Journal of Natural Sciences Research www.iiste.org
ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online) DOI: 10.7176/JNSR
Vol.9, No.8, 2019

Effects of Hydroponic Fodder Feeding on Milk Yield and Composition of Dairy Cow: Review

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Abstract
The aim of this paper was to review the effects of hydroponic fodder feeding on milk yield and composition of the dairy cow. Hydroponic fodder is an effective solution for fodder scarcity and is very promising for sustainable livestock production in different regions of the world. Hydroponics fodder production involves growing of plants without soil for a short duration (5-10 day). In hydroponic fodder production system, it can be possible to grow 5-10kg of green fodder from 1kg seeds. The nutritional increase in crude protein, fibre, ether extract, vitamins and minerals were constantly observed in hydroponic fodder. However, there was a loss of 10-25% dry matter content depending on grain type and duration. The hydroponics fodder feeding improves milk yield and composition of a dairy cow through increased intake and digestibility of nutrients. However, more information is needed to confirm the benefit of hydroponic fodder feeding as part of ration for dairy cow.
Keywords: hydroponic fodder, nutrient composition, dairy cow, milk yield, milk composition
DOI: 10.7176/JNSR/9-8-01
Publication date: April 30th 2019

Introduction

Green fodder is the natural diet for livestock (Jemimah *et al.,* 2018). For a sustainable dairy farming, quality green fodder should be fed regularly to the dairy animals (Naik *et al.* 2012a). However, due to many reasons, green fodder production has been facing a serious crisis and so the dairy cow productivity (Jemimahe *et al.,* 2018). The major constraints in production of green fodder by dairy farmers are the unavailability of land for fodder cultivation due to small land holding size, more growth time and natural calamities. Further, the non-availability of quality fodders round the year aggravates the constraints of the sustainable dairy farming (Naik *et al.,* 2013a). Due to these constraints, hydroponics technology becomes as an alternative way for growing fodder for farm animals (Sneath and Mclntosh, 2003, Naik *et al,* 2011a, Naik *et al.,* 2012b, Naik *et al.,* 2013b, Naik, 2014). The technology of green fodder production is especially important in the regions where forage production is limited (Abu Omar *et al.,* 2012) due to natural calamities. The green fodder is produced from grains, having a high germination rate and grown for a short period of time in a special chamber that provides the appropriate growing conditions (Sneath and McIntosh, 2003). The adoption of this technique has enabled the production of fresh forage from oats, barley, wheat and other grains (Rodriguez-Muela *et al.,* 2004). Over recent years, severe shortages in feed supplies for livestock have been experienced in many countries due to repeated droughts as well as shortages of water for irrigation (Abu Omar *et al.,* 2012; Al-Karaki, 2011). Therefore, many projects to produce forages have been established during the last two decades to cover some green and dry forage needs in these countries (Al-Karaki, 2011).

Sprouting is a simple technique to germinate the seeds for the improvement of their nutritive value (Amal *et al.,* 2007). It is reported that green fodder produced under hydroponic conditions has high metabolizable energy, crude protein and digestibility (El-Morsy *et al.,* 2013). Nutritional value of sprouted grain improves due to the conversion of complex compounds into simpler and essential form and by minimizing the effect of anti-nutritional factors during germination (Chavan and Kadam, 1989). Sprouting of grains has resulted in not only increased protein quantity but also quality. This is further complemented by increased sugars, certain minerals and vitamin contents. It has also increased the plant enzyme contents (Shipard, 2005). These enzymes convert the complex compounds of protein into albumin and globulin thus, improves the protein quality (Shewry *et al.,* 1995). Activation of amylase and lipase during germination also increases the sugar and essential fatty acid content of grains (MacLeod and White, 1962; Chavan and Kadam, 1989). Indeed, using sprouted barley and maize in growing goat revealed improvement in digestibility of nutrients, body weight gain and feed conversion efficiency. Similarly, the inclusion of hydroponic oats in feeding sheep seems to improve the milk production (Micera, 2009). Therefore, the objective of this paper was to review the effects of hydroponic fodder feeding on performance of dairy cow.

Hydroponic Fodder Production

The word hydroponics has been derived from two Greek words hydro means ‘water’ and ponic means ‘working’. Thus, fodder produced by growing plants in water or nutrient rich solution but without using any soil is known as hydroponics fodder or sprouted grains or sprouted fodder (Dung *et al.,* 2010a). Hydroponics is the state of technology that has revolutionized the green fodder production in the 21st century. Hydroponics is a method of growing green fodder without soil in environmentally controlled houses or machines (Al-Karaki and Al-Hashimi,

ISSN 2224-3186 (Paper) ISSN 2225-0921 (Online) DOI: 10.7176/JNSR
Vol.9, No.8, 2019

2012). Hydroponic fodder is an effective solution for fodder scarcity and is very promising for sustainable livestock production in different regions. It is essentially the germination of a seed and sprouted into a high quality, highly nutritious, disease-free animal food in a hygienic environment free of chemicals like insecticides, herbicides, fungicides and artificial growth promoters (Jensen and Malter, 1995; Al-Hashmi, 2008). This process takes place in a very versatile and intensive hydroponic growing unit where only supplying cereal grain with necessary water, nutrients and sunlight to produce a grass and root combination that is very lush and high in nutrients. This green fodder is extremely high in protein and metabolizable energy, which is highly digestible by most animals (El-Morsy *et al.,* 2013). Hydroponics is a year-round growing system that produces a consistent quantity and quality of plant material or fodder, regardless of outside weather.

In hydroponics fodder production technology, water-soaked seeds are kept on trays and allowed to germinate (sprout) inside controlled environment for a short duration (Taparauskiene, 2015). Green fodder production takes 5 to 10 days (Cuddeford, 1989; Mooney, 2005; Merisco, 2009) with a 0.5m^3 usage of water for production of 1 tons of feed in the area of about 100m^2 (Taparauskiene, 2015). From 1kg seeds, it can be possible to grow 5-10kg of green fodder (Buston *et al.,* 2002; Shtaya, 2004; Al-Karaki, 2011; Islam *et al.,* 2016). In addition to this, recycling of water in hydroponic fodder production system allows solving problems related to water scarcity. At the end of the growing period, the fodder is fed to livestock as a supplement in the same way that hay and silage are currently used (Merisco, 2009).

Nutritive Value of Hydroponic Fodder

The chemical composition of hydroponic fodder grown from various grains was reported by different research in various conditions. There is a general consensus that there is no significant gain in fodder dry matter increase through sprouting grain and producing hydroponic fodder when compared to the starting dry matter of the grain used. Grain usually contains around 85-87% dry matter and hydroponic fodder usually contains 80-85% water (Weldegerima, 2015). Research results show a large diversity in dry matter gain or loss, ranging from 10% loss to 15% gain over 8-10 sprouting cycle (Starova, 2016). Abd Rahim *et al.* (2015) stated that the germination of barley resulted in about 18% loss in DM. Similarly, Shtaya (2004) showed that the germination of wheat for 5 to 7 days resulted in a 17% loss of total DM while a 25% loss in DM of wheat after 12 days of sprouting. Loss of DM is probably due to the use of carbohydrates and energy by seeds for metabolic activities of the growing plant, without adequate replacement by photosynthesis of the young plant. This photosynthesis begins around the fifth day when the chloroplasts are activated (Al-Karaki and Al-Momani, 2011; Adjlane *et al.,* 2016). In Dung *et al.* (2005) study, there was a 21.9% loss of DM over 7 day sprouting period. Seed soaking leads to the activation of enzymes, solubilisation and digestion of starch stored in the endosperm to simple sugars. This provides a substrate for the young developing plant for metabolic activities. These substrates are respired to produce energy, giving off carbon dioxide and water. This loss of carbon dioxide leads to a loss in dry matter (Emam, 2016).

Table 1. Summary of hydroponics barley chemical composition

	Chemical Composition (% DM)				
Variable	**DM**	**MM**	**OM**	**TNC**	**CF**
Dry seeds	88.9 ±0.1	4.02±0.4	95.98±0.4	11.3±2	7.66±0.7
Soaked seeds	62.0±0.1	4.2±0.1	95.8±0.1	9.2±0.3	16.7±0.9
4 days	22.3±1.6	2.6±0.2	97.4±0.2	11.1±0.1	9.3±1.2
6 days	17.8±2	2.9±0.3	97.1±0.3	11.6±0.6	10.9±0.4
8 days	16.91±2	3 5±0.1	95±0.1	15.6±0.1	19.2±0.9
Leaves	8.1±0.14	5±0.0	95±0.0	27.1±0.7	21.40±0.4
Roots	8.1±0.6	4.1±0.2	95.9±0.2	12.9±1.6	24.3±0.5

DM: dry matter; MM: mineral matter; OM: organic matter; TNC: total nitrogen content. CF: crude fiber; fodder units. (Source: Adjlane *et al.,* 2016)

However, the nutritional quality gains are constantly noted in hydroponic fodder. This is especially in crude and digestible protein, the gains of which range from 2-4%. The same is valid in various extents for some vitamins and micro-nutrients. Protein, which is not used for growth, increases in sprouted grain. This increase in protein was due to a decrease in dry weight through respiration during germination (Sale, 2015). The absorption of nitrates facilitates the metabolism of nitrogenous compounds from carbohydrate reserves, thus increasing crude protein levels. Fiber content increased from 3.5% in cereal barley grains to 6.5% and 8% in a 5 and 8 day green barley fodder, respectively (Abd Rahim *et al.*, 2015). Chung *et al.* (1989) found that the fiber content was increased from 3.75% in barley grain to 6% in 5-day sprouts. In Dung *et al.* (2005) study, there were an increase in crude protein and some mineral concentrations (except B, Mn and K) in sprouts in comparison to the grain.

Table 2. Comparison of hydroponically produced wheat forage to wheat pasture

Nutrient	**Hydroponics green fodder**	**Conventional green fodder**
DM	22	21
Crude protein (g/kg)	288	200
Crude fat (g/kg)	93	40
Crude fiber (g/kg)	65	180
Total digestible energy (MJ/Kg)	187	187
Macro-elements (g/kg)		
Phosphorus	9	3.6
Potassium	3500	31
Calcium	2.9	3.5
Sodium	3.2	-
Chloride	1900	6.7

Source: Ghaly *et al.,* 2007

Thadchanamoorthy *et al.* (2012) studied hydroponic maize fodder as a source of feed for six New Zealand White rabbits (4 to 5 weeks old). At 10th day after planting moisture, ash, CP, EE, CF, NDF and ADF% in sprouted maize were higher (73.93, 3.09, 16.54, 6.42, 8.21, 29.27 and 10.16 % respectively) than the levels found in grain (10.26, 1.48, 8.21, 4.69, 2.11, 19.22 and 5.5% respectively). Lorenz (1980) stated that the sprouting of grain caused increased enzyme activity, a loss of total DM, an increase in total protein, a change in amino acid composition, a decrease in starch, increases in sugars, a slight increase in crude fat and crude fiber, and slightly higher amounts of certain vitamins and minerals. Most of the increases in nutrients are not true increases; they simply reflect the loss of DM, mainly in the form of carbohydrates, due to respiration during sprouting. As total carbohydrates decreases, the percentages of other nutrients are increases (Dung *et al.*, 2005; Helal, 2015).

Table 3. Nutrient changes in barley sprouted over a 13-day period

		Harvest days			
Parameters	Original seed	4	7	10	13
DM	90.40	202.32^{a}	136.14^{b}	103.04^{c}	102.28^{c}
CP	12.7	177.19	171.05	182.50	175.93
NDF	13	470.10	510.17	525.35	540.53
ADF	6.0	166.53^{c}	214.61^{b}	236.34^{ab}	261.47^{a}
ADL	-	30.73	39.24	59.49	51.48
Ash	2.2	43.89^{c}	49.78^{b}	53.90^{ab}	57.57^{a}

Source: AKbağ *et al.*, 2014

In Al-saadi (2016) study, the crude protein, ash, ether extract, non-protein nitrogen, true protein and neutral detergent fiber were significantly higher in green fodder comparative to grain. According to Resh (2001), sprouting of grains affected the enzyme activity, increased total protein and changes in amino acid profile, increased sugars, crude fiber, certain vitamins and minerals, but decreased starch and loss of total dry matter. The enzymes also cause the inter-conversions of these simple components leading to an increase in quality of amino acids as well as the increase in concentrations of vitamins (Plaza *et al.,* 2003).

Table 4. Proximate composition of sprouted sorghum and grain at 7 days

Constituent (DM basis)	Sorghum Grains	Sorghum sprouts
Dry matter	95.08^{a}	24.61^{b}
Crude protein %	4.1^{b}	4.92^{a}
Ether extract	1.45^{b}	2.15^{a}
Ash %	1.08^{b}	1.12^{a}
Crude Fiber%	1.06^{b}	2.16^{a}

Source: Sale, 2015

Effect on Intake

Determination of dry matter intake is very important in feed evaluation, not only to prevent the deficiency or excess intake of nutrients but also can assist the use of nutrient efficiently (NRC, 2001). There are some arguments about the use of the sprouting grains for the convenience of green forage production in hydroponics system to be as part of feed in livestock feeding systems (Shtaya, 2004; Prasad, *et al.,* 1998; Tudor *et al.,* 2003). Sole feeding of green fodder did not support the expected production traits in the animals whereas feeding in conjunction with dry fodder improved its utilization (Prasad *et al.,* 1998). Abd Rahim *et al.* (2015) noted that the dry matter intake of green fodder by feedlot cattle and dairy cattle were low due to its high moisture content. The total consumption of both as fed and dry matter was higher in dairy cows receiving 7% maize hydroponic fodder as supplementation compared with control treatment (Nugroho *et al.,* 2015). This could be caused by a good palatability of maize hydroponic fodder, so it could stimulate the increased consumption of other types of feed (Singh; Chaudry, 2007). However, there was a report which indicates a decrease in the DM intake of the animals when hydroponics fodder is fed (Heins and Paulson, 2016). Similarly, Naik *et al.* (2014) were reported lower dry mater intake on supplementation of hydroponic fodder for dairy cow. Lower DM intake associated with the feeding of hydroponics green fodder may be due to the high water content of the hydroponics green fodder that might have made it bulky leading to limited DM intake by the animals (Fazaeli *et al.* 2011).

Table 5. Least squares means for economics by fodder group for organic dairy cows

Measurement	No Fodder	Fodder
Dry matter intake (kg/cow)	17.5[a]	14.5[b]
DMI/milk	1.35	1.27

(Source: Heins and Paulson, 2016)

Effect on Digestibility

Nutrient digestibility increased by using sprouted grains in the ruminant diet. Fayed (2011) determined that the addition of sprouted barley with rice straw and Tamarix Mannifera increased DM, OM, CP, EE, CF, NDF and ADF digestibility. This may be due to the presence of bioactive catalysts which increases digestion and absorption of nutrients and the release of energy. Similarly, Ibrahim *et al.* (2001) reported that addition of sprouted grains increases nutrient digestibility. Sharif *et al.* (2013) observed increased digestibility by using sprouted grain in the diet of broilers and large animals. This was achieved possibly by changes in rate and extent of digestion and absorption. During germination, enzymes are produced which reduces the viscosity of the digesta and improves the digestion and absorption of nutrients (Annison, 1993). This is also due to the presence of grass juice factor (Finney, 1982; Elvehjen *et al.,* 1934) which may be a good source of nutrients for rumen micro-organisms.

Table 6. Dry matter and nutrient digestibility on dairy cows

	Treatment	
Digestibility (%)	NMHF	MHF
Dry matter	76.0±8.99	77.0±4.24
Organic matter	78.0±8.49	78.5±3.99
Crude protein	83.0±6.27	82.6±3.35
Ether extract	91.5±3.86	90.9±1.68
Nitrogen free extract	76.0±9.01	76.9±4.14
Total digestible nutrient	71.8±7.52	72.7±3.54

*NMHF=no maize hydroponic fodder, MHF=maize hydroponic fodder (*Source: Nugroho *et al.,* 2015)

Moghaddam *et al.* (2009) conducted an experiment to determine the effect of sprouted grains on nutrient digestibility. They replaced barley with sprouted barley at the level of 0, 33, 66 and 100%. They concluded that nutrient digestibility was increased by increasing the level of sprouted barley. They reported that 100% replacement resulted in better nutrient digestibility as compared to other levels. Similarly, Helal (2015) reported that digestibility coefficients of all nutrients were significantly higher in sprouted barley supplemented sheep. In general, feeding of hydroponics fodder increased the digestibility of the nutrients of the ration which could be attributed to the tenderness of the fodder (Reddy *et al.,* 1988). In the Naik *et al.* (2014) study, there was increased ($P<0.05$) in the digestibility of CP and CF of the cows due to a feeding of hydroponics maize fodder. However, the increase ($P>0.05$) in the digestibility of DM, OM, EE and NFE was non-significant. These result revealed that feeding hydroponic fodder improves the digestibility of most nutrients.

Effects on Milk Yield and composition

Hydroponic fodder can help to improve the quality and quantity of milk production. Research results indicated that milk yield was improved. There were 3.9% increase in the milk yield due to feeding of hydroponics barley fodder (Heins and Paulson, 2016) and 13.7% increase in the milk yield due to feeding of hydroponics maize fodder (Naik *et al.,* 2014), which may be due to the higher DCP and TDN content of the ration (Moghaddam *et al.,* 2009; Naik *et al.,* 2014, Helal 2015). Likewise, Grigorev *et al.* (1986) showed that replacing 50% of the maize silage with 18kg of hydroponic barley grass increased cows' milk yields by 8.7%, while milk fat was depressed. This improvement may be due to increase in nutrient quality of hydroponic fodder through sprouting. Early research on hydroponic sprout reported the presence of a grass juice factor that improved livestock performance (Finney, 1982; Elvehjen *et al.,* 1934). More recent research has also indicated that hydroponic sprouts are a rich source of nutrient and they contain the grass juice factors that improve the performance of livestock (Nutrigrass, 2007). Adjlane *et al.* (2016) study on dairy cows supplemented with hydroponic barley (10kg) indicated that milk yield was increased significantly (16.14 vs. 13.49 litre/day). Abd Rahim *et al.* (2015) were also observed a slight improvement in milk protein, milk fat and total solids in dairy goat but were not significant in sheep supplemented with barley green fodder.

Table 7. Summary table of the main results obtained in 2 lots of cows

	Lots	Control group	Experimental group
Milk production (l)	Before test	14.65±0.70	15.38±0.19
	During test	13.49±1.71	16.14±1.48
	TDE (%)	11.32±0.52	11.23±0.82
	SNF (%)	6.98±0.16	6.90±0.15
	Water (%)	88.68±0.52	86.86±4.29
	Fat content (%)	4.31±0.42	4 ±0.30
	Protein content (%)	2.66±0.05	2.62±0.07

TDE=total digestible energy; SNF=solid not fat (Source: Adjlane *et al.,* 2016)

A test completed on milk production with a diet of fodder versus one of the normal feeds such as grain, hay or silage showed a vast improvement in milk production and butterfat content. A group of 60 cows on a fodder diet increased their milk production by 10.07%. In addition, the fodder fed group also produced a butterfat content of 14.26% higher as compared to those fed on a regular diet (Ryan, 2003). In another study from Canadian, there was an increase in 3.6kg per day milk production per cow over the lactation period. Furthermore, from South Africa, milking cows dropped 3.6 litres of milk per milking after leaving off the green fodder, which was fed at the rate of 6.8kg per day (Mooney, 2002). Naik *et al.* (2013) result also revealed that milk yield was increased by 0.5-2.5 litres/animal/day due to the feeding of hydroponic fodder to dairy animals. In Šidagis *et al.* (2014) study, they were concluded that malt sprouts were increased the whole milk yield and milk fat content, but had no significant influence on milk protein content. Naik *et al.* (2014) were reported 13.7% increase in the milk yield due to hydroponic maize feeding. These improvements might be due to a stimulated appetite of the cow as a result of the daily feeding of fresh green fodder (Ryan, 2003).

Table 8. Least squares means for production, SCS, MUN, body weight, and body condition score by fodder group for organic dairy cows

Measurement	No Fodder	Fodder
Milk (kg/d)	13.3	12.3
Fat (kg/d)	0.48	0.44
Fat (%)	3.75	3.68
Protein (kg/d)	0.39[a]	0.35[b]
Protein (%)	2.99	3.04
Milk urea nitrogen (mg/dl)	13.45[a]	16.45[b]
Body weight (kg)	505.2	502.7
Body condition score	3.17	3.17

(Source: Heins and Paulson, 2016)

However, Williams (1956) observed no change in milk production or fat percentage. In another study, Tinley and Bryant (1938) found that the difference in milk yield between the sprout-fed and control groups was not significant. Likewise, Chinnam (2015) in lactating buffalo reported no significant effect on milk production upon feeding hydroponic maize fodder. The conclusion of 8 tests by Bartlett *et al.* (1938) showed that feeding sprouted maize had no advantage in either milk yield or quality. Marisco *et al.* (2009) were also found no change in goat milk yield between those fed on hydroponic sprouts and those fed on traditional diets. Sheep milk yield, milk protein, milk fat and total solids were also not affected by feeding hydroponic barley.

Conclusion

Dairy cattle require green fodder for high milk yield. However, it cannot available throughout the year and in some area, it is difficult to have access for green fodder. Thus, hydroponic fodder production has become an alternative way to fulfill this green fodder requirement of the dairy cow. The adoption of this technique has enabled the production of fresh forage from grains without soil. Hydroponic fodder has high nutritive value due to the conversion of complex compounds into simpler and essential form, and activation of enzymes during germination. Thus, it contains high protein, vitamins and minerals which are essential for dairy cows. There were improvements in digestibility and intake of nutrients results in increased milk yields and quality like milk fat of dairy cow on the feeding of hydroponic fodder. In general, research data on dairy cows is limited to determine definitively whether or not feeding the fodder changes production enough to warrant the additional cost. Therefore, this area requires further information to draw a concrete conclusion about feeding hydroponic fodder.

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