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Hydroponic fodder production: A critical assessment

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Introduction

The methods of hydroponic fodder production date back to the 1800s (Kerr et al., 2014), or earlier, from the 'Hanging Gardens of Babylon' era, when European dairy farmers fed sprouted grains to their cows during winter to maintain milk production and improve fertility (Anonymous, 2008). There is renewed interest in this technology due to shortage of green fodder in most of the Middle East, African and Asian countries. Fodder production cannot easily be increased due mainly to ever increasing human pressure on land for production of cereal grains, oil seeds and pulses. To meet this increasing demand for green fodder, one of the alternatives is hydroponic fodder to supplement the meager pasture resources. The word hydroponics is derived from two Greek words: 'hydro' meaning water and 'ponos' meaning labour i.e. water working. Hydroponic green fodder can be produced both in large, sophisticated, automated commercial systems with environmental control, or in low cost systems, where the ambient environment is suitable for fodder production. Fodder seeds utilize tap water, or nutrient-enriched solutions for plant nourishment in the absence of soil. Hydroponic fodder is also called fresh fodder biscuits, sprouted fodder or sprouted grain or alfaculture. Today, hydroponics are used in harsh climates such as deserts, areas with poor soil or in urban areas where high land costs have driven out traditional agriculture. Hydroponic fodder production is probably 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. Hydroponic fodder production is a boon for farmers whose soil is rocky and infertile. It is a viable farmer friendly alternative technology for landless farmers for fodder production. Fodders including maize, barley, oats, sorghum, rye, alfalfa and triticale can be produced by hydroponics. Others, including cowpea, horse gram, sun hemp, ragi, bajra, foxtail millet and Jowar have also been grown successfully by the use of hydroponics (Rachel Jemimah et al., 2015).

High-cost hi-tech hydroponic systems

These are highly sophisticated, fully automated fodder production systems with controlled environments, and are immune to natural weather variations. The required water, light, temperature, humidity and aeration are fully controlled by sensors.

The provision for recycling of water is also available. In India, Government established 11 hi-tech hydroponic units under Rashtriya Krishi Vikas Yozna (RKVY) at the Research Complex, Goa of the Indian Council of Agriculture Research (ICAR) and in Dairy cooperatives of Goa State. Likewise in Kerala the Dairy Development Department (KDDD), Integrated Dairy Development Project, has introduced a scheme to produce hydroponic green fodder. The department has already distributed 24 hydroponic fodder units to selected dairy farmers.

The procedure, in brief, for production of hydroponic fodder comprises procuring clean, sound, intact, untreated, viable seeds/grains of high quality (Sneath and McIntosh, 2003; Naik et al., 2015). The seeds should be soaked in 0.1-1.5% bleach solution (sodium hypochlorite) or 1-2% hydrogen peroxide solution for 30-60 minutes (Rachel Jemimah et al., 2015; Starova Jeton, 2016), and thereafter washed in tap water. The seeds are then soaked in fresh aerated water for different periods: 4 h (Naik et al., 2014), 8 h (Starova Jeton, 2016), 12-16 h or overnight (El-Deeba et al., 2009; Al-Karaki and Al-Momani, 2011; Brownin, 2017), 6-20 h (Rachel Jemimah et al., 2015) or 24 h (Shashank Sinsinwar et al., 2012; Reddy, 2014) depending on the hardness of the seed coat. Temperature of the water or solution used for soaking also affects the germination rate. The optimum temperature for soaking the seeds is 23 ºC (Sneath and McIntosh, 2003). After soaking, the seeds are spread at up to one cm depth in plastic or light weight metallic trays with holes to facilitate drainage of the waste water/nutrient solution, which can be collected in a tank and recycled. The seed rate (quantity of seeds loaded per unit surface area), which varies with the type of seeds, also affects the yield of the fodder. The recommended seeding rate for production of hydroponic barley, wheat or sorghum fodder is 4-6 kg/m^2 (Al-Karaki and Al-Momani, 2011; Starova Jeton, 2016), and for maize fodder is 6.4-7.6 kg/m^2 (Naik and Singh, 2013; Naik, 2014; Naik et al, 2017a), respectively. The seed cost contributes 85-90% of the total cost of production of hydroponic fodder (Naik et al., 2014; Rachel Jemimah et al., 2015). The trays are placed in hydroponic racks, and seeds are irrigated with fresh tap water or nutrient enriched solution. The trays should never be exposed to direct sunlight, strong wind and heavy rain. During the growing period, the seeds are kept moist by drip or spray irrigation but are not saturated. The environmental factors for optimum growth of a fodder are: temperature between 19 to 22 ºC, humidity between 40-80% (optimum being 60%), light (2000 lux in intensity) between 12-16 h and aeriation for 3 minutes after every 2 h (El-Deeba et al., 2009; Starova Jeton, 2016). The sprouts grow, albeit slowly outside the optimal conditions mentioned above, but at higher temperatures humidity mould infestation is one of the biggest challenges that needs addressing. For barley seed sprouts, the peak nutrient and biomass yield was at the 6th day of sowing, and this is the optimum stage for harvesting the fodder. Hydroponic fodder (20-30 cm grass mat containing roots, spent seeds and green shoots; Photo 1) is ready for harvesting within 6-8 days and requires a small piece of land for production (Mooney, 2005; Reddy, 2014).

The electricity requirement for the production of hydroponic fodder is much lower than for traditional

Photo 1. Hydroponic maize fodder production in India
(Photo credit: P.K. Naik, Central Avian Research. Institute Regional Centre, Bhubaneswar, India)

fodder production. Amongst different hydroponic fodders such as sprouted barley, oats, rye, triticale, and wheat, the sprouted barley has the highest forage quality (Heins et al., 2015).

Irrigation water with or without nutrient enrichment: The comparative evaluation of hydroponic barley produced by using tap water or nutrient solution revealed that sprouts grown with nutrient solution had higher crude protein and ash contents than those grown with tap water. The Ca, K, P, Mg, Na, Fe, Cu and Zn concentrations were higher in barley fodder produced using nutrient solution (Peer and Leeson, 1985; Dung et al., 2010; Fazaeli et al., 2012). However, there was no significant difference in dry matter (DM) loss and *in sacco* degradability of nutrients. Moreover, earlier reports indicated that the nutrient requirements of the seedlings are satisfied from the nutrients reserves in the seeds (Bewley, 1997; Dung et al., 2010). Use of nutrient solution also increases cost of fodder production. It was concluded that there was no additional advantage of using nutrient solution for producing hydroponic fodder (Dung et al., 2010; Fazaeli et al., 2012).

Low cost hydroponic systems

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. 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 etc. (Kerr et al., 2014; Reddy, 2014; Anonymous, 2015; Starova Jeton, 2016), where the temperature, humidity and light can be controlled are used for hydroponic fodder production. The Indian Institute of Technology, Kharagpur developed a low cost hydroponic system in a room, two walls of which were made up of bricks, while the other two sides (North-South) had double glazed glass windows, which permited sunlight to get through, but prevented a rise in temperature inside the hydroponic system. Bamboos were used for the construction of shelf racks (Shashank Sinsinwar et al., 2012; Kide et al., 2015).

Owing to decreasing available land, the intensive labour and pesticide requirement, together with an inadequate supply of water in the Southern states of India, Tamil Nadu Veterinary and Animal Sciences University developed a hydroponic system at the University Research Farm at Madhavaram Milk Colony. This is a low cost mobile system producing 40 kg hydroponic fodder/day. The system is being sold to dairy farmers at Indian National Rupees (INR) 48000.0 (US $750; Tensingh Gananaraj et al., 2016). The ICAR research complex in Goa and Govind milk and milk products in Satara District in Maharashtra in India assisted in developing on-farm low cost hydroponic systems (Photo 2) and 17 dairy farmers are now producing and feeding hydroponic fodder.

In Malawi, hydroponic fodder has been produced in a simple greenhouse containing wooden frame shelving on which trays containing seeds are stacked (Yvonne Kamanga, 2016). Naik et al. (2013) reported that the rack could be made up of wood, steel or polyvinly chloride (PVC) pipes, but they have also used an existing wall of a building to construct a lean-to-shade net greenhouse, which reduced the cost of construction. It is difficult to control or adjust the humidity and air circulation in low-cost hydroponic production units, especially during the dry hot summer months. In Tanzania, the temperature and humidity inside the hydroponic fodder systems are controlled using only a hydro-net and a hydro-cloth, to ensure good growth and nutritional value of the fodder (Anonymous, 2016). Fresh water is used for irrigation of the hydroponic fodder by using manual or automatic micro-sprinklers or a knapsack sprayer at frequent intervals. In low cost hydroponic systems the internal environment of the greenhouse is more influenced by the outside climatic conditions. Therefore, the types of fodder to be grown hydroponically depend upon the season and climatic condition of the locality/region. The seeds sprout within 24 h and grow up to 20-30 cm in 7-8 days, when they are ready for harvest and feeding. In hi-tech greenhouses, about 8-15 units of electricity are required to produce 600 kg of hydroponic maize fodder daily, which can be reduced significantly in low cost shade net structures (Naik et al., 2013).

Photo 2. Low cost hydroponic fodder production unit in India
(Photo credit: Dr. P.K. Naik, Central Avian Research Institute Regional Centre, Bhubaneswar, India)

Advantages of hydroponic fodder

There are a number of advantages of hydroponic fodder production.

Efficiency: By providing the optimal environment the efficiency of fodder production is increased remarkably. Hydroponic systems minimize water wastage since it is applied directly to the roots and is often recycled and used several times. However, the water should be clean because bacteria and fungi proliferate during recycling during the growth cycle. It is, therefore, suggested to go for infrared filtering of the water before recycling (FAO, 2015). It has been reported that about 1.5-2 liters are needed to produce 1 kg of green fodder hydroponically in comparison with 73, 85, and 160 liters to produce 1 kg of green fodder of barley, alfalfa, and Rhodes grass under field conditions, respectively. Under hydroponic systems this equates to only 2-5% of water used in traditional fodder production (Al-Karaki and Al-Momani. 2011; Naik, 2014; Rachel Jemimah et al., 2015; Yvonne Kamanga, 2016). This is especially important in areas suffering from chronic water shortages or where the infrastructure for irrigation does not exist.

Space: Hydroponic systems require much less space and time than conventional systems, which makes the former ideal for urban dwellers with limited yard space. The plant root systems of hydroponic fodder are much smaller than in a traditionally grown fodder, which means higher numbers of plants per unit of space. It is also easy to start a hydroponic system indoors, wherein number of racks with multiple tiers (vertical farming) are used, minimizing land requirement thereby resulting in land preservation. Crop rotation is not necessary in hydroponics, the same fodder species can be grown throughout the year. Using hydroponics technology, about 600-1000 kg maize fodder can be produced daily in 7-8 days growth cycle, in only 45-50 m2 area compared with one ha required in traditional farming (Naik and Singh, 2013; Rachel Jemimah et al., 2015). Another study revealed that only one square meter space is required to produce fodder for two cows per day and the milk yield was increased by 13% (Yvonne Kamanga, 2016).

Use of pesticides, insecticides and herbicides: Traditional outdoor farming must rely on herbicides, fungicides and/or insecticides for optimum production. Hydroponic fodder is grown in a controlled environment without soil and, therefore, is not susceptible to soil-borne diseases, pests or fungi, there by minimizing use of pesticides, insecticides and herbicides. An outbreak of pests or infections in hydroponically grown fodder can be quickly controlled by spraying the crops with appropriate pesticides or fungicides. Fresh and clean water should be used for irrigation as water-borne plant diseases spread quickly.

Fodder yield: 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. Plants mature faster and more evenly under a hydroponic system than a conventional soil based system . One kg of un-sprouted seed yields 8-10 kg green forage in 7-8 days (Sneath and McIntosh, 2003; Naik et al., 2013; Reddy, 2014; Anonymous, 2015; FAO, 2015; Yvonne Kamanga, 2016). The hydroponics maize fodder yield on fresh basis is 5-6 times higher than that obtained in a traditional farm production, and is more nutritious (Naik et al., 2014).

Fodder quality: The crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF) and Ca content increased, but organic matter (OM) and non-fibrous carbohydrates (NFC) content decreased ($P<0.05$) in the hydroponic green forage compared with the original seed on a DM basis (Abdullah, 2001; Fazaeli et al., 2012; Kide et al., 2015; Mehta and Sharma, 2016). Hydroponic fodder is a rich source of vitamin A, vitamin E, vitamin C, thiamin, riboflavin, niacin, biotin, free folic acid, anti-oxidants like β-carotene (Finney, 1982; Cuddeford, 1989; Naik et al., 2015) and minerals (Bhise et al., 1988; Chung et al., 1989; Fazaeli et al., 2012). Shipard (2005) and Naik et al. (2014) found that hydroponic fodder is also a rich source of bioactive enzymes, with the highest activities in sprouts being generally between germination and 7 days of age (Chavan and Kadam, 1989). The fatty acid concentration showed a significant ($P<0.05$) positive relationship with the growth period. The concentrations of linoleic, linolenic and stearic acids increased ($P<0.05$) linearly with sprouting time (Peer and Leeson, 1985). Besides, helping in the elimination of the anti-nutritional factors such as phytate in the grains, hydroponic fodders are good sources of chlorophyll and contain a grass juice factor that improves the performance of livestock (Naik et al., 2015). The crop is free from antibiotics, hormones, pesticides, or herbicides (Naik, 2014).

The *in sacco* degradability of barley grain (BG) and hydroponic barley sprouts (HB) was comparable (Dung et al., 2005). These findings were confirmed when HB were supplemented to herbage-based or haylage-based diets evaluated by a dual-flow continuous-culture fermentor system. In addition the methane output and bacterial protein synthesis were also comparable with those obtained by using BG supplemented diets (Hafla et al., 2014: Mehta and Sharma, 2016). The availability of metabolizable energy (ME) in hydroponic barley was lower than the original barley grain (Fazaeli et al., 2012).

Impact on animal production: Because hydroponic fodders are highly succulent, their intake varied between 15 to 25, 0.25 to 2.0, 1.5 to 2.0 and 0.1 to 0.2 kg/animal/day in large ruminants, small ruminants, adult pigs and rabbits respectively (Naik et al., 2013; Rachel Jemimah, 2015), or 1.0 to 1.5% of body weight (Starova Jeton, 2016). Saidi and Abo Omar (2015) reported that hydroponic barley fodder (HBF) had no effect on feed intake, body weight change, milk yield, and milk composition; however, HBF had positive effects on ewe's health, mortality, conception rate and abortion. Hydroponic fodders are highly digestible, palatable and relished by the animals. Feeding vitamin-rich hydroponic green barley fodder did not increase bioavailability of nutrients for fattening calves. There was no effect of the fodder on average daily gain (ADG), but feed cost was increased by 24% (Fazaeli et al., 2011). Rachel Jemimah et al. (2015) found no adverse effects on ADG and feed conversion ratio (FCR) in goat kids and rabbit kittens fed hydroponic horse gram or sunn hemp fodder replacing 50% of a concentrate mixture. A 90-day feeding trial on 3-month-old weaned Awassi ram lambs showed that feeding hydroponic barley fodder improved ($P<0.05$) feed intake, ADG and FCR significantly compare to those fed a ration containing barley grains (Mysaa Ata, 2016). Feeding hydroponic fodder to beef cattle resulted in leaner meat containing more omega-3-fatty acids and vitamins (Maxwell Salinger, 2013).

Reddy et al. (1988) observed significant increases in the digestibility of nutrients in lactating cows fed hydroponic fodder compared to those fed Napier bajra (NB-21) green fodder. Feeding of a total mixed ration (TMR) containing either hydroponic maize fodder (HMF) or Napier bajra hybrid green fodder (NBH) for 68 days to lactating dairy cows did not have any significant effect on digestibility of nutrients, except that the digestibility of CF and NFE was higher ($P<0.05$) in the HMF fed group (Naik et al., 2014). The daily milk yield was 8.0-14.0% higher in animals fed TMR containing hydroponic maize or barley fodder than those fed conventional green fodder (Reddy et al., 1988; Naik et al., 2014; Rachel Jemimah et al., 2015; Yvonne Kamanga, 2016). Naik et al. (2017b) further reported that feeding of hydroponic maize fodder by replacing 50% maize grains in the concentrate mixture did not have any adverse effect on nutrient utilization and performance of low yielding lactating cows. Besides increased milk yield, conception rate, herd health and longevity were also improved (Naik et al., 2015). Furthermore, it must follow that improved animal health stemming from higher quality hydroponic fodder will reduce veterinary costs.

Hydroponic fodder heavily infested with *Aspergillus clavatus* should not be fed to dairy/beef cattle. Animals may develop posterior ataxia, knuckling of fetlocks, dragging of hind legs, high stepping in the hind limbs, stiff gait, tremors, progressive paresis, hypersensitivity, recumbency, clonic convulsions, decreased milk yield and possibly death (McKenzie et al., 2004).

Consistency of feed: One of the major obstacles being faced by many beef producers is the variability/ inconsistency of plant species within their pasture, due mainly to seasonal fluctuation. By feeding hydroponic fodder, one is assured of the quality and quantity of fodder that is being consumed. This consistency of feed can lead to better-tasting end products of consistent quality, which is one of the major goals of the beef producers. Similarly consistency in feed can also increase the quality of meat and other products of swine and poultry. Hydroponic fodder production is a way to substantially improve the quality of animal products (Maxwell Salinger, 2013).

Reduced carbon footprints: Hydroponics are more environmentally friendly than traditional agriculture, because fertilizers are rarely used. This reduces greenhouse gas emissions considerably (Anonymous, 2016). In traditional farming, run-off can lead to the degradation of the surrounding environment (Naik, 2014). Hydroponic systems help in reducing the fuel consumption for transportation of product from distant agricultural farms and carbon emissions in turn.

Major disadvantages of hydroponics

Loss in total dry matter: A number of studies reported that sprouting resulted in 7-47% loss in DM from the original seed after sprouting for a period of 6-7 days of growth, mainly due to respiration during the sprouting process (Sneath and McIntosh, 2003; Dung et al., 2005; 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 DM with a shift from starch in the seed to fiber and pectin in the roots and green shoots.

Availability of nutrients: Sneath and McIntosh (2003) showed that sprouted barley fodder was 3.4 times more expensive per kg of DM than the original barley grains. Similarly ME (cents/MJ), CP ($/kg DM) and FCR (feed cost/kg live weight gain) were 3.7, 2.2 and 2.5 times costlier using hydroponic fodders than the original grains, respectively (Sneath and McIntosh, 2003), confirming the earlier report of Appleman (1962) who found that hydroponic oat and barley grass may be 2.1 and 3.8 times costlier than rolled oats and barley in terms of food energy.

Decades of research and farmer experience indicate that the costs associated with hydroponic fodder production are 2 to 5 times those of the original grain (Tranel, 2013).

Economics of hydroponics

Traditional fodder production requires a major investment for the purchase of land, in addition to investment in agricultural machinery, equipment, infrastructure required for pre- and post-harvesting, including handling, transportation and conservation of fodder. It also requires labour, fuel, lubricants, fertilizers, insecticides, pesticides, and weedicides. On the other hand, hydroponic fodder production requires only seed and water as production inputs with modest labour inputs. Hydroponics minimises post-harvest losses, with no fuel required for harvesting and post harvesting processes. Moreover, in hydroponic systems it takes only 7-8 days to develop from seed to fodder while it takes 45-60 days under traditional systems. However, the initial investment required for setting up hi-tech, sophisticated, automated commercial hydroponic fodder production systems, with environmental control, plus operational costs are much higher than traditional soil-based fodder production farming. Such hydroponic systems require much more specialized equipment and technical knowledge than is required in traditional farming. Mold is highly likely and thus prevention or treatment could further involve investment. Therefore, even if there are benefits of feeding hydroponic fodder, the benefits are usually outweighed by the costs (Tranel, 2013; Reddy, 2014).

The feed cost/kg milk was higher when animals were fed maize fodder produced from a hi-tech hydroponic system, mostly due to higher cost of hydroponic fodder production [INR 4.0 to 4.50/kg; 1 US $ = 65 INR] than green fodder produced by traditional farming (INR 1.50/kg; Reddy et al., 1988; Naik et al., 2014). However, farmers of the Satara district of Maharashtra found that the cost of milk production of hydroponic fodder was reduced remarkably to INR 2.0-3.50 per kg (Naik et al., 2013) in a low cost shade net system with home-grown or locally purchased seeds. Accordingly when fodder was produced in low cost hydroponic system, the feed cost/kg milk was reduced remarkably (25 to 30%) and net profitability was improved considerably (Boue et al., 2003; Naik et al., 2013; FAO, 2015; Rachel Jemimah et al., 2015).

Conclusion

In developed countries where there is no dearth of quality feed and fodder, the hydroponic production of fodder is less competitive than traditional fodder production when compared on per kg dry matter basis. High initial investment on fully automated commercial hydroponic systems and high labour and energy costs in maintaining the desired environment in the system adds substantially to the net cost of hydroponic fodder production. Such systems are not successful in developing countries.

Conversely, low cost hydroponic systems have been developed by utilizing locally available infrastructure where there is an acute shortage of fodder and water; local irrigation systems are not well established; transportation and fuel costs are high; and seasonal variations of fodder prices are extreme. Typical lean periods of fodder production are the norm, investment in controlling temperature and humidity are low, and so is the cost of labour. Under such situations the cost structure is often shifted in favour of hydroponic fodder production, and it may find a niche in increasing livestock production.

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