

Potentials of Hydroponic Fodder System as a Sustainable Animal Feed Production Alternative in Nigeria: A Review

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Abstract

Livestock production in Nigeria is a major contributor to the economy with ruminant production making up a significant part. Over the years however, animals especially ruminants have relied mostly on forages and herbs from the natural pasture as sources of nutrients. Natural pasture is unfortunately limited in quantity and quality necessitating the adoption of innovative approaches to ameliorating the feed challenge. These innovative approaches include introduction of improved forages, combination of cereal crops with trees, and legume crop based green fodder, agroforestry and inter-cropping and recently hydroponic fodder production. Hydroponic fodder production, a technique of growing plants without soils is increasingly being adopted as an alternative to conventional fodder production. The hydroponic system has the advantage of producing fodder within a short time in a small area with less water and labour, possibly recycled all-year round at low cost. The system takes advantage of the variation in the chemical and structural changes of grains to significantly increase the quality and quantity of nutrients resulting in significant benefits. Considering the effect of sprouting on cereal grains, biomass yield, nutrient and anti-nutrient compositions, digestibility, application of hydroponic fodder in monogastric animal production, climate change, urban livestock production and the socioeconomic feasibility, it is concluded that the adoption of the hydroponic fodder production system holds lots of promise in mitigating the challenges of sustainable animal feed production in Nigeria.

Keywords: Hydroponic fodder, forage, animal feed, livestock



Potential du système de fourrage hydroponique comme alternative durable pour la production d'aliments pour animaux au Nigéria - Un examen

Résumé

La production animale au Nigéria est un contributeur majeur à l'économie, la production de ruminants en constituant une part importante. Au fil des ans, les animaux, en particulier les ruminants, ont principalement compté sur les fourrages et les herbes des pâturages naturels comme sources de nutriments. Malheureusement, les pâturages naturels sont limités en quantité et en qualité, ce qui nécessite l'adoption d'approches innovantes pour atténuer le défi alimentaire. Ces approches innovantes comprennent l'introduction de fourrages améliorés, la combinaison de cultures céréalières avec des arbres, le fourrage vert à base de légumineuses, l'agroforesterie et la culture intercalaire, et récemment la production de fourrage hydroponique. La production de fourrage hydroponique, une technique de culture de plantes sans sol, est de plus en plus adoptée comme alternative à la production de fourrage conventionnelle. Le système hydroponique présente l'avantage de produire du fourrage en peu de temps dans une petite zone avec moins d'eau et de main-d'œuvre, potentiellement recyclé toute l'année à moindre coût. Le système tire parti de la variation des modifications chimiques et structurelles des grains pour augmenter significativement la qualité et la quantité des nutriments, ce qui se traduit par des avantages importants. Compte tenu de l'effet de la germination sur les céréales, du rendement en biomasse, de la composition en nutriments et en anti-nutriments, de la digestibilité, de l'application du fourrage hydroponique dans la production animale monogastrique, du changement climatique, de la production animale

urbaine et de la faisabilité socio-économique, on peut conclure que l'adoption du système de production de fourrage hydroponique est très prometteur pour atténuer les défis de la production durable d'aliments pour animaux au Nigéria.

Mots-clés: Fourrage hydroponique, fourrage, alimentation animale, bétail

Running title: Hydroponic fodder system for animal production in Nigeria

Introduction

Livestock production is a major economic activity in Africa, and accounts for one-third of the global livestock production (AU-IBAR, 2016), and about 40% of the agricultural gross domestic product (GDP) of the continent (Panel, 2020). Livestock production is expected to become increasingly important in the sub-Sahara African countries because of the increasing demand for animal food products, such as meat, milk, and eggs (Alexandratos and Bruinsma, 2012; Balehegn *et al.*, 2021). Ruminants are the most popular livestock produced in Africa and are predominantly under the control of traditional holders or pastoralists who constitute a major socio-economic group in the continent (Kubkomawa, 2016; Balehegn *et al.*, 2021). It has contributed substantially to the national wealth in Nigeria, while serving as an essential source of the animal protein and industrial raw materials (Olajide and Akpan, 2020). Indeed, animal products contributed about 17.0% of the dietary energy needs in many developing countries in the tropics (Alexandratos and Bruinsma, 2012). The consumption of livestock products in Nigeria was projected to grow at 3% annual rate from 2012 to 2050, with the poultry population projected to increase above 500% during the period (Varrella, 2020). The livestock industry specifically contributed about 1.89% of the Nigerian GDP in 2020 (Varrella, 2021). The most crucial constraint to livestock production in Nigeria being poor nutrition or inadequate feed supply (Bamaiyi, 2013; Kubkomawa, 2016), evidenced by the unmet demand and subsequent scarcity and high cost of feed resources for intensive production systems (Esonu, 2009; Ifeduba, 2018;

Moses, 2019), and the search for sustainable alternatives (Okoli *et al.*, 2014; Achonwa *et al.*, 2017; Ohanaka *et al.*, 2017; Ukwu *et al.*, 2022). The major contributors to poor feed supply to the traditionally managed livestock in Nigeria include the recurrent climate change (Olagunju, 2015; Blanch, 2017), the shrinking agricultural lands for livestock grazing (Kubkomawa *et al.*, 2016; Osinowo, 2020) and pastoralist-farmer conflicts (Okoli *et al.*, 2012; Blanch, 2017; Iro, 2020).

Over the years, ruminant production has been an efficient method of converting plant materials such as grasses, browses and crop residues into protein-rich food for humans. Ruminants being less efficient in converting grains to animal protein play valuable roles in sustaining the agricultural system in marginal environments, thus making such lands become productively utilized (Downing, 2016; Osinowo, 2020). In a sustainable agricultural system, forage and pasture should be the most important feed for ruminants due to their low unit production costs, widespread availability, and limited competition as human food (Alexandratos and Bruinsma, 2012; Wilkinson and Lee, 2017). The dietary intake of ruminants is predominantly composed of 90.0% roughage which is made up of leaves of broadleaf species, grasses, hay, silage, and crop residues, thereby making them a primary converter of natural sources that otherwise have no direct value to humans unlike non-ruminants (Mottet *et al.*, 2017). These animals, especially cattle, sheep, and goats, while contributing hugely to the national economy, are also major contributors to the socio-economic well being of

smallholder farmers as sources of income, employment, store of wealth, raw materials, soil fertility enhancement, and as draught animals, among many others benefits (Rota and Sidahmed, 2010; Kubkomawa *et al.*, 2015). These benefits may vary within and across different agro-ecological zones and tribal groups in Nigeria. In the southern zone, for example, sheep and goats are highly prized for cultural activities, as source of manure and financial security (Okoli *et al.*, 2003; Oluwatayo and Oluwatayo, 2012), while in the northern zone where cattle, sheep and goats are more concentrated, they have much significance in the sociocultural lives of the Hausa/Fulani and other tribes (Fakoya and Oloruntoba, 2009; Lawal-Adebowale, 2012; Kubkomawa, 2017).

The common naturally occurring forages available for ruminant production in Nigeria include the *Andropogon tectorum*, *Panicum maximum* (now *Megathyrsus maximus*), and *Pennisetum purpureum* among others (Aregheore, 1996; Kubkomawa, 2016). During their early stages of development, and the early rainy season, these forages are capable of providing ruminants with adequate levels of carbohydrates, protein, and some vitamins and minerals (Ajayi, 2008; Kubkomawa *et al.*, 2016). They grow rapidly during the early rainy season and become abundant for ruminant consumption (Lawal-Adebowale, 2012). During the late rainy season and as the dry season sets in, however, the protein levels in the grasses drop and the fibre fraction, such as the lignin content increases; this tends to affect the voluntary intake by the animals (Aregheore, 2001; Kubkomawa *et al.*, 2016). Thus, the forage quality and availability vary greatly from the wet season to the dry season; and this consequently affects the productivity of the animals (Ogunbosoye and Babayemi, 2010). In order to overcome (or mitigate) the effects of this poor quality and inadequate forage supply, the livestock farmers engage in various forms of

supplementary feeding which may involve the use of crop residues and green foliage from wild trees and shrubs (FAO, 2023). This, sometimes lead to unsustainable practices such as felling of trees, indiscriminate and over-grazing in lowland areas and riverbanks without recourse to any form of rehabilitation programs. This therefore leads to denudation of the grazing lands, with large-scale loss of biomass and resultant adverse effects on livestock rearing at many traditional livestock production locations (Singh and Meena, 2011; Osinowo, 2020). The farmer-herder conflicts in Nigeria is essentially driven by the inadequate supply, poor nutritional quality and seasonality of forage and water availability which significantly underlies the migratory behaviour of herders (Kubkomawa, 2016; Iro, 2020; Osinowo, 2020). This is currently the major challenge to ruminant production in Nigeria and requires knowledge-based intervention to ensure sustainability of the livestock enterprise (or industry?) in the country (Babayemi *et al.*, 2010; Lamidi and Ologbose, 2014; FAO, 2019; Osinowo, 2020).

A strategy that has the potential to ameliorate the poor ruminant feed supply challenges is intensive fodder production for animals managed in ranches or for distribution to traditional herders (Kerr *et al.*, 2014; Tulu *et al.*, 2023). Conventional fodder and forage production using either annual, perennial or permanent forages is practiced in many parts of the world. Emerging consensus and policies are however gradually shifting at both global, regional, and national levels to highlighting 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 (Foley, 2011; van Zanten *et al.*, 2015; Field, 2018). Innovative approaches that require minimal land use such as the hydroponic fodder production are also being used to overcome the challenge of poor fodder production and

availability in different regions of the world (Christensen, 2013; Salo, 2019). Hydroponic fodder production is the technique of growing fodder plants without soil and is increasingly being adopted as an alternative to conventional fodder production (Sneath and McIntosh, 2013; Naik *et al.*, 2015). In this technique, the fodder seeds utilize tap water or a nutrient-enriched solution for nourishment in the absence of soil to sprout and grow up to 30 - 35 cm tall within 6 - 7 days which are harvested and offered as highly nutritious feed to the animals. This feed resource, apart from being high nutrient density fodder, is capable of being produced year-round without limitations due to climatic and other environmental factors (Starova, 2016; Sawant, 2021). The hydroponic system can produce 10 times as much as the amount of fodder from the conventional traditional fodder production system (Oluwaniyi, 2016), and could be adopted to ease the pressure on land, overcome the challenges of water shortage due to erratic rainfall, and frequent draught that constrain green fodder production and supply at the major livestock production locations in Nigeria (Oluwaniyi, 2016; Steve, 2020).

This paper reviews the potentials of hydroponic fodder system as an alternative resource for sustainable ruminant feed production in Nigeria.

Fodder Production in Nigeria

Fodder is defined as feed made from farming or other agricultural processes for feeding domestic animals. It refers specifically to plants cut and carried to animals as against forage which are plant materials that the animals obtain by themselves while growing on the field. FAO (2023) also defined fodder as feed given to the dairy animals rather than that which they forage for themselves and are mostly cultivated for animal feed. Fodder could be derived from natural or cultivated grasses, shrubs or trees, cereals or legumes and crop residues. It provides

an economic nutrient source which is highly relished by livestock. Green fodder plays an important role in the feeding of, mostly, ruminant livestock by enhancing their productive and reproductive performances through the supply of essential nutrients, bulk for effective digestion, and for gastrointestinal tract (GIT) motility (Mohapatra *et al.*, 2019). It also helps in reducing the cost of production by replacing a part or most of the concentrate in the animal feed (FAO, 2023). Fodder crops are either annual or perennial or permanent crops. They are cultivated on arable land and are grazed or cut and fed to livestock either fresh or conserved in the form of silage or hay. Generally, there are 3 types of green fodder available, cereal crop-based, tree-based, and legume crop-based green fodder (Roysfarm, 2022) and their production at any location will usually depend on the type of livestock, climatic conditions, cropping systems and the socioeconomic conditions of the farmers (Suman and Thakur, 2021).

Fodder and forage crops are critical in the development of the Nigerian livestock industry, since the bulk of the animal protein products especially milk and meat, consumed in Nigeria are derived from ruminant animals, that depend on these crops for their nutritional needs (Shiawoya and Tsado, 2011; Muhammad, 2019). Ibrahim *et al.* (2018) reported that marginal land areas within and around urban centres, including streams, unprotected gutters, marshy land, ponds and protected institutional, industrial, and uncompleted residential areas, serve as the major sources of fodder for livestock rearing in the semi-arid part of northern Nigeria. According to Kubkomawa *et al.* (2016), a variety of crop residues are also available for livestock feeding in Nigeria, with some being abundant, and more useful than others which are available only in small quantities and therefore of secondary importance. They however, emphasized that crop residues, by-products and browse plants

remained the most outstanding feed supplements for cattle and other ruminants in Nigeria. Presently, the combined effects of urbanization due to high population growth, and increase in crop production activities, have reduced grazing areas and range lands; raised the cost of animal feed; and limited urban livestock production to few smallholder individuals under home-care in Nigeria (Amadou *et al.*, 2012; Kubkomawa, 2016). Moreover, the few urban households that keep livestock, due to the reasons of culture, economic gain, or hobby, are increasingly facing the challenge of scarcity of cheap feed stuffs needed to feed their livestock. The use of alternatives such as crop residue and agro-industrial by-products have however, been reported to be relatively expensive compared to natural browse and forage, which are very cheap and more nutritious (Ibrahim *et al.*, 2018). The availability of quality forage and pasture has drastically reduced over the years due to climate change event and limited access to pastoral lands and water supply leading to the migration of pastoralists to places with relative abundance of forage, this has resulted in incessant clashes with crop farmers and insecurity (Okoli *et al.*, 2012 and 2014; Oluwafisayomi, 2021). The popular strategies advocated for ameliorating the constraints to ruminant feeding in the country include forage conservation, utilization of crop residues, and agro-industrial by-products, utilization of cultivated fodder crops and browse plants, use of concentrate feed, integration of ruminant and crop production and nutrient supplementation of poor forage (Bogoro, 2006; Aina, 2012; Lamidi *et al.*, 2013; Lamidi and Ologbose, 2014; Kubkomawa *et al.*, 2019). Industry intervention efforts such as the Advancing Local Dairy Development in Nigeria (ALDDN) have explored models and strategies such as private led commercial fodder production (CFP) to mitigate free-range or open grazing of livestock and the attendant conflicts with crop farmers (Oluwafisayomi, 2021).

Fodder production from natural pastures in Nigeria

Fodders from natural pastures are critically important in ruminant production in regions where land is abundant and relatively undisturbed. In Nigeria, about 97.0% of the ruminant animals are dependent on natural forage crops for their productivity, indicating its central role in the sustenance of the country's livestock industry (Njidda, 2010; Njidda and Olatunji, 2012; Kubkomawa *et al.*, 2019). These feed resources that consist mainly of grasses, legumes, and browses vary widely and are spread across the major agro-ecological zones of the country (Okoli *et al.*, 2003; Shiawoya and Tsado, 2011; Olawoye and Kubkomawa, 2018). The role of forage and fodder crops in Nigeria's farming systems is particularly reflected in their contribution to soil fertility and the sustenance of the livestock sub-sector of the nation's economy. Shiawoya and Tsado (2011) reported that about 32.42 million hectares of grazing land and 39.41 million hectares of crop land in Nigeria provide substantial amount of feed for the country's domestic animals and wildlife. Usman and Nichol (2022) however, reported that in areas surrounding urban centers in the northern Savannah zone of the country, grazing land diminished by 150 % and fallow land by about 300 % between 1980 and 2014, while in rural areas, the rates were much lower. Again, extensive areas of the grazing land are composed of indigenous forage species, which are of low yield and quality (Shiawoya and Tsado, 2011), indicating the need for forage cultivation to meet the nutritional needs of livestock.

The available natural pasture varies across different zones of the country due to geo-climatic variations and human activities and have resulted in pastureland vegetation comprising mixtures of trees, shrubs and grasses (Olawoye and Kubkomawa, 2018; Kubkomawa and Kenneth-

Chukwu, 2019). The indigenous natural grasses grow under high temperature regimes which stimulate their rapid maturation and consequent decrease in their nutrient values. Thus, they are relatively abundant and high in nutrient quality during the rainy season months, but rapidly decline in quantity and quality as they mature during the early dry season months of November and April in Southern Nigeria (Babayemi and Bamikole, 2006; Ojo *et al.*, 2017). The trees and shrubs on the other hand are drought resistant and remain evergreen due to their deep rooting system that allows them to reach subsurface soil nutrients and moisture. Indigenous and exotic trees, shrubs, and twigs, therefore, abound and serve as important animal feed resources particularly during the off-season periods, when green grasses are no longer readily available (Kubkomawa *et al.*, 2019). Several studies have evaluated these natural feed resources for livestock production at different locations in Nigeria (Okoli *et al.*, 2003; Aduku, 2004; Bayala *et al.*, 2014; Amole *et al.*, 2002).

Cultivated fodder production

Cultivated forage or fodder crops include grasses, legumes or food-feed crop species that have been deliberately sown to provide forage and fodder to livestock (Jank *et al.*, 2014). Forage, grasses, and legumes are the principal sources of nutrients for most livestock in developing countries, and contribute to the production of meat, milk, and other animal products like leather and wool (Fuglie *et al.*, 2021). Over the decades, different improved varieties of forages have been introduced and researched by different government agencies with the aim of improving the natural pastures and providing more nutritious forage to the national herd (Kubkomawa, 2016). Recently, there has been renewed interest in fodder production particularly in northern and southwestern Nigeria, possibly because of diminishing grazing land and yield potentials of natural fodder which tend to be lower than

cultivated ones. For example, Adewale (2020), reported that the government of Kano state initiated a project to produce Gambia grass seeds for cultivation on a 4,000-hectare grazing land. According to Mwenndia *et al.* (2017), such forage production initiatives are key to meeting the increasing demand for forage which has been predicted to double by 2050.

Forage plants such as *Centrosema pubescens*, *Stylosanthes guianensis*, *Brachiaria* and *Panicum* hybrids among others have been promoted as candidate forage plants for improving the nutritional quality of available natural forage during the dry season months (Omokaye, 2001; Mwendia *et al.*, 2017). Fodder bank technology which involves the planting and conversion of improved forage varieties such as *S. guianensis* and *C. pubescens* into supplementary or fallback forage kept in small to large plots for dry season use have also been practiced in Nigeria with limited success (Kubkomawa, 2016). Singh (2020) reported a 36, 40 and 44% deficiency in the availability of cultivated fodder, dry fodder, and concentrates, respectively in India, indicating therefore the need to increase cultivation of fodder crops in that country. The production of forage species as cash crops which are conserved and sold as hay or silage to pastoralists during the dry season has also been advocated in Nigeria (Mwendia *et al.*, 2017; Adeoye, 2021). In most smallholder farms, fodder cultivation however, competes for space with the cultivation of food crops. There is, therefore, the need to determine whether fodder cultivation is economically more beneficial than food crop production on a case-by-case basis in developing countries (Ouda, 2001). The persistent conflicts between herders and crop farmers also demands the need to find a nexus between forage land utilization and livestock management that will reduce these conflicts. Again, recent frequent variations in environmental temperatures and relative

humidity adversely affect the growth pattern, quality, development and gross yield of cultivated fodder (Chapman *et al.*, 2012; Attia-Ismail, 2019). These problems indicate the feed challenge to the Nigerian livestock industry and underscores the need for the development or adoption of innovative methods for forage production for continued sustenance of the industry.

Innovative approaches to fodder production

Unavailability of land, feed resources and labour requirements are major constraints faced by livestock farmers in Nigeria (Fakoya and Olorunfoba, 2009; Kubkomawa, 2016). Yield potentials of natural forages tend to be lower than cultivated ones which limits the quality and quantity of feed and therefore the productivity of livestock and the quality of their products (Kubkomawa, 2017; Murthy *et al.*, 2017; Kubkomawa *et al.*, 2018). Innovative approaches to fodder production have therefore been considered, for instance, the integration of forage crops and livestock production is a popular alternative approach for increasing the area and production of forage crops. Agroforestry and inter-cropping approaches are also used to maximize the outputs from the limited available lands (Laroche *et al.*, 2015). Mechanization has also been introduced to address the issue of costly labour-intensive fodder production and processing which are time consuming, and cause delays leading to deterioration of fodder quality (Sehay *et al.*, 2016).

More recent technologies such as sprouted fodder production have been shown to significantly increase the nutritional value of grains compared to direct feeding of the whole grains to the stock. In addition, sprouted fodder utilizes less water than traditional forage, thus, making them ideal for drought prone locations (Sneath and McIntosh, 2003; Rahman *et al.*, 2019; Elmulthum *et al.*, 2023). Different types of cereals can be

successfully grown using this approach which has been termed hydroponic fodder production system (Christensen, 2013; Tranel, 2013). In fact, hydroponics fodder production maybe a viable solution to ending the nomadic cattle herders-sedentary farmer conflicts in West Africa, since it is a soil-less system of cultivating animal fodder with water or mineral rich solution in limited space, thus, eliminating the need for pasture lands and contact with crops farmers (Naik *et al.*, 2011; Oluwaniyi, 2016; Hauser *et al.*, 2021). The system offers farmers the availability of all-year round nutritious green fodder to feed their animals because it can produce green fodder within a short period (7 - 10 days) and requires only a small piece of land for the production to take place (Naik *et al.*, 2015; Oluwaniyi, 2016). It is therefore gaining popularity, especially among livestock investors in Africa and other regions constrained by limited resources for conventional green fodder production as a sustainable option for decreasing the food/feed production competition (Tranel, 2013; Elmulthum *et al.*, 2023).

Hydroponic Fodder Production

Hydroponics is a technique used for growing plants in water without soil, usually in a controlled environment (Singh, 2020). The method dates to the nineteenth century (Kerr *et al.*, 2014), or earlier from the Hanging Gardens of Babylon era (Espiritu, 2022), when dairy farmers fed sprouted grains to their cows during winter to maintain milk production and improve fertility (Anonymous, 2008; Espiritu, 2022). Hydroponic fodder is also called fresh biscuit, sprouted fodder, or sprouted grain (Rachel *et al.*, 2015). It has been used in livestock fodder production at water deficient arid and semi-arid environments with poor soils or in urban areas where high cost of land makes traditional agriculture unsustainable (Rachel *et al.*, 2018; Elmulthum *et al.*, 2023). Hydroponic fodders are produced by growing seeds without soil, and with limited

water, such that within six to seven days the seeds sprout, and the seedlings grow up to 30 to 50 cm tall and provide highly nutritious fodders (Rahman *et al.*, 2019; Sawant, 2022). Hydroponic fodders have been reported to be more palatable than the conventional fodders due to their differences in water and fibre contents (Naik *et al.*, 2015). Maize, pulses, barley, oats, wheat, and horse gram seeds have been used in the production of hydroponic fodder. The pearl millet and sorghum seeds are not usually used because their sprouted young leaves contain anti-nutrients which can harm livestock (Nyirenda, 2020; Sawant, 2022). Several Nigerian studies have however, documented the successful production and utilization of sorghum hydroponic fodders in the feeding of livestock (Oluwaniyi, 2016; Chana *et al.*, 2021(a,b); Martins *et al.*, 2023).

Oluwaniyi (2016) reported that a 3m x 4m hydroponics room is the equivalent of about 2 acres of natural grassland and can feed about 10 cows or 30 pigs or 40 goats per day. Hydroponic fodder production could therefore save a farmer more than 50.0% land use for animal feed, while increasing the production performance and the yield of products such as milk and meat (Naik *et al.*, 2014; Rahman *et al.*, 2019; Elmulthum *et al.*, 2023). The major advantages therefore include production of fodder within a short time (7 - 10 days) and in a small area, use of less water and labour, the opportunity to recycle water, and all year-round production of high quality organic green grass which translates to healthier animal products at low running cost (Oluwaniyi, 2016; Rahman *et al.*, 2019; Steve, 2020; Elmulthum *et al.*, 2023). Hydroponic fodders are highly palatable, nutritious, and digestible, with studies recording animal intake of 1 - 1.5% of body weight (Starova, 2016). Other studies with large and small ruminants, adult pigs, and rabbits (Naik and Singh, 2013; Rachel *et al.*, 2015) reported 15 - 25, 1.5 - 2.0, 0.25 - 2.0 and 0.1 - 0.2

kg/animal/day intake, respectively. Ghorbel and Kosum (2022) summarized the major advantages of hydroponic fodder production system to include adaptation to extreme climate environments, minimum land use, water requirement, labour, and fodder loss. Others benefits include, all year supply of green fodder, higher yield, relatively low cost of production, and higher nutritive value and intake by livestock. Since the fodder is a natural product, it does not contain synthetic growth promoters, hormones and residues of chemical fertilizers, pesticides, fungicides, intoxicants, and dust that can impact animal and human health (Zhang *et al.*, 2018; Ghorbel and Kosum, 2022). Newell *et al.* (2021) also argued that hydroponic fodder production could reduce greenhouse gas emissions by up to 7.4% per unit mass when compared with conventional barley fodder product.

Despite these advantages, hydroponic fodder production has a few drawbacks which may include high initial cost of setting up the hydroponic units, although this depends on the type and size of the system; the need for constant monitoring and micro-management; quicker reaction of plants to problems such as nutrient deficiency and infections; danger of water electrocution in more complex systems, and the hi-tech nature of the advanced systems which may be too costly for developing countries agriculture (Schoenian, 2016; Ahamed *et al.*, 2023; Brahlek, 2023). Reductions in the total energy, dry matter, and very high moisture content of the hydroponic fodders have also been observed as other disadvantages (Schoenian, 2016; Martins *et al.*, 2023). For example, Sneath and McIntosh (2003) reported that in hi-tech units, the cost of hydroponically grown fodder could be 2 - 5 times that of the same dry matter from the original grain. The high operating cost of the hi-tech units is usually associated the energy needed for the automated growing of the fodder. Low-cost hydroponic systems have

however been developed using locally available materials in many developing countries to address the problem of the expensive, hi-tech commercial hydroponic fodder production systems. Such an approach may improvise any type of shelter such as garage, basement, spare room, farm shed, and huts or greenhouse made of low-density plastic sheets with solid floor in which the temperature, light and humidity can be controlled (Kerr *et al.*, 2014; Naik *et al.*, 2015).

Hydroponic production systems

Hydroponic methods have been used to grow plants for a long time in many countries, especially vegetables to lessen the pressure on lands, and overcome shortage of water, erratic rainfall, and frequent draught that constrain the growing of green crops (Al-Karaki and Al-Hashimi, 2012). The hydroponic production system has become the state-of-the-art technology that has revolutionized the green fodder production in the 21st century because of its eco-friendly method of growing fodder with the cereals at 50.0% faster rate and producing higher yields of better-quality fodder (Tudor *et al.*, 2003; Kide *et al.*, 2015). The technology has been used for year-round commercial fodder production using units like greenhouse, vertical farms, shipping containers or modular boxes in both developed and developing countries (Ahamed *et al.*, 2023). For example, Tobias (2021) recently reported that FAO supported the establishment of 79 simple greenhouses for hydroponic fodder production that benefited about 3350 households in Namibia as a drought mitigation approach. Naik *et al.* (2012) reported the production of fodder at 35.0 - 45.0% lower cost and using only 0.5% of the space needed to grow such species.

The first step towards the 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 are then soaked in 0.1 - 1.5% bleach solution (sodium hypochlorite) or 1.0 - 2.0% hydrogen peroxide solution for 30 - 60 minutes (Rachel *et al.*, 2015; Starova, 2016), and thereafter washed in tap water. The seeds may again be soaked in fresh aerated water for different periods; for example, Naik (2014) soaked the seeds for another 4 hours, Starova (2016) for 8 h and other workers for 12 - 16 h or overnight (El-Deeba *et al.*, 2009; Al-Karaki and Al-Momani, 2011; Shashank and Krishna, 2012; Reddy, 2014; Brownin, 2017) depending on the hardness of the seed coat. The temperature of the water or solution used for soaking may also affect the seed germination rate. Sneath and McIntosh (2003) reported that the optimum temperature for soaking the seeds is 23°C. After soaking, the seeds are spread at about one centimeter depth on plastic or light weight metallic trays with holes to facilitate drainage of the wastewater/nutrient solution, which could be collected in a tank and recycled. The seeding rate or quantity of seeds loaded per unit surface area varies with the type of seeds which also affects the fodder yield. The recommended seeding rate for production of hydroponic barley, wheat or sorghum fodder is 4 - 6 kg/m² (Al-Karaki and Al-Momani, 2011; Starova, 2016). For maize fodder, 6.4 - 7.6 kg/m² has been suggested (Naik *et al.*, 2013; Naik, 2014; Naik *et al.*, 2017). The seed cost contributes about 85.0 - 90.0% of the total cost of production of the hydroponic fodder (Naik *et al.*, 2014; Rachel *et al.*, 2015). The trays are ideally placed on hydroponic racks, and the seeds irrigated with fresh tap water or nutrient enriched solution. They are usually not exposed to direct sunlight, strong wind, and heavy rain. The seeds are kept moist by drip or spray irrigation without saturating them. The environmental conditions for optimum growth of a fodder include temperature range of 19 - 22°C, humidity range of 40.0 - 80.0% (60.0% optimum), light intensity of about 2000 lux for 12 - 16 hours and aeration for 3 minutes after every 2 hours (El-Deeba *et al.*,

2009; Starova, 2016). Mould infestation of the seeds has been reported to be a major challenge at higher temperatures and humidity.

Mooney (2005), and Reddy (2014) reported that hydroponic fodder yield of 20 - 30 cm tall grass mat containing roots, spent seeds and green shoots is usually ready for harvesting within 6 - 8 days. Excellent biomass yields and peak nutrient composition have been reported for barley seed sprouts by the 6th day of sowing and has therefore been recommended as the optimum period for harvesting the fodder under the hi-tech production system. The electricity demand to produce hydroponic fodder is much lower than for traditional irrigation water distribution with or without nutrient enrichment. The use of nutrient solution has also been associated with higher crude protein, total ash, and essential mineral contents in the fodder than the use of tap water (Peer and Leeson, 1985; Dung *et al.*, 2010; Fazaeli *et al.*, 2012), although no significant effect has been reported for dry matter content. Use of nutrient solution however increases the cost of fodder production indicating that overall, there are limited additional advantages of using nutrient solution for producing hydroponic fodder (Dung *et al.*, 2010; Fazaeli *et al.*, 2012).

Types of hydroponic systems

Hydroponic systems are usually modified to recycle and reuse the nutrient solutions and supporting media (Sharma *et al.*, 2018). The hydroponic growing method could be the open system, that does not require the recycling of the water or nutrient solution and the closed system that recycles the excess water or nutrient thus preventing wastage. Ghorbel *et al.* (2022) described six types of hydroponic system setups, which are based on the flow of nutrient solution, application of electricity and disposition of plants. These setups include, the wicking system, deep water culture (DWC), drip system, an ebb and flow system, nutrient film technique (NFT) and aeroponics (Ghorbel *et al.*, 2022). The

wicking system has been adjudged the most suitable for fodder production because of its low maintenance, simplicity, affordability, and zero energy need, although it may not be suitable for large-scale production (Verner *et al.*, 2017; Ahamed *et al.*, 2023).

High-tech hydroponic systems

These are the highly sophisticated, fully automated fodder production systems with controlled environment that are immune to natural weather vagaries. The required water, light, temperature, humidity, and aeration are fully controlled by sensors and micro-controllers, with provision for recycling of water. Monitoring these parameters helps to keep a close watch on the system while data are collected and used for further evaluation of the quality of the harvest and other scientific analysis. Internet of Things (IoT) could be used to accumulate data, which are stored in a server (Kumar and Cho, 2014; Bharti *et al.*, 2019). In smaller systems, android applications are used to collect and store data in a personalized format, which also helps to secure sensitive data (Bharti *et al.*, 2019). Recent developments have introduced wireless automation and control of growth parameter to the production system. Through this, the integration and adaptation of the existing automation system with digital technologies such as the IoT to enable real-time monitoring of the fodder production has been achieved (Ahamed *et al.*, 2023). Commercial modular farms, which are flexible and self-contained systems that allow the growing of fodder in stackable vertical trays in warehouse-like structures or shipping containers with the help of artificial lighting has become popular in many developed countries (Santos *et al.*, 2018; Ahamed *et al.*, 2023). Such systems have been reported to produce as much as 2700 kg of sprouted wheat or barley grass per day, which would have required 35 - 50 acres of land to produce under the conventional fodder production system. The major draw backs to the

hi-tech system are the high initial cost, the need for technical skill, electricity, internet access and regular monitoring needed to keep it running. These are the major constraints to the adoption of the hi-tech production systems in a developing country like Nigeria (Bulcha *et al.*, 2022).

Low-cost hydroponic systems

The expensive, hi-tech commercial systems are being replaced in developing countries by low-cost hydroponic fodder production systems made from locally available materials. The cost of such systems depends upon the type of construction materials used, which may include shelter such as garage, basement, room or low-density plastic sheets, greenhouse or poly-hut with solid floor or compacted earth, concrete, or cobblestone (Kerr *et al.*, 2014; Reddy, 2014; Starova, 2016). In situations where the temperature, humidity and light can be controlled, low-cost hydroponic fodder production can be developed in a room in which the east-west walls are brick, and the North-South walls have double glassed windows that permit sunlight into the room, while preventing excessive increase in temperature inside the room (Kide *et al.*, 2015). In other adaptations of the system, the wall of a building or a concrete fence could be used to construct a lean to-shade net greenhouse, to reduce the cost of construction (Bakshi *et al.*, 2017). It is usually difficult to control or adjust the humidity and air circulation in low-cost hydroponic production units, especially during the hot dry season months. Bamboo sticks and waste woods have also been used in the construction of the shelf racks on which the sprouting seed trays are placed (Shashank and Krishna, 2012; Kide *et al.*, 2015). Naik *et al.* (2013) also reported that the racks used in stacking the hydroponic trays could be made of wood, steel or polyvinyl chloride (PVC) pipes.

A low-cost mobile system that can produce 40 kg of hydroponic fodder/day was reported by Tensingh *et al.* (2016) to have been used to mitigate diminishing land, rural labour, water and

pesticide accumulation problems in Tamil Nadu, India. Kamanga (2016) reported the production of hydroponic fodder in a simple greenhouse containing wooden frame shelves on which the hydroponic trays were stacked in Malawi, southern Africa. The internal environment of such low-cost units is usually influenced by the climatic conditions of the area, thus influencing the types of fodder plant that could be successfully grown at the location. A study in Tanzania showed that the temperature and humidity inside a low-cost hydroponic fodder system could be controlled using a hydro-net and a hydro-cloth, to ensure good growth and nutritional value of the fodder (Bakshi *et al.*, 2017). Fresh water is used for irrigation of the seeds with the aid of manual or automatic micro-sprinklers or a knapsack sprayer at the desired interval. Available published results show that the fodder could grow up to 20 - 30 cm before harvest in 7 - 8 days (Naik *et al.*, 2011, 2012 and 2013). The high electricity needs of the hi-tech system can be eliminated in the low-cost system, thus, significantly reducing the cost of fodder production (Naik and Singh, 2013). The low-cost system is therefore better adapted to the technology constrained developing countries like Nigeria.

The Effect of Sprouting on Cereal Grains

The sprouting of cereal grains for fodder production results in varied chemical and structural changes in the grains. The grain variety, quality, and sprouting conditions such as nutrient supply, pH, water quality, soaking time etc. are the critical factors that influence the sprouting and quality of the fodder produced (Sneath and McIntosh, 2003; Chrisdiana, 2018; Chana *et al.*, 2021b). During germination, enzyme activation causes the hydrolysis of nutrients in the seed to change to their simpler forms (Dung *et al.*, 2010; Lemmens *et al.*, 2018a), and is followed by the mobilization of the major storage reserves in the seed resulting in the

growth of the seedling (Bewley, 1997; Penas and Martinez-Villaluenga, 2020). The physical and biochemical reactions that underlie the process, include the weakening of seed coat, turning on of metabolic activities, activation of gene transcription, relaxation of the embryonic cell walls, and reassembly and biogenesis of organelles (Logan *et al.*, 2001; Ali and Elozeriri, 2017; Farooq *et al.*, 2022). The process, according to Bewley (1997) is divided into three phases with the initial rapid imbibition of water by the dry seeds being the first phase and results in all the matrices and cell contents becoming fully hydrated. During the second phase there is limited water uptake (plateau phase) in addition to a strong metabolic reactivation, while phase three is associated with further increase in water uptake which results in cell elongation and completion of germination. The rapid imbibition of water causes the quiescent dry seeds to rapidly revitalize their metabolic activity, including remobilization, degradation, and accumulation, resulting in biochemical, nutritional and functional changes in the seeds (Dziki *et al.*, 2015; Ali and Elozeriri, 2017). Thus, the enzymatic hydrolysis of seed nutrients such as proteins, lipids and carbohydrates, and the transportation of metabolites are dependent on water availability and imbibition (Bewley and Black, 1994). Other extrinsic factors that could prolong or terminate seed dormancy thereby influencing germination and seedling development include light, temperature, and media conditions (Oh *et al.*, 2004; He *et al.*, 2016; Meng *et al.*, 2017). The primary and secondary metabolites formed from the process have been shown to exert differential biological and health effects when consumed, compared with non-germinated seeds (Nelson *et al.*, 2013; Ikram *et al.*, 2021).

The modification that occurs in the grains during sprouting, help to transform their inherent nutrients and antinutrients into digestible and essential forms, thus, improving their nutritional

values (Chavan and Kadam, 1989; Nelson *et al.*, 2013; Ikram *et al.*, 2021). Sprouting has specifically been shown to result in changes in the carbohydrate, protein, lipid, γ -aminobutyric acid, phytate, mineral content and antioxidant activities in the grain (Azeke *et al.*, 2011; Hung *et al.*, 2012; Youssef *et al.*, 2013; Benincasa *et al.*, 2015; Cho and Lim, 2016; You *et al.*, 2016; Lemmens *et al.*, (2018b). Significant increases in the quantity and quality of proteins, sugars, minerals and vitamins were reported by Naik *et al.* (2015), indicating that significant nutritional benefit are derivable from hydroponic fodder production. The hydroponic fodder production system also allows access to the plant root system which is usually not possible in conventional fodder due to the interference of soil-borne adulterants and compounds.

Biomass Yield from Hydroponic Fodder

Several studies have shown that biomass yields are significantly higher in hydroponic fodder production from grains when compared with their corresponding conventional fodder production. The hydroponically sprouted grains resemble a mat of 20 - 30 cm height, consisting of germinated seeds, roots, and leaves. The fresh yield of the hydroponic fodder has been shown to be mostly influenced by the type of seed (Sneath and McIntosh, 2003), days of harvesting (Dung *et al.*, 2010), degree of drainage of free water prior to weighing (Molla and Brihan, 2010), seed quality and seedling rate (Fazaeli *et al.*, 2012), irrigation frequencies, nutrient solution used, and light intensity (Naik *et al.*, 2012; Islam *et al.*, 2016). Some of these studies have also shown that the duration of growth has major influence on biomass yield and fodder height. Mohapatra *et al.* (2019) also reported that hydroponic fodder yield from maize, cow pea, rice and wheat were influenced by different seasons during three consecutive years. Al-Ajmi *et al.* (2009) reported a 2.76 to 3.0 ratio of green fodder to a kilogram of barley seeds, while maize, wheat and oats

seeds were reported by Rahman *et al.* (2019) to increase multiple folds in biomass yield over the quantity of seeds. Dung *et al.* (2010) and Fazaeli *et al.* (2012) specifically reported a range of 3.7 - 4.5-fold increase in the fresh weight of 6 - 7 days grown hydroponics barley fodder. Rachel *et al.* (2017) on the other hand reported a seed to fodder production ratio of 4.5 for foxtail millet. Naik *et al.* (2014) in their study reported an increase of 5 - 6 folds in the fresh weight of the hydroponically sprouted maize grains. In another study (Naik *et al.*, 2012) however reported a yield of 3.5 - 6.0 folds as being common for hydroponically sprouted maize grains in India.

Murthy *et al.* (2017) reported higher biomass yield after 5 days with millet seeds followed by sorghum, barley, and maize, while barley recorded the highest plant height, followed by maize, millet, and sorghum. Rahman *et al.* (2019) specifically reported 2573, 2736 and 3500 kg of fresh fodder from one kilogram of oat, maize, and wheat respectively after 8 days of growth. These studies confirm that variations exist across seeds and seasons of hydroponic fodder production. Mohapatra *et al.* (2019) reported the results of a study in which the seeding rates of 330 - 350 g barley and oats grain per tray (about 1 - 2 cm depth) was adopted and tap water containing the nutrient solution was used to irrigate plants twice a day (early morning and late afternoon) throughout the growing period at a fixed rate of 500 mL/tray/day. The average green fodder biomass yields (50.0% DM) at 7 days after sprouting were 5.21 (2.61 kg DM) and 6.32 (3.16 kg DM) kg barley and oats per 1 kg barley and oats grain respectively. Ndaru *et al.* (2020) in their study also established that corn hydroponic fodder weight stabilized on the 20th day of growth beyond which it decreased, while the fodder height stabilized by the 16th day of growth. Gebremedhin (2015) and Kide (2015) reported that hydroponically grown maize and barley recorded increased nutrient profile along with improved fresh fodder weight over those grown

on soil, also indicating the influence of growth media on the weight of hydroponic fodder.

According to FAOSTAT (2019), the average global production of sorghum was 50 megatons in that year with Nigeria being the second largest producer after the USA. In 2018, 6.86 million tons of sorghum grains were produced in Nigeria with an average productivity of 1,120 kg per hectare (IFAD, 2018). Sorghum is an important staple crop for millions of people, especially in West Africa, where the crop is the third most popular cereal crop and accounts for 20.7% of total cereal production (FAO, 2020). Sorghum grains can be used as a maize substitute in livestock feed because their nutritional values are similar even when grown for pasture and hay (Etuk *et al.*, 2012). It can also be grown for fodder for grazing animals or cut green and used in making silage or hay. Since some varieties stay green for a long period of time, their stalk is grazed by livestock after grains harvest (Balole and Legwaila, 2006; Heuze *et al.*, 2019). Sorghum fodder is highly relished by ruminants, and since it is drought resistant and can grow where maize is not able to grow because of high temperature or dry condition, it is used in ruminant feeding at many tropical and subtropical locations (Pedersen and Fritz, 2000). Therefore, because of its availability and possible lower cost, sorghum should be the preferred grain for hydroponic fodder production in Nigeria in place of wheat and barley which are used in the temperate countries.

Different sorghum varieties have been used for hydroponic fodder production in tropical developing countries, with varying results in both biomass yields, nutrient composition, and anti-nutrient contents (Chrisdiana, 2018; Wahyono *et al.*, 2018; Chana *et al.*, 2021a). A study in Nigeria by Oluwaniyi (2016) indicated that sorghum grains showed more resistance to mould growth than wheat grains during hydroponic fodder production, with the fodder reaching about 15 cm

in height after 10 days of growth. The wheat fodder trays on the other hand were covered with mould by the third day, thus, inhibiting sprouting and growth of the fodder. Chana *et al.* (2021a) reported a weight range of 2550 to 3500 g for the 8th day hydroponic fodder from different sorghum cultivars produced from 800 g of seed. Murty *et al.* (2017) however reported a change from 1.08 to 6.1 kg (464.82 % increase) on the 5th day for sorghum fodder produced under low-cost greenhouse production system. Garuma and Gurmessa (2021) in their study with four varieties of sorghum reported that twice watering per day watering frequency resulted in a better biomass yield, root height, leaf weight and leaf root ratio, while 9 days was the optimal duration for hydroponic sorghum fodder growth. Chana *et al.* (2021a) also reported a height range of 12.33 to 15.67 cm for the different sorghum cultivars grown for 8 days. The authors reported that beyond the 8th day, the fodder heights reduced, such that by the 16th day, they measured between 6.33 and 11.00 cm. Murthy *et al.* (2017) however, reported a height of 10.8 cm for the 5th day hydroponic sorghum fodder produced under low-cost greenhouse production system. Martins (2023) in a recent study at our station reported that although millet seeds produced shorter fodder, the percentage increases in weight after 8 days of sprouting was significantly higher than that of two sorghum cultivars.

Conclusion and Recommendations

Sustainable animal feed production and availability is critical to the livestock industry in Nigeria. Hydroponic fodder production systems could be an emerging alternative in facilitating sustainable animal feed production considering the challenges of climate change, seasonal variation in feed availability, issues of quality and quantity of fodder for all-year-round production. This could also provide feed sources for several classes of livestock including poultry to reduce competition with human food including the

prevalent conflict triggering pastoralist system of livestock production.

Nevertheless, several issues related to the socioeconomic feasibility of the hydroponic fodder production system across different animal production situations at various locations including traditional practices, disease prevalence, local policy, seasonal availability of feedstuff, costs, and moral issues and importantly, the type of grains to be used should be critically considered in a structured study.

It will be appropriate for the low-cost hydroponic fodder production system to be adopted as an innovative stop gap measure to mitigate the current challenges of feed availability for pastoralists and urban farmers at locations that are not traditional to them. Also, the emergence of more modern livestock production outfit in Nigeria should incorporate the high – tech hydroponic fodder production system as part of the sustainable feed production strategy both for their stock and as an alternative revenue venture which will over time complement the long held traditional practices.

References

- Achonwa, C. C., Ogbuewu, I. P., Ogundu, E.C., Kubkomawa, I. H., Uchegbu, M. C. and Okoli, I. C. 2017. Browse abundance and the methodologies for their selection as candidate feed resources in Nigeria. A review. *Nature and Science*, 15(5), 82 -94.
- Adeoye, A. A. 2021. Changing smallholder farmers' behaviour towards buying animal feed. *Business Day*, August 30, 2021.
- Adewale, M. 2020. Kano agro project invests ₦88 million on fodder production. *The Guardian Nigeria* September 14, 2020. Retrieved from <https://guardian.ng/features/agro-care/kano-agro-project-invests-n88-million-on-fodder-production/>.
- Aduku, A. O. 2004. *Animal nutrition in the tropics feed and feeding, pastures*

- management, monogastric and ruminant nutrition*. Davicom, Nigeria.
- Ahamed, M. S., Sultan, M., Shamshiri, R. R., Rahman, M. M., Aleen, M. and Balasundram, R. R. 2023.** Present status of fodder production in controlled environments: A review. *Smart Agricultural Technology*, 3 (20230 100080).
- Aina, A. B. J. 2012.** Goat (*Capra hircus*): A misunderstood animal. 35th Inaugural Lecture, Federal University of Agriculture Abeokuta, Nigeria
- Ajayi, F. T. 2008.** Nutritional evaluation of Guinea grass (*Panicum maximum*) intercropped with some legumes for West African Dwarf goats. Thesis, University of Ibadan, Nigeria.
- Al Ajmi, A., Salih, A. A., Kadim, I. and Othman, Y. 2009.** Chemical constituents and heavy metals contents of barley fodder produced under hydroponic system in GCC countries using tertiary treated sewage effluents. *Journal of Phytology*. 1(5), 342 - 348.
- Alexandratos, N. and Bruinsma, J. 2012.** World agriculture towards 2030/2050: The 2012 revision. ESA Working Paper No. 12 - 03. Food and Agricultural Organization, Rome.
- Ali, A. S. and Elozeiri, A. A. 2017.** Metabolic processes during seed germination. InTech.doi:10:5772/intechopen.70653.
- Al-Karaki G. N. and Al-Hashimi, M. 2012.** Green fodder production and water use efficiency some forage crops under hydroponic condition. *Internl. Schol. Res. Network*.
<https://doi.org/10.5402/2012/924672>.
- Al-Karaki, G.N. and Al-Momani, N. 2011.** Evaluation of some barley cultivars for green fodder production and water use efficiency under hydroponic conditions. *Jordan Journal of Agricultural Sciences*, 7(3).
- Amodou, H., Dossa, L. H., Lompo, D. J., Abdulkadir, A. and Schlecht, E. 2012.** A comparison between urban livestock production strategies in Burkina Faso, Mali, and Nigeria in West Africa. *Tropical Animal Health and Production*, 44, 1631 - 1642.
- Amole, T., Ayantunde, A., Balehegn, M. and Adesogoan, A. T. 2002.** Livestock feed resources in West Africa. *Agronomy Journal*, 114(1), 26 - 45.
- Anonymous 2008.** Grass Fodder by hydroponic in 8 days. <https://grassfodder.com/hydroponic.php>. Accessed April 25, 2023.
- Aregheore, E. M. 1996.** Natural grasses and ruminant interaction in the dry season in Delta state, Nigeria. *World Review of Animal Production*, 31 (1-2), 74 - 79.
- Aregheore, E. M. 2001.** Effect of supplementation of crop residues-based diets on the performance of steers grazed on natural pasture during the dry season. *African Journal of Range and Pasture Science*, 18, 25 – 29.
- Attia-Ismail, S. 2019.** Impact of climate change on forages production, world wide efforts for mitigation and adaptation and concept of smart climate agriculture. In: *Arid-lands: Biodiversity, management and conservation*. Nova Science Publishers, Inc, New York, USA. Pp, 207 - 223.
- AU-IBAR 2016.** Livestock policy landscape in Africa: A review. <http://www.au-ibar.org/component/jdownloads/finish/36-vet-gov/2712-livestock-policy-landscape-in-africa-a-review>.
- Azeke, M. A., Egielewa, S. J., Eigbogbo, M. U. and Ihimire, I. G. 2011.** Effect of germination on the phytase activity, phytate and total phosphorus contents of rice (*Oryza sativa*), maize (*Zea mays*), millet (*Panicum miliaceum*), sorghum (*Sorghum bicolor*) and wheat (*Triticum aestivum*). *Journal Food Science Technology*, 48, 724 - 729.

- Babayemi, O. J. and Bamikole, M. A. 2006.** Effect of *Tephrosia candida* DC leaf and its mixture with Guinea grass on in vitro fermentation changes of feed for ruminants in Nigeria. *Pakistan Journal of Nutrition*, 5, 14 - 18.
- Babayemi, O. J., Inyang, U. A., Ifut, O. J. & Isaac, I. J. 2010.** Nutritional value of cassava waste ensiled with *Albizia saman* pod as feed for ruminants in off season. *Agricultural Journal*, 5(3), 220 - 224.
- Bakshi, M. P. S., Wadhwa, M. and Makkar, H. P. S. 2017.** Hydroponic fodder production: A critical assessment. *Broadening Horizons* No 48, December 2017. 10 pages.
- Balehegn, M., Kebreab, E., Tolera, A., Hunt, S., Erickson, P., Crane, T. A. and Adesogan, A. T. 2021.** Livestock sustainable research in Africa with a focus on the environment. *Animal Frontiers*, 11(4), 47 - 56.
- Balole, T. V. and Legwaila, G. M. 2006.** *Sorghum bicolor* (L.) Moench. Record from Protabase. Brink, M. & Belay, G. (Eds). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands.
- Bamaiyi, P. H. 2013.** Factors militating against animal production in Nigeria. *International Journal of Livestock Research*, 3(2), 54 - 66.
- Bayala, J., Ky-Dembele, C., Kalinganire, A., Alain, O. and Hamidou, N. 2014.** Review of pasture and fodder production and productivity of small ruminants in the sahel ICRAF Occasional Paper No 21. World Agro Forestry Canter.
- Benincasa, P., Galieni, A., Manetta, A. C., Pace, R., Guiducci, M., Pisante, M. and Stagnari, F. 2015.** Phenolic compounds in grains, sprouts and wheat grass of hulled and non-hulled wheat species. *Journal of Science, Food and Agriculture*, 95, 1795 - 1803.
- Bewley, J. D. 1997.** Seed germination and dormancy. *Plant Cell*, 9, 1055 - 1066.
- Bewley, J. D. and Black, M. 1994.** *Physiology of development and germination*, 2nd edition. Plenum Press, New York, USA.
- Bharti, N. K., Dongargaonkar, M. D. and Das, S. 2019.** Hydroponic system for soilless farming integrated with android application by Internet of Things and MQTT broker. *IEEE Pune Section International Conference (PuneCon)*. MIT World Peace Universality, Pune, India, December 18 - 20, 2019. 5pages.
- Blanch, R. 2017.** Pastoral conflict and supplying Nigeria with meat: How can the paradox be solved? Field Investigations on Pastoralist-Farmer Crisis Areas. <https://www.academia.edu/33433878/>
- Bogoro, S., Kalla, D. J. U. and Fomukong, B. 2006.** Chemical composition and in situ rumen degradability of blood meal and urea treated crop residues. *Nigerian Journal of Experimental and Applied Biology*, 7(1), 27 - 35.
- Brahlek, A. 2023.** Advantages and disadvantages of hydroponic. Retrieved from <https://www.trees.com/gardening-and-landscaping/advantages-disadvantages-of-hydroponics> on April 25, 2023.
- Brownin, D. A. 2017.** Hydroponic fodder systems. <https://worldagnetwork.com/hydroponic-foddersystems/>
- Bulcha, B., Diba, D. and Gobena, G. 2022.** Fodder yield and nutritive value of hydroponically grown local barley landraces. *Ethiopian Journal of Agricultural Science*, 32, 31 - 49.
- Chana, Z. M., Abubakar, M., Kalla, D. J. U. and Bello, K. M. 2021a.** Effect of cultivator and harvesting time on growth components and chemical composition of hydroponic sorghum fodder. *Nigerian Journal of Animal Science and Technology*, 4(4), 35 - 45.
- Chana, Z. M., Abubakar, M., Kalla, D. J. U. and Bello, K. M. 2021b.** Growth performance of Balami rams fed four varieties of

- hydroponic sorghum fodder (HSF) with supplement in semi-arid environment. *Journal of Agriculture and Environment*, 17 (2), 63 - 70.
- Chapman, S. C., Chakraborty, S., Dreccer, M. F. and Howden, S. M. 2012.** Plant adaptation to climate change opportunities and priorities in breeding. *Crop Pasture Science*, 63, 251 - 268.
- Chavan, J. and Kadam S. S. 1989.** Nutritional improvement of cereals by sprouting. *Food Science and Nutrition*, 28(5), 401 - 437.
- Chrisdiana, R. 2018.** Quality and quantity of sorghum hydroponic fodder from different varieties and harvest time. *IOP Conf. Series: Earth and Environment Science*, 119, (2018) 01204. Pp: 1 - 5.
- Christensen, S. 2013.** A new approach to feeding livestock. *Sprouted Fodder System*. www.naturessed.com
- Cho, D. H. and Lim, S. T. 2016.** Germinated brown rice and its bio-functional compounds. *Food Chemistry*, 196, 259 - 271.
- Downing, T. 2016.** Ruminants are more important to the world than you might have thought. *Dairy Bearing*. <https://blogs.oregonstate.edu/dairy/2016/12/12/ruminants-important-world-might-thought/>.
- Dung, D. D., Godwin, I. R. and Nolan, J. V. 2010.** Nutrient content and in sacco degradation of hydroponic barley sprouts grown using nutrient solution or tap water. *Journal of Animal and Veterinary Advances*, 9, 2432 - 2436.
- Dziki, D., Gawlik-Dziki, U., Kordowska-Wiater, M., Domań-Pytka, M. 2015.** Influence of elicitation and germination conditions on biological activity of wheat sprouts. *J. Chem.*, 1-8.
- El-Deeba, M. M., El-Awady, M. N., Hegazi, M. M., Abdel Azeem, F. A. and El-Bourdyny, M. M. 2009.** Engineering factors affecting hydroponics grass-fodder production. In: *Agricultural engineering and variables of the present epoch. The 16th Annual Conference of the Misr Society of Agricultural Engineering*, 25, 1647 - 1666.
- Elmulthum, N. A., Zeineldin, F. I., Al-Kateeb, S. A., Al-Barrak, K. M., Mohammed, T. A., Sattar, M. N. and Mohmand, A. S. 2023.** Water use efficiency and economic evaluation of the hydroponic versus conventional cultivation systems for green fodder production in Saudi Arabia. *Sustainability*, 2023, 15(1), 822.
- Esonu, B. O. 2009.** Unconventional feed resources for livestock development and food security. Paradigms for Nigeria livestock industry. 14th Inaugural Lecture, Federal University of Technology, Owerri, Nigeria.
- Espiritu, K. 2022.** History of hydroponics: When was hydroponics invented? *Gardening*, June 21, 2022.
- Etuk, E. B., Ifeduba, A.V., Okata, U. E., Chiaka, I., Okoli, I. C., Okeudo, N. J., Esonu, B. O., Udedibie A. B. I. and Moreki, J. C. 2012.** Nutrient composition and feeding value of sorghum for livestock and poultry: A review. *Journal of Animal Science Advances*, 2(6), 510 - 524.
- Fakoya, E. O. and Oloruntoba, A. 2009.** Socio-economic determinants of small ruminants' production among farmers in Osun state, Nigeria. *Journal of Humanities, Social Sciences and Creative Arts*, 4(1), 90 - 100.
- FAO 2019.** The future of livestock in Nigeria. Opportunities and challenges in the face of uncertainty. Food and Agricultural Organization of the United Nation, Rome.
- FAO 2020 FAOSTAT.** Food and Agricultural Organisation, Rome. Retrieved on 16 November 2020 from <http://www.fao.org/faostat/fr/#data/QC>. G oogle Scholar.
- FAO 2023.** Gateway to dairy production and products Food and agricultural Organization of the United Nations, Rome. Dairy

- production and products: Production systems (fao.org).
- FAOSTAT 2019.** Production and yield quantity of sorghum in world. Food and Agricultural Organisation, Rome. <http://www.fao.org/faostat/en/ttdata/qc/visualize>.
- Farooq, M. A., Ma, W., Shen, S. and Gu, A. 2022.** Underlying biochemical and molecular mechanisms for seed germination. *International Journal of Molecular Sciences*, 23(15), 8502.doi.10.3390/ijms23158502
- Fazaeli, H., Golmohammadi, H. A., Tabatabayee, S. N. and Asghari-Tabrizi, M. 2012.** Productivity and nutritive value of barley green fodder yield in hydroponic system. *World Applied Science Journal*, 16(4), 531 - 53.
- Field, C. R. 2018.** *Utilization of marginal and arid range lands for livestock and wildlife in Africa.* BSAP Occasional Publication, 2021. Cambridge University Press, UK.
- Foley, J. A. 2011.** Solutions for a cultivated planet. *Nature*, 478: 337–342.
- Fuglie, F., Peters, M. and Burkart, S. 2021.** The extent and economic significance of cultivated forage crops in developing countries. *Frontiers in Sustainable Food Systems*, 26(5), | <https://doi.org/10.3389/fsufs.2021.712136>.
- Garuma, Z. and Gurmessa, K. 2021.** Evaluation of hydroponic fodder performance of different varieties of sorghum. *International Journal of Research - Granthaalayah*, 9(2), 1 – 10.
- Gebremedhin, W. K. 2015.** Effect of growing media on nutrient profile of conventional and hydroponic maize fodder. *Internal Journal of Scientific Research*, 4(9), 225 - 227.
- Ghorbel, R., Chakchak, J., Kosum, N. and Cetin, N. S. 2022.** Hydroponic technology for green fodder production; Concept, advantages, and limits. *Proceedings of the 6th International Students Science Congress*, Izmir, Turkey. Pp.: 10.
- Ghorbel, R. and Kosum, N. 2022.** Hydroponic fodder production: An alternative solution for feed scarcity. *Proceedings of the 6th International Students science Congress*, Izmir, Turkey. 9 pages.
- Hauser, M., van Rooyen, A., Kee-Tui, S.H., Ajeigbe, H. and Henze, J. 2021.** Towards a green new deal mitigating conflicts between pastoralists and farmers. Issue Brief, International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), Kenya. 4 pages.
- He, H., Willems, L.A.J., Batushansky, A., Fait, A., Hanson, J., Nijveen, H., Hilhorst, H. and Bentsink, L. 2016.** Effect of parental temperature and nitrate on seed performance are reflected by partly overlapping genetic and metabolic pathways. *Plant Cell Physiology*, 57, 473 - 487.
- Heuze, V., Tran, G., Hassaoun, P. and Lebas, F. 2019.** Fonio (*Digitaria exilis*) forage. Feedipedia, a programme by INRAE, CIRAD, AFZ and FAO. <https://www.feedipedia.org/node/460> Last updated on August 30, 2019, 11:43.
- Hung, V. P., Maeda, T., Yamamoto, S. and Morita, N. 2012.** Effects of germination on nutritional composition of waxy wheat. *Journal of Science, Food and Agriculture*, 92, 667 - 672.
- Ibrahim, A. M., Idris, H. A. and Kiyawa, A. I. 2018.** Economic and environmental implications of fodder production in Kano metropolis. *Dutse Journal of Pure and Applied Sciences*, 4(1), 29 - 41.
- IFAD 2018.** Developing nutrition-sensitive value chains in Nigeria. Findings from research for development. International Fund for Agricultural Development (IFAD) <https://www.ifad.org/en/web/knowledge/>
- Ifeduba, A. V. 2018.** Development of computer models on the performance response of chickens fed alternative feedstuffs. M.Sc

- Thesis, Federal University of Technology, Owerri, Nigeria.
- Ikram, A., Saeed, F., Afzaal, M., Imram, A., Niaz, B., Tufail, T., Hussain, M. and Anjum, F. M. 2021.** Nutritional and end use perspectives of sprouted grains: A comprehensive review. *Food Science and Nutrition*, 9(8), 4617 - 4628.
- Iro, I. 2020.** Where modernization has failed and traditionalism has thrived: A look at commercial ranching and Fulani herding system. <https://www.gamji.com/fulani9.htm>
- Islam, R., Jalal, N. and Akbar, M. A. 2016.** Effect of seed rate and water level on production and chemical analysis of hydroponic fodder. *European Academic Research*, 4 (8), 6724 - 6753.
- Jank, L., Barrios, S. C., do Valle, C. B., Simeao, R. M. and Alves, G. F. 2014.** The value of improved pasture to Brazilian beef production. *Crop and Pasture Science*, 65(11), 1132 - 1137.
- Kamanga, Y. 2016.** YAP proposal #255: Hydroponic fodder: Increasing milk production and income! YAP-Youth Agripreneur Project. <https://blog.gfar.net/2016/03/09/yap-proposal-42-hydroponic-fodder-increasing-milk-production-andincome-yvonne-kamanga-malawi>. Updates from the Global Forum on Agricultural Research.
- Kerr, S., Conway, L. and Conway, A. 2014.** Fodder for forage: Facts, folly, fable or fabulous. Small Farms. oregonstate.edu/sfn/w14 fodder.
- Kide, W. G. 2015.** Effect of growing media on nutrient profile of conventional and hydroponic maize fodder. *International journal of Scientific Research*, 4(9), 225 - 227.
- Kide, W., Desai, B. and Kumar, S. 2015.** Nutritional improvement and economic value of hydroponically sprouted maize fodder. *Life Sciences International Research Journal*, 2, 76 - 79.
- Kubkomawa, I. H. 2016.** Studies on the characteristics of pastoral cattle production in Adamawa state, guinea Savanna zone of Nigeria. PhD Thesis, Federal University of Technology, Owerri, Imo state, Nigeria.
- Kubkomawa, I. H. 2017.** Indigenous breeds of cattle, their productivity, economic and cultural values in sub-Saharan Africa. A review. *International Journal of Research Studies I Agricultural Sciences*, 3(1), 27 - 43.
- Kubkomawa, H. I., Adamu, S. M., Achonwa, C. C., Adewuyi, K. A. and Okoli, I. C. 2018.** Beef production and marketing in Nigeria: Entrepreneurship in animal agriculture. *International Journal of Veterinary Sciences and Animal Husbandry*, 3(2), 26 - 40.
- Kubkomawa, I. H., Kenneth-Chukwu, O. M., Krumah, L. J., Yerima, I. N., Audu, Z. and Nafarnda, W. D. 2019.** Fodder bank establishment and management for dry season maintenance of small-scale livestock industry: A review. *Nigerian Journal of Animal Production*, 46(4), 211 - 221.
- Kubkomawa, I. H., Kenneth-Chukwu, O. M. 2019.** Forage resources utilization and management for greater ruminant production: A review. *International Journal of Agricultural Research, Sustainability and Food Sufficiency*, 6(1), 295 - 314.
- Kubkomawa, I. H., Ogundu, U. E., Okoli, I. C. and Udedibie, A. B. I. 2016.** Current nutrient resource characterization and the limitations of pastoral cattle producers in Nigeria. *International Journal of Agricultural Research, Sustainability and Food Sufficiency*, 3(5), 91 - 106.
- Kubkomawa, I. H., Krumah, L. J., Etuk, E. B. and Okoli, I. C. 2015.** Current pastoral cattle production situation in West Africa: A review. *Dynamic Journal of Animal Science and Technology*, 1(1), 1 - 17.
- Kumar, R. R. and Cho, J. Y. (2014).** Reuse of hydroponic waste solution . *Environmental*

- Science and Pollution Research, 21(16), 9569 - 9577.
- Lamidi, A. A. and Ologbose, F. I. (2014).** Dry season feeds and feeding: A threat to sustainable ruminant animal production in Nigeria. *Journal of Agriculture and Social Research*, 14 (1), 17 – 30.
- Lamidi, A. A., Aina, A. B. J. and Alikwe, P. C. N. 2013.** Digestibility and nitrogen balance of sole malted sorghum sprout, maize stover and rice straw in west African Dwarf goat. *African Journal of Livestock Extension*, 11, 6 - 10.
- Laroche, G., Gelinat, N., Doyon, M., Domon, G. and Olivier, A. 2015.** Integrated agroforestry inter-cropping system in contrasted agricultural landscape: A SWOT-AHP analysis of stakeholders' perception. *Proceedings of XIV World Forestry Congress*. 7 - 11 September 2015, Durban, South Africa.
- Lawal-Adebowale, O. A. 2012.** Dynamics of ruminant livestock management in the context of the Nigerian agricultural system. In: Javed, K. (Ed.). *Livestock production*. IntechOpen, London, 61 p. <https://doi.org/10.5772/52923>.
- Lemmens, E., Moroni, A.V., Pagand, J., Heirbaut, P., Ritala, A., Karlen, Y., Le, K., van de Broeck, H. C., Brouns, F. J. P. H., de Brier, N. and Delcour, J. A. 2018a.** Impact of cereal sprouting on its nutritional and technological properties: A critical review. *Comprehensive Reviews in Food Science and Food Safety*, 18(1), 305 - 328.
- Lemmens, E., De Brier, N., Spiers, Goos, P., Smolders, E., Delcour, J. 2018b.** The impact of wheat germination and hydro-thermal processing on phytate hydrolysis and the distribution, speciation and bio-accessibility of Fe and Zn. In: *Proceedings of the International Symposium on Zinc*, September 5 - 7, Leuven, Belgium.
- Logan, D. C., Millar, A. H., Sweetlove, L. J., Hill, S. A., and Leaver, C. J. 2001.** Mitochondrial biogenesis during germination in maize embryos. *Plant Physiol.*, 125, 662–672.
- Martins, U. 2023.** The potential of selected local seeds for hydroponic fodder production in Owerri, south-eastern, Nigeria. MSc Thesis Defence, federal University of technology, Owerri, Nigeria
- Martins, U., Giwa, L. A., Ohanaka, A. U. C., Ukwadinamor, J. U., Anyanwu, N. J. and Okoli, I. C. 2023.** Impact of growth period on biomass yield and dry matter content in sorghum and millet hydroponic fodders. *International Journal of Agriculture and Rural Development*, 26(1), 6688 - 6693.
- Meng, Y., Shuai, H., Luo, X., Chen, F., Zhou, W., Yang, W. and Shu, K. 2017.** Karrikins: Regulators involved in phytohormones signaling networks during seed germination and seedling development. *Frontiers in Plant Science*, 7, 2021. doi.103389/fps.2016.02021.
- Mohapatra, K. K., Mohapatra, S, Ekka, R., Behera, R. C. and Mohanta, R. K. 2019.** Variations in round-the-year fodder production in a low-cost hydroponic shed. *National Academy Science Letters*, 42(5), 383 - 385.
- Molla, A. and Birhan, D. 2010.** Competition and resource utilization in mixed cropping of barley and durum wheat under different moisture stress levels. *World Journal Agricultural Science*, 6(6), 713 - 719.
- Mooney. J. 2005.** Growing cattle feed hydroponically. *Meat and Livestock*, Australia. 30 p.
- Moses, P. C. 2019.** Approaches, practices, and nutrient contents of small-holder pig farms diets at two Local Government Area in Imo state, Nigeria. B. Agric Tech. Project Report, Federal University of Technology Owerri, Imo State, Nigeria.
- Mottet, A., de Haan, C., Falcucci, A., Tempio, G., Opio, C. and Pierre Gerber, P. 2017.** Livestock: On our plates or eating at our table? A new analysis of the feed/food debate.

- Global Food Security*, 14, 1 - 8, <https://doi.org/10.1016/j.gfs.2017.01.001>.
- Muhammad, I. R. 2019.** Forage and fodder production in Nigeria: its sensitivity in sustainable ranching. Inaugural Lecture No. 36, Bayero University Kano, Nigeria.
- Murthy, A. K., Dhanalakshmi, G. and Chakravarthy, K. 2017.** Study on performance of different fodder crops under low-cost greenhouse hydroponic fodder production System. *International Journal of Environment, Agriculture and Biotechnology*, 2 (2), <http://dx.doi.org/10.22161/ijeab/2.2.50>.
- Mwennidia, S., Notenbaert, A. and Araba, D. 2017.** How forage production can play a role in Nigeria's nomadic/farm-holder's conflict. cgspace.cgiar.org.
- Naik, P. K. 2014.** Hydroponics green fodder for dairy animals. In: Bakshi, M.P.S. and Wadhwa, M. (Eds.). *Recent advances in animal nutrition*. Satish Serial Publishing House, New Delhi. Pp: 191 - 210.
- Naik, P. K., Dhuri, R. B., Karaunakaran, M., Swain, B. K. and Singh, N. P. 2014.** Effect of feeding hydroponic maize fodder on digestibility of nutrient and milk production in lactating cow. *Indian Journal of Animal Science*, 84(8), 880 - 883.
- Naik, P. K., Dhuri, R. B. and Singh, N. P. 2011.** Technology in production and feeding of hydroponic green fodder. Extension Folder No 45/2011, ICAR Research Complex for Goa, Goa, India.
- Naik, P. K., Dhuri, R. B., Swain, B. K. and Singh, N. P. 2012.** Cost of production of hydroponics fodder maize. In: *Proc. of 8th Biennial Animal Nutrition Association Conference on 'Animal Nutrition Research Strategies for Food Security*. November 28-30, 2012, Bikaner, Rajasthan, India.
- Naik, P. K., Dhuri, R. B., Swain, B. K. and Singh, N. P. 2013.** Water management for green fodder production as livestock feed in Goa. In: Abstracts of International Conference on 'Water Management for Climate Resilient Agriculture' held at Jalgaon, Maharashtra, India, May 28 - 31. Pp: 126 - 127.
- Naik, P. K. and Singh, N. P. 2013.** Hydroponic fodder production: An alternative technology for sustainable livestock production against impending climate change. In: *Compendium of model training course, management strategies for sustainable livestock production against impending climate change*. November 18 - 25, 2013.
- Naik, P. K., Swain, B. K., Chakurkar, E. B. and Singh, N. P. 2017.** Effect of seed rate on yield and proximate constituents of different parts of hydroponics maize fodder. *India Journal of Animal Science*, 87(1), 109 - 112.
- Naik, P. K., Swain, B. K. and Singh, N. P. 2015.** Production and utilization of hydroponics fodder: A review. *Indian Journal of Animal Nutrition*, 32, 1 - 95.
- Ndaru, P. H., Huda, A. N., Marjuki, Prasetyo, R. D., Shofiatun, U., Nuningtyas, Y. F., Ndaru, R. K. and Kusmartono, 2020.** Providing high quality forage with hydroponic fodder system. *IOP Conf. Series: Earth and Environmental Science*, 478 (2020) 012054.
- Nelson, K., Stojanovska, L., Vasiljevic, T., and Mathai, M. 2013.** Germinated grains: A superior whole grain functional food? *Can. J. Physiol. Pharmacol.*, 91, 429-441.
- Newell, R., Newman, L., Dickson, M., Vanderkooi, B., Fernback, T. and White, C. 2021.** Hydroponic fodder and greenhouse gas emissions: A potential avenue for climate mitigation strategy and policy development. *Facets*, 6, 161 - 163.
- Njidda, A. A. 2010.** Chemical composition, fibre fraction and anti-nutritional substances of semi-arid browse forages of North-eastern Nigeria. *Nigerian Journal of Basic and Applied Sciences*, 18(2), 181 - 188.
- Njidda, A. A. and Olatunji, E. A. 2012.** Evaluation of macro and micro mineral concentrations of browse forages in relation to

- ruminant's requirement: A case study of Gwoza, Bornu state, Nigeria. *Journal of Natural Science Research*, 2(7), 60 - 64.
- Nyirenda, K. K. 2020.** Toxicity potential of cyanogenic glycoside in edible plants. In: Erkekaglu, P. and Ogawa, T. (Eds). *Medical toxicology*. IntechOpen DOI: <https://dx.doi.org/10.5772/intechopen.91408>.
- Oh, E., Kim, J., Park, E., Kim, J. I., Kang, C. and Choi, G. 2004.** PIL5, a phytochrome-interacting basic helix-loop-helix protein, is a key negative regulator of seed germination in *Arabidopsis thaliana*. *Plant Cell*, 16, 3045 - 3058.
- Ogunbosoye, D. O. & Babayemi, O. J. 2010.** Potential values of some non-leguminous browse plants as dry season feed for ruminants in Nigeria. *African Journal of Biotechnology*, 9(18), 2720 - 2726.
- Ohanaka, A. U. C., Nwogu, C. M., Ekenyem, B. U. and Okoli, I. C. 2017.** Practical approaches to palm kernel cake utilization in pig feeding by small-scale farmers in Eastern Nigeria. *Proceedings of the first TropiSymposium, December 7th - 8th 2017*, Owerri, Nigeria. Pp: 174-182.
- Ojo, V. M. O., Adeoye, S. A., Oni, A. O., Adelusi, O. O., Yusuf, K. O., Jolaosho, A. O., Olanite, J.A. and Onifade, O. S. 2017.** Nutritive value of processed feed resources from natural postures within southwest Nigeria. *Archivos de Zootecnia*, 66(256), 469 - 474.
- Okoli, I. C., Ebere, C. S., Uchegbu, M. C., Udah, C. A. and Ibeawuchi, I. I. 2003.** A survey of the diversity of plants utilized for small ruminant feeding in South-eastern Nigeria. *Agriculture, Ecosystem and Environment*, 96, 147 - 154.
- Okoli, I. C., Enyinnia, N. C., Elijah, A. G. and Okoli, C. G. 2014.** Cattle feeding management of pastoralists and conflict resolution strategies in tropical humid rain forest zone of southeastern Nigeria. *Journal of International Science Publication: Agriculture and Food*, 2, 16 - 17.
- Okoli, I. C., Enyinnia, N. C., Elijah, A. G., Omede, A. A. and Unamba-Opara, C. I. 2012.** Animal reproductive management practices of Fulani pastoralist in the humid rain forest of Imo state, Nigeria. *Journal of Animal Science Advances*, 2(2), 221 - 225.
- Olajunju, T. E. 2015.** Drought, desertification and the Nigerian environment. A review. *Journal of Animal and Veterinary Advances*, 7(7), 196 - 209.
- Olajide, E. and Akpan, S. 2020.** Livestock production in Nigeria: A thriving industry. One Health and Development Initiative (OHDI), October, 2020. Abuja, Nigeria.
- Olawoye, U. H. and Kubkomawa, H. I. 2018.** *Principles of pasture and range management for agricultural science and related disciplines*. Tapas Publishing Co., Owerri, Nigeria.
- Oluwafisayomi, K. 2021.** Commercialized animal feed: Lessons from Advancing Local Dairy Development in Nigeria. *Business Day*, September 7, 2021
- Oluwaniyi, O. O. 2016.** Hydroponic fodder production: A sustainable solution to ending conflicts between farmers and Nomadic-Fulani nomads in Nigeria. <https://www.nairaland.com/3518538/hydroponics-fodder-production-nigerian-grass>. Retrieved April 12, 2023.
- Oluwatayo, I.B. and Oluwatayo, T. B. 2012.** Small ruminants as a source of financial security: A case study of women in rural southwest Nigeria. Working Paper 2012-2, Institute for Money, Technology and Financial Inclusion, University of California, Irvine, USA. 21 pages.
- Omokaye, A. T. 2001.** Forage yield and chemical composition of Centro (*Centrocema pubescens*) in the year of establishment at Shika, Nigeria. *Tropical Grassland*, 35, 53 - 57.
- Osinowo, O. A. 2020.** Strategies for improving ruminant production in Nigeria: The ranching

- option. In: *Animal Agriculture: The value-chain goldmine of Nigeria's agro-revolution. Proceedings of the 45th Annual Conference of the Nigerian Society for Animal Production*, Bauchi, Nigeria.
- Ouda, J. O. 2001.** Feeding and care of livestock. In: *Managing dryland resources. A manual for Eastern and Southern Africa*. International Institute for Rural Reconstruction (IIRR), Silang, Cavite, Philippines.
- Panel, M. M. 2020.** Meat, milk and more: Policy innovations to shepherd inclusive and sustainable livestock systems in Africa. International Food Policy Research Institute, Washington DC. <http://www.ifpri.org/cdmref/pl5738coll2/id/133855/filename/134065.pdf>.
- Pedersen, J. F. and Fritz, J. O. 2000.** Forage and fodder. In: C.W. Smith (Ed.). *Sorghum, origin, history, technology, and production*. John Wiley and Sons Inc., Hoboken, NJ, USA.
- Peer, D. and Leeson, S. 1985.** Feeding value of hydroponically sprouted barley for poultry and pigs. *Animal Feed Science and Technology*, 13, 183.
- Penas, E. and Martinez-Villaluenga, C. 2020.** Advances in production, properties and applications of sprouted seeds. *Foods*, 9(6), doi:10.3390/foods9060790.
- Rachel, J. E., Gnanaraj, P. T., Muthuramalingam, T., Devi, T., Babu, M. and Sunharesan, A. 2015.** Hydroponic green fodder production. TANUVAS Experiment, Tamil Nadu Veterinary and Animal Science University, India.
- Rachel, J. E., Gnanaraj, P. T., Muthuramalingam, T., Devi, T. and Vennila, C. 2018.** Nutritive value of hydroponic yellow maize fodder and conventional green fodder -a comparison. *International Journal of Agricultural Science & Veterinary Medicine*, 6(1), 98 - 101.
- Rahman, M. M., Jahan, S., Amanullah, S. M., Kabir, M. A., Tamanna, R. J., Hassan, M. M., Deb, G. K. and Hossain, S. M. J. 2019.** Study on comparative biomass yield, nutritional quality and economics of hydroponic sprout produced from different grains *Bangladesh Journal of Livestock Research*, 26 (1&2), 51 - 60.
- Reddy, Y. R. 2014.** Hydroponic fodder production. <http://www.authorstream.com/presentation/kiranreddy526438-2376257-hydroponic-fodderproduction/>
- Rota, A. and Sidahmed, A. 2010.** Livestock planning, challenges and strategies for livestock development in IFAD: IFAD's Livestock Position Paper. International Fund for Agricultural Development, Rome.
- Roysfarm 2022** Green fodder production starting guide for beginners. Green Fodder Production Starting for Beginners (roysfarm.com)
- Salo, S. 2019.** Effect of hydroponic fodder feeding on milk yield and composition of dairy cow: Review. *Journal of Natural Science Research*, 9(8): doi:po.7176/ JNSR.
- Santos, J. M., Rodriguez, V. E. and Carballo, M. C. 2018.** Using hydroponics to produce green fodder in the Canary Islands, Guimar, Spain.
- Sawant, A. 2021.** Growing hydroponic fodder step by step (7-days). Agriculture Guruji. Retrieved from <http://ariculturalguruji.com/hydroponic-fodder/> on January 4, 2022.
- Sawant, A. 2022.** Growing hydroponic fodder step by step guide (7 Days). Agriculture Guruji. Retrieved from agricultureguruji.com on April 24, 2023.
- Schoenian, S. 2016.** Hydroponic fodder: Is it a viable option for feeding sheep, goat and other livestock? Maryland Small ruminant Page. <https://www.sheepandgoat.com/hydrofodder#>
- Sehay, C. S., Pathrak, P. K. and Singh, S. K. 2016.** Mechanization in fodder production. Indian Grassland and Fodder Research Institute. Jhansi, UP. Pp. 7 - 12.

- Sharma, N., Acharya, S., Kumar, K., Singh, N. and Chaurasia, O. P. 2018.** Hydroponics as an advanced technique for vegetable production. An overview. *Journal of Soil and Water Conservation*, 17(4), 364 - 371.
- Shashank, S. and Krishna, T. C. 2012.** Development of a cost-effective, energy sustainable hydroponic fodder production device. Project Report, Indian Institute of Technology, Kharagpur, India.
<http://suruchiconsultants.com/pageDownloads/>
- Shiawoya, E. L. and Tsoda, D. N. 2011.** Forage and fodder crop production in Nigeria, problems, and prospects. *World Journal of Life Science and Medical Research*, 1(4), 88 - 93.
- Singh, R. 2020.** Method of hydroponics green fodder production. In: *Fodder production*. Retrieved from <https://www.pashudhanpraharee.com/> on January 4, 2022.
- Singh, K. M. and Meena, M. S. 2011.** Forage and fodder production - An economic view. In: Anil Kumar Singh, M. A. Khan, Nataraja Subash, K. M. Singh (Eds.). *Forages and fodder-Indian perspective* (First Edition). Daya Publishing House, New Delhi.
- Sneath, R. and McIntosh, T. 2003.** Review of hydroponic fodder production for beef cattle. Project Report NBP 332. Oct. 2003. Meat and Livestock, Queensland Government Department of Primary Industries, Dalby Queensland, Australia. Pp. 1 - 55.
- Starova, J. 2016.** Hydroponic fodder production. Feed the future programme of US Government global hunger and food security initiative in Ethiopia. United States Agency for International Development, Washington DC, USA.
- Steve, M. K. 2020.** Hydroponic fodder advantages and disadvantages. The plant list: A working list of all plant species' <http://www.theplantlist.org/tp1.1/record/kew-408976>. n. Retrieved 30 January 2015.
- Suman, M. and Thakur, D. 2021.** Round the year available green fodder: A step to profitable dairy farming. *India Dairyman*, April 2021, 68 - 72.
- Tensingh, G. P., Rachel, J. E. and Muthuramalingam, T. 2016.** Low cost hydroponic device. New technologies for livestock farmers-Introduction and release-2016. TANUVAS Experiment, Tamil Nadu Veterinary and Animal Science University, India.
- Tobias, P. 2021.** Hydroponic fodder production: An innovative solution in times of drought. Namibia Econ., <https://doi.org/http://www.fao.org/fao-stories/article/c/1374689/>.
- Tranel, L. F. 2013.** Hydroponic fodder system for dairy cattle? *Animal Industry Report*, 659, 42.
- Tudor, G., Darcy, T., Smith P. and Shall, C. 2003.** The intake and live weight change of drought master steers fed hydroponically grown, young sprouted barley fodder. *Journal of Food Agriculture*, 23(1), 80 - 89.
- Tulu, D., Gadissa, S., Hundessa, F. and Kebede, E. 2023.** Contribution of climate-smart forage and fodder production for sustainable livestock production and environment: Lessons and challenges from Ethiopia. *Advances in Agriculture*, Article ID 8067776, 11.
<https://doi.org/10.1155/2023/8067776>
- Ukwu, C. P., Yahaya, A., Okere, P. C., Aladi, N. O., Odoemenam, V. U., Obikaonu, H. O., Uchegbu, M. C. and Okoli, I. C. 2022.** The production, uses, nutritional and anti-nutritional characteristics of cocoyam as a potential feed ingredient in the tropics. A review. *Nigerian Journal of Animal Science*, 24(3), 91 - 111.
- Usman, M. and Nichol, J. 2022.** Changes in agricultural and grazing land, and insights for mitigating farmer-herder conflicts in West

- Africa. *Landscape and Urban Planning*, 222(2), 104383.
- Van Zanten, H. H. E., Mollenhorst, H., Klootwijk, C. W., Van Middlelaar, C. E. and De Boer, I. J. M. 2015.** Global food supply: Land use efficiency of livestock system. *International Journal of Life Cycle Assessment*, doi:10.1007/S//367-015-949-1.
- Varrella, S. 2020.** Consumption of livestock products in Nigeria, 2012 - 2050, by product. Statista GmbA, Hamburg, Germany.
- Varrella, S, 2021.** Livestock contribution growth to GDP in Nigeria, 2019 - 2021. Statista GmbH, Hamburg, Germany.
- Verner, D., Vellani, S., Klausen, A.L. and Tebaldi, E. 2017.** Refugee and host communities and frontier agriculture: Climate smart and water saving agriculture technologies for livelihoods. World Bank, Washington DC, <https://doi.org/10.4569/29753>
- Wahyono, T., Hardani, S. N. W. and Sugoro, I. 2018.** Low irradiation dose for sorghum seed sterilization: Hydroponic fodder system and *in vitro* study. *Bulletin Peternakan*, 42(3), 215 - 221.
- Wilkinson, J. M. and Lee, M. R. F. 2017.** Use of human-edible feed by ruminant livestock: A review. *Animal*, 12(8), 1735 - 1743.
- You, S. Y., Oh, S. G., Han, H. M., Jun, W., Hong, Y. S. and Chung, H. J. 2016.** Impact of germination on the structures and *in vitro* digestibility of starch from waxy brown rice. *Int. J. Boil. Macromol.*, 82, 863 - 870.
- Youssef, M. K. E. S., El-Fishawy, F. A. E. K., Ramadan, E. S. A. E. N. and Abd El-Rahman, A. M. 2013.** Nutritional assessment of barley, talbina and their germinated products. *Sci. J. Crop Sci.*, 2, 8 - 19.
- Zhang, C., Campana, P. E., Yang, J., Yu, C. and Yan, J. 2018.** Economic assessment of photovoltaic water pumping integration with dairy milk production. *Energy Conversion and Management*, 177, 750 - 764.
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