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Application, Socio-economic Feasibility of Hydroponic Fodders and Nutrient Utilization in the Nigerian Livestock Industry: *A Review*

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Abstract

Hydroponic fodders produced from readily available grains are highly nutritious, and contain more nutrients than most conventional fodders, dry feeds, or grains, especially in their carbohydrate, protein, mineral, and vitamin contents. Sorghum and millet hydroponic fodders may however contain significant levels of antinutrients such as cyanide, phytin and tannins which may be harmful to livestock. Varying levels of hydroponic fodders have been used to replace concentrates in the diets of ruminants, monogastrics, and rabbits with promising improvements in growth performance, feed efficiency and cost of production. Hydroponics fodder production practice has been applied to urban and peri-urban livestock farming constrained by limited rangelands for forage production, and labour costs. There is also research evidence of potentials for hydroponic fodder system to reduce land and water usage and greenhouse (GHG) emissions from fodder production, thus, providing better carbon sequestration opportunities than the conventional farming approach, and therefore contributing to climate change mitigation objectives. Sustainable forage production technologies such as the hydroponic fodder system could minimize the adverse impacts of climate change and conflicts in vulnerable livestock producing zones. Specifically, livestock production in drought prone zones of Nigeria could be sustained through the use of the fresh green fodders produced from the hydroponic units in addition to the improvements in their livestock performance. The socioeconomic feasibility of the hydroponic fodder production system across the different animal production realities at the various locations such as seasonal availability of feedstuff, abundance of year round natural fodder, traditional practices, disease prevalence and local policy constraints will however be considered before the introduction of the technology .Training and supply of capital inputs on hydroponic fodder production could be applied by appropriate government agencies as livelihood empowerment programme for low-income farmers, unemployed youths and women at different locations in the country. There is however the need to explore the feasibility of commercial hydroponic fodder production among pastoralists, and urban farmers and at the traditional and non-traditional livestock production locations in Nigeria.

Keywords: Hydroponic fodder, forage, feedstuff, livestock farming

Running title: Hydroponic fodders utilization in the Nigerian livestock industry

Introduction of Problem

A major contributor to poor feed supply to livestock in Nigeria is the shrinkage of the grazing lands that produce the needed forage for livestock feeding (1). (2) estimates show that Nigeria has 70.80 million hectares of agricultural land, 37 million hectares of which are arable lands currently being contested by pastoralists, resulting in the frequent conflicts with crop farmers (3, 4,5). In addition to these agro-ecological challenges, livestock production in Nigeria has encountered other institutional bottle necks which are combining to replace pastoral grazing lands with other allegedly more beneficial uses (6, 1). There is also a gradual buildup of consensus by stakeholders on the need to reduce the land area allocated to livestock production, through the development of production systems that utilizes only marginal lands for livestock production (7, 8,9). Some level of sedentary system such as ranching that relies on improved feeding, and modern animal health care services has also been advocated as a possible solution to this problem (10, 1, 11). Local innovative technologies, and approaches needed to produce quality fodder for the livestock at such sedentary locations have however received limited research attention in the country (12). The production of livestock feeds without the use of land or landless green fodder production has recently received a lot of attention in some European, American and Asian countries (13). Such feed production concepts are urgently needed in developing countries like Nigeria in other to sustain the growth, and development of the already constrained livestock industry. They could also aid the mitigation of the incessant conflicts that have plagued the industry in recent years (3, 5).

Sprouting of seeds to produce livestock fodder is increasingly becoming one of the viable methods of producing high quality feedstuff for livestock production (14). Sprouts are products obtained from germination of seeds, through their development in water or other media before processing into feed. Sprouting is defined as the natural process by which seeds or spores germinate, and put out roots, and shoots, so that the established plants produce new leaves or buds or the other new developing parts experience further growth (14). According to (15), the interest on sprouting seeds for fodder production has focused principally on low-cost processing at the backyard farm level to produce additive free fodder having peculiar characteristics such as unique color, rich flavor, and high content of bio-active substances. Moreso, sprouting is a simple and inexpensive process which could be achieved without sophisticated equipment. It has a quick production cycle of 2 to 3 weeks at most, and occupies limited space in the green house (16, 17), and provides comparatively higher yields of quality feedstuff than the traditional forage production methods (18). Fodder production from sprouted seeds therefore has both potential economic, and ecological values for the global and national livestock industries (19, 20).

The fodder produced by growing plants without soil is known as hydroponic fodder or sprouted fodder (21). It is a method of producing year-round green fodder without soil, in water or nutrient rich solutions in houses or machines within a short period (22, 23). In advanced countries, hydroponic fodders are usually produced in green houses, which are framed or inflated structures covered with transparent materials that provide the ease for environmental control (24). Though this method has made a great impact on fodder production in these countries, the requirements for air conditioning in such high-tech systems to maintain cold, and dry environments (23) could be very expensive and may therefore not be adaptable to the smallholder nature of the Nigerian industry (20, 25, 26). There is no doubt however that sprouting of cereal grains such a sorghum, millet, barley, wheat and maize among others in hydroponic units to produce fodder would engender improved forage supply and livestock production in the country (27, 28).

Sprouted grains and their fodder have been shown to contain higher quantity and quality of proteins, sugars, minerals and vitamins (20), although the starch and dry matter (DM) levels are lower (27, 29). **S**prouting has also been reported to alter the amino acid profile of the seeds in addition to increasing the crude protein content of hydroponic fodder (30). Again, both the roots and shoots of hydroponic fodders are usually consumed by the animals, thereby resulting in limited loss of the fodder during feeding when compared with the conventional grasses. The green hydroponic fodder can also replace the expensive concentrate component of the diet, thereby reducing the cost of feeding. The hydroponic fodder production system has been applied to monogastric, (31,32) ruminant (33, 34, 35), and urban animal production (36*, 37*). The technology has also been applied as a viable solution the current climate change challenges (38, 39) and the conflicts between herders and crop farmers in some parts of Nigeria (40, 41). The socioeconomic benefits of the hydroponic fodder production system, and the feasibility of its application may however vary across the different animal production realities of different regions, in terms of local food policies and cost of the available grains. There is therefore the need for the continued assessment of the sociocultural and economic realities of applying the technology at any given location, especially in the poor communities where there may be some moral resistance to the shifting of human food resources to the feeding of animal (23) .

This paper reviews the available literature on the nutritional values of hydroponic fodders, their applications in various animal production systems and the socioeconomic implications of their adoption in animal feeding across the different animal production realities in Nigeria.

Nutrient Composition of Hydroponic Fodders

Hydroponic fodders has been reported to contain more nutrients than conventional fodders, dry feeds, or grains, especially in carbohydrate, minerals, and vitamins contents (42). (43) compared the nutritional compositions of commercial maize fodder harvested at 60 days and hydroponic maize fodder grown for 8 days, and reported higher crude protein, ether extract, nitrogen free extract (NFE), macro-nutrients and trace elements in the hydroponic fodder. The nutrient composition of cereal grains indeed changes after sprouting. For example, (44) showed that sprouting of wheat for 5 to 7 days results in a 17.0% decrease in total dry matter (DM), and a 25.0% decrease after 12 days of sprouting. A major drawback to hydroponic fodder quality is therefore the significant loss in DM which (45) and (46) in their early studies reported to range from 9.4 - 18% after sprouting the cereals for 5 to 7 days. More recent studies have however reported loss of 75% or more of the DM content of a seed during the hydroponic fodder production period (47, 48). This loss is usually influenced by the grain type and duration of growth (49, 13). (48) reported a remarkable decrease in the DM content of hydroponic wheat fodder with the advancement of growing days , with the value being less than 12.5% of the 90 .0% DM in the initial wheat grain by day 8 of sprouting . In a recent study at our station, (27) reported that the DM contents decreased progressively from 89.72, 89.96 and 91.92% in the white sorghum, red sorghum, and millet seeds to 19.49, 19.90 and 13.75% respectively on the 8th day sprouting. This decrease in DM has been attributed to the decrease in the starch content of the hydroponics fodder (50). During sprouting, starch is catabolized to produce the soluble sugars needed to augment the energy needs of the growing plants for respiration, and cell wall synthesis, such that any decrease in the starch content causes a corresponding decrease in DM (20).

(45), and (51) reported that the protein in green barley hydroponic fodder is similar to that of the grain, while the crude protein is higher in the green fodder because of the relative decrease in the other proximate components. The authors also reported that the crude protein content of sprouts increased from day 4, corresponding to the extension of the root system, and absorption of nitrates to facilitate the metabolism of nitrogenous compounds from the carbohydrate reserves, thus increasing the crude protein levels. A more recent study by (52) reported increasing crude protein and fiber values in maize hydroponic fodder from 12.36 and 5.56 % respectively on the 8th day of harvesting to 18.43 and 10.90% respectively on the 20th day of harvesting. (21) however, observed that the use of nutrient solution during the process enhances the crude protein content of hydroponics fodder, usually due to the uptake of nitrogenous compounds from the solution. Sprouting has also been reported to alter the amino acid profile of maize seeds and increase the crude protein content of maize hydroponic fodder (30).

The fatty acid concentration in hydroponic fodders has also been shown to exhibit a significant positive relationship with the growth period. For example, the concentration of linoleic, linolenic and stearic acids was reported by (45) to increase linearly with sprouting time. The average ether extract composition value of maize hydroponics fodder produced in Nigeria was reported to be 3.55%, (31), and is similar to the value range of 3.27 - 3.49% reported by (54) and (20) in India. According to (55), hydroponic fodder has simpler forms of vitamin, starch, protein and lipids than their originating grains, and usually translates to positive effects on the performance of the animals when incorporated into their diets. Hydroponic fodder is particularly a good source of vitamins A, E, C, thiamine, riboflavin, folic acid and biotin, in addition to minerals , antioxidant, β-carotene, and chlorophyll (46, 18, 56). The fiber content of hydroponic fodder was reported by (46) to also increase from 3.5% in barley grains to 6.5 and 8.0% in the 5th and 8th day green barley fodder, respectively. The crude fiber value range of 7.35 - 21.20% has been reported by (20). A Nigerian study by (57) reported much lower values and increase (2.30 - 2.65%) in the fiber content of finger millet sprouted for 4 days, while (31) reported 14.77% crude fiber content in a 7th day maize hydroponic fodder. The increase in the crude fiber content of maize hydroponics fodder was attributed by (58) to the build-up of cellulose, hemicellulose and lignin in the forage. During the sprouting process, the total ash content increases due to the absorption of minerals by the root system (43). (52) however reported that the ash content of maize hydroponic fodder remained relatively stable at 2.02 - 2.60% from the 12th to the 20th day of growth. Indian studies have reported the value of total ash in maize hydroponic fodder to range from 1.75 - 3.80% (59) in agreement with the 3.33% reported by (31) in Nigeria.

The neutral detergent fiber (NDF) and acid detergent fiber (ADF) compositions of the seed usually increase in hydroponic fodder (60, 18). Maize grain was reported by (51) to contain 19.2% NDF, and 5.5% ADF, which increased to 29.3, and 10.3% respectively by the 10th day hydroponic fodder production. The NDF and ADF contents of hydroponically grown sorghum varieties were also reported to be higher than the NDF and ADF content of the non-sprouted grain across varieties (62). (34) studied the 8th day chemical compositions of the hydroponic fodder produced from four Nigerian sorghum cultivars and reported an NDF range of 37.14 - 44.69%, ADF (20.83 - 31.32%), and hemicellulose (13.37 - 16.31%). (21) explained that the fibre content of hydroponic fodder is mostly derived from the root and seed husk during the maturation process and endosperm formation, resulting in the increasing values of the ADF and NDF in the fodder as the organic matter content decreases. (63) however, reported that feedstuff containing NDF values of less than 45.0% are classified as high quality, while those having the value range of 45.0 to 65.0% are classified as medium and those higher than 65.0% are of low quality.

Generally, the crude protein, NDF, ADF and Ca contents increase in sprouted grains, while the organic matter (OM) and non-fibrous carbohydrate (NFC) contents decrease. Sprouted grains are also rich sources of bio-active enzymes, with the highest activities in the sprouts being between the germination and 7th day of growth (64). These protease activities break down the complex proteins in the grain into albumin, globulin, and amino acids, resulting in better protein quality, while the amylase and lipase activities increase the sugar and fatty acid contents of the fodders respectively (64, 65).

Antinutrient Contents of Hydroponic Fodders

In addition to being a good source of essential nutrients, hydroponic fodder contains lower levels of anti-nutritional factors such as phytin, cyanide and tannin when compared with the grains. Hydroponic fodders are also good sources of chlorophyll and grass juice factor that improves the performance of livestock (20). (56) reported a considerable variation in leaf chlorophyll index of different seeds used in hydroponic fodder production, with the 5 - 8th day seedling values being significantly higher than those of seedlings from the earlier days. Abiotic stressors such as reduction in water availability, salt, heavy metals, pollution, and heat have also been shown to cause changes in the mobilization of stored reserves, alter hormonal balance and structural organization of proteins in the seed, and potentially affect the seed germination and seedlings development (66). These stressors may influence the physicochemical reactions associated with seed germination and thus, synthesize primary and secondary metabolites in the fodder, which on consumption may exert varied biological effects on the growth and health of animals. Water stress has particularly been shown to cause oxidative stress in germinating seeds leading to increased concentrations of phenols and flavonoids in the young leaves (67). It has also been shown to influence the ratio of chlorophyll a and b, and carotenoids in barley leaves (68). (57) equally report some increases in the flavonoid and antioxidant contents and decreases in the phytate, trypsin inhibitor and tannin contents of germinated millet seeds. The Nigerian millet (*Pennisetum americanum*) seeds contain 1.38 - 1.43 mg/kg of potential ionic cyanide. (69) reported 0.05 mg/100g cyanide concentration in fonio (*Digitaria exilis*) seeds, while the 0.18 mg/kg tannin concentration was considered low.

Sorghum grains particularly contain varying amounts of tannin and cyanogenic glycosides, depending on the variety, growth stage, and environmental conditions (70, 71). For example, some common sorghum varieties in Australia have been shown to record relatively high cyanide concentrations of between 400 and 900 mg/kg, while (72) reported a cyanide concentration range of 265.00 - 315.00 mg/kg in sorghum from Nigeria. Dhurrin, and amygdalin are the major cyanogenic glycosides produced in the immature sorghum leaves during sprouting, with the levels decreasing with plant age (71). (73) however, reported that the cyanide content of hydroponic sorghum fodder specifically increased with nutrient solution irrigation and the harvest age. This has been attributed to the rate of enzymatic activity during germination which results in the conversion of the cyanogenic glycoside to hydrogen cyanide. Upon consumption by ruminants, cyanogenic glucosides are converted to prussic acid (hydrocyanic acid 'HCN') in the rumen and may cause fatal poisoning. Prussic acid impacts sorghum by inducing sulphur deficiency, which increases when the forage has a high prussic acid level, mostly because sulphur is used to detoxify HCN in animals. Animals are able to breakdown the prussic acid when there is enough sulphur reserve in their body tissues.

Sulphur deficiency will however enhance the potency of the prussic acid, resulting in anorexia which in turn leads to a decline in average daily weight gain (74, 75, 76). (77) observed that the safe limit for hydrogen cyanide in green forage fed to livestock is 500 ppm on a dry basis, and that higher levels in sorghum fodder will be toxic to animal health. (78) reported that sprouted sorghum from four Nigerian sorghum varieties recorded 4000 - 7000% cyanide after 2 - 6 days of sprouting, thus highlighting the need to exercise caution in the use of Nigerian sorghum cultivars for hydroponic fodder production.

Digestibility and Feeding Value of Hydroponic Fodders for Ruminants

Fresh fodders produced from h**ydroponic units have been reported to be generally rich in highly digestible nutrients (79).** They are also rich in enzymes and digestible fibers, chlorophyll and grass juice factors, but low in antinutrients such as phytin and therefore could be used to improve animal productivity (65, 22). The presence of the juice factor **,** and simple nutrients in the hydroponic fodder helps to stimulate the appetite, while the stable pH of the fodder is favorable to the rumen microorganism in ruminants, thus making for better digestion (23) .The improvements reported in the digestibility of dietary nutrients has been attributed to the tenderness of the fodder, which helps to eliminate variability and inconsistency in quality associated with plants species and their effects on the productivity of ruminants (80, 20). (81) also attributed the higher digestibility to the presence of bio-active substances in the hydroponic fodder that stimulate the digestion and absorption of the nutrients. The voluntary intake of hydroponics fodder by different livestock species is also usually high because of its tasty nature, since the animals consume the seeds alongside the roots and the shoots, thus ensuring that no nutrient is wasted (59, 82, 79).

In a study by (53), barley sprouts were supplemented to herbage-based or haylage-based diets and evaluated by a dual-flow continuous-culture fermentation system. The *in sacco* degradability of barley grain and the barley hydroponic sprouts were reported to be comparable, while the methane output and bacterial protein synthesis were found to be comparable with results obtained by (83), with barley grain supplemented diets. The available metabolizable energy in barley hydroponic fodder has also been reported by (18) to be lower than that in the original barley grain. (33) also reported significant differences in the digestibility of crude protein and ether extract among cross-bred calves fed diets supplemented with 50.0 and 75.0% maize hydroponic fodder, and non-supplemented ones. The digestibility of DM, crude fiber, NFE, ADF and NDF were however similar. (84) reported that feeding Beetal goats with barley and hydroponic corn fodders in the semi-arid Sargodha, Pakistan, resulted in improvements in digestibility and performance. Specifically, the goats fed the hydroponic fodder-based diets exhibited highly significant improvements in nutrient digestibility and total nitrogen balance compared to the control. The supplementation of the diets of Tellicherry buck kids with maize hydroponic fodder was also found to improve the dry matter, organic matter, crude fiber, ether extract and nitrogen free extract digestibility in the kids (85). Cross bred calves were fed maize hydroponic fodder as 50.0 and 75.0% replacement of conventional calve stater diet (20.0% crude protein and 70.0% total digestible nutrient) for 90 days, without any adverse effects on body weight gain and dry matter intake (33). These reports suggest that hydroponic fodder inclusion in diets at the appropriate levels enhances nutrient digestibility in different livestock.

Increase in body weight of ruminants usually indicates improvements in ruminal microbial activity , and nutrient digestibility. For example, beef cattle fed maize hydroponic fodder have been reported to record an average daily increase of 200 g in body weight . (35) reported that Balami rams fed sorghum hydroponic fodder of the Jigari variety recorded the highest DM intake, and live weight gain and consequently the lowest feed conversion ratio over those fed fodder produced from the the red chakalari, white chakalari, and kaura varieties, although all the varieties sustained the growth of the rams. The supplementation of the diets of Tellicherry buck kids with hydroponic maize fodder at 25.0 and 50.0% replacement of concentrate was also reported by (85) to have attained puberty earlier, had higher scrotal circumference, testicular volume, and fresh semen characteristics. They also exhibited more intense sexual behaviors than the control kids, indicating significant enhancement of their overall reproductive performance. Several reports also exist on the effects of hydroponics fodder on milk yield and quality. (86) reported that when 10 kg of barley hydroponic is given to cross bred Holstein cows as replaced for corresponding weight of oat hay, the milk yield increased by 4.7% compared to the control groups. (59) reported a 13.7% increase in milk production when traditional Napier hybrid grass was replaced with maize hydroponic fodder . Other Studies have also compared the milk yields from animals fed cereal grains, hay or silage with those fed hydroponic fodder and reported better yields from the latter. Feedback from farmers in south Africa, India and Canada have also highlighted similar improvements in milk yield due to feeding hydroponics fodder to dairy animals (87, 88). The increased milk yield has been attributed to the high content of quality protein and bio-active enzymes in the hydroponic fodders (89, 90).

Application of Hydroponic Fodder to Monogastric Animal Production

Monogastric animals such as pigs and poultry require the expensive cereal grains and legumes in their diets, which also serve as important human food in most tropical developing countries. As the population of farmed monogastric animals and their cereal feed needs increase in response to the increasing demand for animal products in these countries, the need to reduce the dependency on these grains by incorporating alternative feedstuff arise (91, 92). Hydroponic fodders could be used to reduce the cost of feeding monogastric animals and rabbits which naturally have low digestibility capacity for cellulose and lignin, and hence require the inclusion of feed materials containing high quality energy, protein, fat, minerals and vitamins in their diets (82, 79**).** Few studies have however reported the potential value of hydroponic fodder utilization in monogastric animal feeding, probably because their GITs are not adapted to efficient forage digestion.

Pig production: (31) in their study hydroponic fodder utilization by pigs in the warm humid environment of southwest Nigerian reported that 50.0% replacement of growing pig concentrate ration with maize hydroponic fodder improved their growth performance. Specifically, there were improvements in crude protein, fiber, ether extract digestibility, and consequently feed conversion ratio. Feeding the maize hydroponics fodder to the pigs also resulted in a decrease in the total daily feeding costs of the experimental rations, compared to control concentrate diet. Sole feeding of the maize hydroponic fodder however reduced their growth performance. (36) also reported that up to 20.0% replacement of the concentrate diet of weaner piglets with 10^{th} days maize hydroponic fodder for six weeks resulted in improved growth, nutrient digestibility, and cost of production, although 10.0% replacement was regarded as optimal. Younger sprouts of less than 10 days old have however, been shown to be richer in soluble proteins and amino acids (46), and may therefore yield better performance results when fed to weaner piglets. (79) evaluated the effect of wheat hydroponic fodder as a supplement on the growth performance of piglets during a 12-week feeding trial. They reported 0.27, 0.08 and 0.06 feed efficiency in the piglets fed 0 (control), 15.0 and 30.0% wheat hydroponic fodder respectively, although the other growth performance parameters such as dry matter intake, final body weight, and average daily gain were superior in the control animals. Weight loss has been reported in pigs fed sole hydroponics fodder diets. This has been attributed to the low DM of the fodder and the fact that pigs being monogastric animals cannot thrive solely on fodder-based diets (93).

Poultry production: Recent studies have also shown that hydroponic fodders could be used to reduce the cost of feeding poultry in small-scale farms, especially when it is produced in the farm. Within this context, the hydroponic fodder system and other innovative technologies has been proposed for research and application in intensive poultry meat and egg production farms (32). (94) had proposed a cost-effective method of producing hydroponic fodder in an organic pastured poultry system for feeding broilers and laying hens. (95) fed finisher Kuroiler (broiler) chicks with basal diets replaced with 4^{th} day barley hydroponic fodder at 25.0, 50.0, 75.0 and 100.0% levels and reported that the 25.0% replacement level recorded the highest mean live weight, while the 75.0% inclusion level scored the highest gross margin of 50.0% and benefit cost ratio of 2.0, indicating significant effects on production. (96) reported that 10.0 and 20.0% replacements of pelleted broiler feed with hydroponic barley fodder resulted in improvements in weekly body weight, body weight gain, feed intake, and feed conversion ration in the birds fed the fodder for 3 (starter) and 5 weeks. Decreases in the total fungi, bacteria, and *E. coli* counts in the gut were also observed, while the lactobacillus count, villi height and crypt depth of the jejunum in the birds fed the 10.0% fodder diet also increased. The overall economic indices of feeding the hydroponic fodder also translated to reduction of 9.0% in production cost. Another study by (97) evaluated the effect of wheat hydroponic sprouts on the growth performance, carcass characteristics and lipid profile of broiler chicken, and reported significant improvements in growth performance parameters at 50 g/Kg dietary inclusion of the wheat sprouts. Total serum cholesterol and triglyceride values were significantly reduced, while the high-density lipoprotein (HDL) was increased in the birds, indicating that 50 g/kg dietary inclusion of the wheat hydroponic sprouts in the diets of broilers has positive impact on their performance. Again, (98) fed 7th day sorghum hydroponic fodder to grower pullets at 25.0, 50.0 and 75.0% basal diet replacement levels, and reported that apparent digestibility, true digestibility, body weight gain, feed intake and feed conversion ratio declined with increasing inclusion level of the fodder. The study concluded that 25.0% of the 7th day sorghum hydroponic fodder is the optimal replacement level of the basal diets of grower chicken, beyond which the energy: protein ratio of the feed will be adversely affected.

Hydroponic fodders have also been applied to poultry breeding and maintenance of parent flocks in small farms, within the framework of sustainable development of poultry farming and creation of added value through the production of feedstuff (32). The authors specifically reported significant increases in hen-day production (11.6%), weight gain in broilers at harvest (13.3%), and hatchability of fertile eggs (12.2%), with a corresponding decrease in production costs in response to the feeding of hydroponic fodder to chickens in family farms. (99) studied the effect of hydroponic green herbage at 20.0, 25.0, 30.0, and 35.0% dietary inclusion rates on the reproductive quality of parent flocks of geese and reported an optimal inclusion level of 25 - 30% as reflected by survival, and hatching egg production rates. Improvements were also recorded in carotene and vitamin contents of egg yolks, while the overall production profitability increased by 9.6%, thus highlighting the benefits of adding hydroponic herbage in the diets of parent geese. (66) also reported that turkey fed hydroponic wheat sprouted fodders in their diets at 5, 10, 15 and 20% replacement of concentrate diet recorded increased live weight with the exception of those fed the 20% replacement diet. Ad libitum feeding of laying Japaneses quail with fresh barley hydroponic fodder was also reported by (101) to significantly increase the egg laying rate, relative weights of gizzard and testes, fertility and number of hatched chicks/female but had no significant effect on egg quality and blood indices.

Application of Hydroponic Fodder to Rabbit Production

Hydroponic fodders produced from different types of grains have been used to feed rabbits. This is because hydroponic fodders contain significant levels of quality fibers which help to improve the digestion and nutrition of rabbits (102). (103) reported that rabbit kits fed concentrate diets replaced with 50% yellow maize hydroponic fodder recorded significantly higher body weight gain, superior FCR and lower cost of production than the control and the 25% replacement group. (104) also fed a combination of pea and wheat hydroponic fodders to rabbit and reported higher fodder intake, and weight gain than when they were fed solely on any of the fodders. (82) fed maize hydroponic fodder to New Zealand White rabbits as a replacement for concentrate mixtures and reported that 50.0% replacement recorded significant increase in body weight, and average daily weight gain when compared with the control, while cost of feeding was insignificantly higher.

The effects of feeding a concentrate diet containing 25% replacement of barley hydroponic fodder and supplemented with 0.5 g/kg of an enzyme product containing xylanase and beta-glutamase used in wheat and barley-based diets for 56 days were evaluated by (105). They reported overall best performance effects in the groups that received the 25% barley hydroponic fodder with or without the enzyme supplementation in terms of growth, nutrient digestibility and economic efficiency. (102) also investigated the dietary effect of maize hydroponic fodder on the production and reproductive performances of rabbits. The rabbits were fed concentrate-based diets replaced with the maize hydroponic fodder at 25, 50 and 75% replacement levels. The group fed the 50% fodder replacement diet recorded better live weigh gain, superior feed efficiency in the young and does, higher litter weight and individual kit weight. The group also recorded higher profit value than the other groups, indicating that 50% replacement of the concentrate ration with maize hydroponic fodder is good for growth, reproduction and profitable production of rabbits. Overall, these findings suggest that hydroponic fodders production could be used to improve the profitability rabbit production in Nigeria and that up to 50% of the concentrate diet could be replaced with such fodder.

Application Hydroponic Fodder System to Urban Livestock Production

The global urban population was estimated at 4.2 billion in 2018 and was projected to add 2.5 billion person by 2050, with the developing countries accounting for a greater percentage of this increase (106). Presently, about 40.0% of the sub-Saharan population lives in urban areas, with many of the urban poor engaging in farming activities for survival and improvement of their food security (107, 108). Urban farming encompasses both crop and animal husbandry within the administrative boundaries of an urban center , and as a means of food security contributes to household food availability and dietary diversity, while providing significant employment opportunities across the food supply chain (109, 110). Urban livestock farming has been recognized as an important part of urban agriculture that plays positive roles in improving living conditions among the urban poor in many developing countries (111, 112).

(9) reported that the key constraints outlined by urban farmers in southeastern Nigeria were socioeconomic, institutional and infrastructural constraints, especially poor access to land and farming space. Urban dairy farmers in Ethiopia specifically listed lack of land (50.0%) and shortage of feed (38.9%) among the major constraints they face (113). The space constraint could be addressed using hydroponic fodder production system, since it could be carried out in a very small space, especially when grown in trays in vertical units. Thus, the technology could be used to address the problem of feed shortage encountered in urban animal husbandry (37) . (36) also reported that the hydroponics fodder production practice is well suited for urban and peri-urban areas in Nepal where rangelands for forage production are limited. The higher cost of labour for conventional agriculture also makes the hydroponics system a viable option for reducing the cost of feed production for urban livestock (114). Therefore, with minimal training and little capital input, unemployed youths and women could start the business of hydroponic fodder production and supply the products to rabbit, pig, poultry and ruminant farmers in peri-urban and urban areas.

Application of Hydroponic Fodder to Climate Change and Farmer Conflicts

The most evident effects of climate change to the subsistence smallholder livestock farmers in the tropical developing countries are usually the effects on the productivity of forage crops and range lands (115) . Studies have shown that these farmers are vulnerable to climate change events because of the the warmer baseline climates of the tropical regions , and also the fact that subsistence agriculture which is frequently characterized by limited technological inputs and adoption remains their major occupation and source of income (89, 116). The increasing environmental temperatures, and atmospheric carbon dioxide levels, and the erratic precipitations recorded in the region in the last few decades have significantly affected the ability of smallholder farmers to source quality forage for their livestock (117, 116). Several studies have reported that erratic climatic conditions cause significant changes in the growth , development, and nutrient compositions of natural pastures (118, 119). The DM content and nutritive value of fodder has been shown to reduce with rise in environmental temperature and increased CO_2 concentration in the atmosphere (120, 121). For example, a 1.00C increase in environmental temperature was reported by (122) to lead to an 8.3% decrease in conventional maize fodder production, while (123) also reported a 34 .0% reduction in wheat fodder production for every 4 .00C rise in temperature . Again, extended droughts resulting from climate change events could cause the drying up of critical water sources for livestock, while at the same time increasing the volume of water consumed by livestock. Indeed, (124) postulated that the trend in global temperature rise could with time increase livestock water consumption by about two to three folds .

Against the background of these subsisting climate change scenarios and their effects on livestock production, the hydroponics fodder production system could serve as an effective alternative technology for sustainable livestock fodder production in many regions of the world. This is because the quest for livestock fodder has become a major conflict triggering issue in countries where availability of arable lands is critical to food and livelihood security. Indeed, more than 70 .0% of the global agricultural land has been shown to be applied to one form of animal agricultural practice or the other (25). Animal agriculture also contributes about 14.5% of the anthropogenic greenhouse gas (GHG) emissions through feed production (45 .0%) , and gastrointestinal tract fermentation in ruminants (39 .0%) (126 , 127). Recent studies have however shown that the hydroponic fodder production approach could be used to reduce the GHG emissions from livestock (38), and therefore the carbon footprint from animal agriculture. (128) for example, studied the carbon sequestration possibility using scenarios that explored the land-sparing potentials of transitioning from conventional to hydroponic barley production and the shift from tillage to no-tillage practices in Alberta, Canada. The results showed the potentials for hydroponics to reduce GHG emissions from barley fodder production by 7.4%, thus, providing better carbon sequestration opportunities than the conventional farming approach, and therefore contributing to climate change mitigation objectives. The authors also postulated that higher reduction in GHG emissions could be achieved with increased seed-to-fodder output .

Several studies have also established that climate events are majorly responsible for the southward migration of pastoral families and their animals in West Africa that triggers the frequent conflicts between them and the indigenous crop farmers in the southern parts of the region (129, 130, 131). (132) investigated the effects of technological innovations on livelihood protection, food security and positive peace among the migrant pastoralists in Nigeria, and recommended the application of appropriate technologies within the precinct of ranching as the best mitigation and adaptation approach. Peace building activities such as the distribution of inputs and planting materials for pasture development and training of extension workers on the production of alternative animal feeds in model pilot ranches in the north central zone of Nigeria are being used to mitigate the competition for natural resources, and sustenance livelihoods and peace among farmers and pastoralists in the zone (40). Pastoral lands however, continue to be lost to a myriad of other developmental activities in the region, indicating that land-based interventions may not be sustainable in the long term, and may need to be augmented with landless innovative options.

In 2021, the H2Grow project, under the World Food Programme (WFP) Innovation Accelerator, facilitated the training of more than 170 pastoralists women from 193 households in the semi-arid Malakyarari communities of Borno state, northeastern Nigeria on hydroponics fodder production. According to the (40), the women that received the training are able to grow enough feed for their livestock, and also sell the excess to their neighbors. The knowledge gained has also been used by one of the beneficiaries to multiply her number of goats from four to seventeen, thereby improving her income and livelihood. (133) reported the successful training of women in Armenian communities that have lost pasture lands to conflicts on hydroponic fodder production, and establishment of hydroponic units in small farms by the WINNET Goris Development Foundation. The project brought new ideas and technologies into the communities, and has also helped to address the security, social and psychological needs of the vulnerable pastoral and farming families impacted by conflicts. Hydroponics system has also been used as an alternative fodder production approach for strengthening the resilience of vulnerable herders within the West Bank in the Palestine (134). Under the 'prepare and respond to shocks affecting low resilience farmers and herders in the West Bank and Gaza Strip' project, the FAO promoted the use of hydroponic technology to provide low-cost, high quality, sustainable sources of year round green fodder to vulnerable herders and their cooperatives. The benefiting herders were able to save about 30.0% of the cost of feed through the use of the fresh green fodders produced from the hydroponic units in addition to the improvements in their livestock performance.

(39) evaluated the impacts of the introduction of hydroponic green fodder production among livestock farmers in the drought prone region of Amhara regional state of Ethiopia. They reported statistically significant improvements in both cattle and goat milk production and therefore recommended scaling up of the technology to cover farmers in other parts of the country. In neighbouring Eritrea, The Ministry of Agriculture also promotes hydroponic fodder farming as a means of alleviating the shortage of animal feed during the dry seasons months and years of poor rainy season (135). It is therefore evident that appropriate policies, intervention strategies and adaptation measures such as sustainable forage production technologies could minimize the adverse impacts of climate change and conflicts in vulnerable livestock producing communities (119).

Socioeconomic Feasibility of Hydroponics Fodder Production System

Despite its many advantages, the socioeconomic feasibility of the hydroponic fodder production system may vary across different animal production realities at various locations, which may include seasonal availability of feedstuff, abundance of year round natural fodder, traditional practices, disease prevalence and local policy constraints. The type of grain used in the fodder production may also be influenced by the availability, cost and moral issues, especially at locations where the food-feed competition demands several policy considerations before extensive use of grains in animal feeding (136). Hydroponic fodder production might therefore not be the solution to livestock feeding constraints at some locations despite the nutritional benefits. Another major challenge at the traditional and small-scale level is the relatively high cost of setting up the fodder production units, which research has tried to address in several Asian countries (137, 138, 139, 140), and the social resistance arising from using grains as animal feed (23). Ideally, grain sprouting for fodder production should be feasible , and even profitable in southern Nigeria that already has well developed intensive, high-value input-driven livestock operations and high cost of agricultural lands and feedstuff (22, 141). The automated hi-tech fodder production approach could be adopted by the large-scale farms in the region as a strategy for controlling , and sustaining their feed production capacities . In northern Nigeria, the decline in the socioeconomic viability of the pastoral production systems as presently structured is paving the way for modern alternatives such as the ranching of animals at secured locations (1). Commercial-scale production of livestock will however require intensive fodder production which could be achieved through the hydroponics production system sustained by the availability of appropriate local and cheap grains (40, 132).

In India, (59) reported that the feed cost/kg of milk was increased by feeding dairy cattle with maize fodder produced from a hi-tech hydroponic system, in response to the higher cost of fodder production . Farmers at the Satara district of Maharashtra in the same country however, reported a net increase in profit of 0.5 dollar from milk per day as a result of feeding dairy animals with hydroponics fodder produced in a low -cost system, using home-grown or locally purchased seeds (138). These reports show that the costs of hydroponics unit and seeds are critical to the profitability of the hydroponic fodder production system at any given location. (36) reported a higher cost of maize hydroponic fodder at Kumaltar, Lalitpur, Nepal than the cost reported by India workers (89, 142, 143), and attributed this variation to the differences in the cost of maize and electricity in the two counties. (144) however, reported that in Saudi Arabia, water use efficiency for hydroponic fodder production is much higher than that of the conventional production method, while the returns and net profit is higher for the latter. They attributed this to the lower dry matter content and the fixed and variable costs incurred by the hydroponic fodder technique. Furthermore, the authors found the hydroponic technique unsuitable for small-scale farming operations in terms of cost benefit ratios, return on investment, and break-even price. A Kenyan study by (145) also reported that pastoralists' decision to purchase fodder is significantly influenced by access to credit, weather and market information, land tenure system, exposure to shocks, off-farm income, age, gender, and proximity to urban centers. The amount of fodder purchased is however significantly affected by access to weather information, exposure to shocks, and livestock holding, indicating that the pastoralists could adopt a commercially focused approach to feeding their animals. Such a study could be undertaken to determine the feasibility of commercial hydroponic fodder production among pastoralists, and urban farmers and at non-traditional livestock production locations in Nigeria.

Conclusion and Recommendations

Hydroponic fodders contain higher levels of quality proteins, sugars, minerals and vitamins, although the starch and dry matter levels are lower than those conventional fodders produced on land from the same seeds. **They can therefore** replace up to 25 to 50% of the expensive concentrate component in the diets of different types of livestock, thereby reducing the cost of feeding. The technology could be used as a climate change and conflict mitigation options at traditional pastoral livestock farming locations. The socioeconomic benefits of the hydroponic fodder production system, and the feasibility of it application may however vary across the different animal production realities of different regions, in terms of local food-feed policies, and cost of the available grains.

The automated low cost or hi-tech hydroponic fodder production approach could be adopted by the small, medium or large-scale farms in southern Nigeria respectively, since the zone has already existing intensive, high-value and input-driven livestock operations and the cost of agricultural lands are relatively high. The declining socioeconomic and political viability of the pastoral production systems in northern Nigeria that paves the way for modern alternatives such as the ranching of animals at secured locations will also require intensive fodder production which could be achieved through the hydroponic fodder production , sustained by the availability local and cheap grains . Training and supply of capital inputs for hydroponic fodder production by appropriate government agencies as livelihood empowerment programme for low-income farmers, unemployed youths and women at different locations in the country is therefore recommended. There is also the need to explore the feasibility of commercial hydroponic fodder production among pastoralists, and urban farmers at the traditional and non-traditional livestock production locations in Nigeria.

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