requirements of the target livestock. This includes testing for factors like protein content and microbial safety.
Disease and pest management	Hydroponic systems should incorporate measures to prevent and control diseases and pests that can affect plant growth. This may involve the use of organic or integrated pest management methods.



Picture 1. Structural and technological parameters of hydroponic fodder [21].

By adhering to these scientific principles, hydroponic fodder production can provide a consistent and efficient source of high-quality nutrition for livestock, contributing to sustainable and resource-efficient animal farming practices.



Picture 2. Hydroponic fodder growing stand scheme: (A) trays sloped at 2.0% and (B) trays sloped at 8.0%; 1—blind, 2—pipe holder, 3—temperature and humidity meter, 4—light-emitting diode (LED) controller, 5—organic glass, 6—aluminium profile frame, 7— polyvinyl chloride (PVC) elbow, 8—total flow adjustment valve, 9—irrigation pump, 10—irrigation tank, 11—growth tray, 12—feed solution flow control valve, 13—collection pipe, 14—disassemble coupling, 15—PVC piping [21].

4. Importance of hydroponic feeds in dairy animal nutrition

Dairy animal nutrition is a fundamental factor in dairy farming, significantly influencing milk yield, quality, and overall animal health [25,26]. Traditional methods of feed production often face challenges related to land availability, resource use, and climate variability. Hydroponic feeds, which rely on controlled environments and water-based nutrient solutions, have emerged as a novel approach to overcome these limitations. One of the significant contributions of hydroponic feeds to dairy animal nutrition is the notable improvement in feed quality [27]. Hydroponically grown crops, such as barley, maize, and oats, are known to exhibit enhanced nutritional content. This is primarily due to the precise control over growing conditions, including temperature, light, and nutrient composition. Studies have shown that hydroponic fodder can contain higher levels of essential nutrients, such as protein, vitamins, and minerals, compared to conventionally grown fodder [28–30]. These improvements in feed quality can directly impact the health and productivity of dairy animals. For example, higher protein content in hydroponic fodder can lead to increased milk production and improved milk composition, including higher butterfat and protein levels. Hydroponic systems enable the efficient delivery of essential nutrients to plants, resulting in increased nutrient availability in the feed. Nutrient solutions are custom-tailored to meet the specific requirements of the target crops, ensuring that they receive optimal levels of macronutrients and micronutrients. This meticulous control over nutrient uptake enhances the bioavailability of key nutrients in the fodder. Dairy animals benefit from improved nutrient absorption, leading to better overall health, increased milk production, and potentially reduced instances of nutrient deficiencies. Research on hydroponic feeds has contributed to our understanding of nutrient management in dairy animal nutrition [27]. Hydroponic feeds offer a sustainable approach to dairy animal nutrition, a topic of growing interest [31]. Traditional feed production can be resource-intensive, with land use, water consumption, and fertilizer application contributing to environmental challenges [32,33]. Hydroponic systems, on the other hand, are highly resource-efficient [34]. They require less land, minimize water use through recirculation, and reduce the risk of nutrient runoff and soil degradation [35]. As the global dairy industry seeks to adopt more sustainable practices, the importance of hydroponic feeds lies in their potential to reduce the environmental footprint of dairy farming [36]. Research in this area has advanced our understanding of how hydroponic systems can contribute to more eco-friendly and resource-efficient dairy production.

5. Influence of hydroponic feed on cow milk yield and milk quality

Hydroponic feed, which involves the cultivation of plants without soil in a nutrient-rich water solution, has the potential to influence cow milk yield and milk quality in several ways [37]. While this approach is not typically used in the dairy industry, it can indirectly impact milk production and quality through changes (Table 2) in animal nutrition and overall herd health [27]. Hydroponic feed can be carefully controlled to provide a consistent and nutritionally balanced diet for cows. This precision in nutrient provision can lead to improved cow health and performance, which may positively impact milk yield and quality. A well-balanced diet can provide the necessary energy, protein, and other nutrients for optimal milk production [38]. Hydroponically grown forage, such as barley (Picture 3) or wheat grass, can be highly nutritious and free from contaminants often found in traditional pasture or stored forage. This cleaner and more nutritious forage can enhance the cow's diet, potentially leading to increased milk production and improved milk quality. Hydroponic systems offer a controlled environment where factors such as temperature, humidity, and light can be optimized for plant growth. These factors can indirectly affect cow comfort and health, potentially reducing stress and promoting milk production. Hydroponically grown crops are less likely to be contaminated with soil-borne pathogens [39], pesticides [40], mycotoxins [41] or heavy metals [42].

Picture 3. Hydroponically grown barley.

Table 2. Effect of feeding system on milk chemical composition [27].

	Control	Hydroponic*
	n=10	*n=10*
Fat, %		
Week I	3.70±3.60	4.54±4.00
Week II	3.07±3.10	4.05±4.00
Week III	3.36±3.10	4.54±4.50
Week IV	3.00±3.30	3.58±4.20
Protein, %		
Week I	2.63±2.60	2.89±2.70
Week II	2.67±2.70	2.82±2.70
Week III	2.63±2.60	2.70±2.70
Week IV	2.68±2.60	2.63±2.70
Solid nonfat, %		
Week I	7.33±7.26	7.99±7.59
Week II	7.44±7.37	7.76±7.55
Week III	7.29±7.10	7.49±7.38
Week IV	7.46±7.10	7.34±7.38
Density, kg/m^3		
Week I	26.2±25.9	29.8±26.9
Week II	26.9±26.7	27.6±26.8
Week III	26.2±25.6	26.2±28.5
Week IV	27.1±25.5	26.2±26.0
Lactose, %		
Week I	3.98±3.90	3.93±4.10
Week II	4.04±4.00	4.20±4.10
Week III	3.95±3.90	4.04±4.00
Week IV	4.06±3.80	3.98±4.00
Ash, %		
Week I	0.56±0.50	0.56±0.60
Week II	0.57±0.60	0.59±0.60
Week III	0.55±0.50	0.57±0.60
Week IV	0.58±0.50	0.57±0.60
pH		
Week I	6.12±6.20	6.50±6.60
Week II	6.38±6.30	6.59±6.50
Week III	6.54±6.50	6.60±6.60
Week IV	6.58±6.50	6.62±6.60

** - Hydroponic is added in amount of 7.60 kg with DM of 15.83 % and chemical composition (DM basis) of 0.51 % EE, 12.00 % CP, 5.76 % ADF, 12.73 % NDF, 2.17 % ash.*

A cleaner food source for cows can lead to improved milk quality [43], with reduced risk of contamination in the milk. Hydroponic systems can provide a consistent and reliable source of fresh forage, reducing seasonal variations in the cow's diet [44]. This consistency can help maintain steady milk production and quality throughout the year. Hydroponic systems often use water more efficiently than traditional agricultural practices [45]. By conserving water resources and minimizing the need for extensive land use, hydroponic feed can contribute to environmental sustainability and potentially support a more stable dairy industry in the face of climate change and resource constraints.

6. Conclusion

It's important to note that the practical application of hydroponic feed in the dairy industry is relatively uncommon, and there may be challenges and costs associated with implementing such systems. Furthermore, the direct impact of hydroponic feed on milk yield and quality may vary depending on the specific crops grown, the feeding strategies, and the management practices employed. More research and field trials would be needed to provide a comprehensive understanding of the effects of hydroponic feed on dairy production.

Conflicts of Interest: The authors declare no conflict of interest.

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