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Smallholder dairy cattle feeding technologies and practices in Tanzania: failures, successes, challenges and prospects for sustainability

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ABSTRACT

In Tanzania, milk production under smallholder farming systems is season sensitive, fluctuations of feeds in both quantity and quality being the major driver. A dry season decline in milk production of over 40% due to feed scarcity is a common phenomenon. Adoption of improved feed production, conservation and utilization technologies and practices in dairy farming communities is poor. This review work was based on a key question which states "Why is adoption of improved dairy nutrition technologies and practices in Tanzania still poor despite being promoted for decades?". We have shown that major opportunities for curbing dry season animal feed shortage include on-farm optimization of production and use of high yielding pasture varieties including napier grass (*Pennisetum purperium* Schumach.) and leguminous fodder species. Crop residues in particular maize stover needs to be optimized for effective dry season feeding. The major reasons for low adoption of proven technologies include limited technical knowhow among smallholder dairy farmers augmented by limited extension services and technological costs. For enhancing sustainable uptake; we suggest promotion of on-farm research, public-private partnerships and dairy farmers' cooperative associations. These are vital for facilitating smooth access to information, investment capital, reliable inputs and markets among the smallholder dairy farmers.

KEYWORDS

Pasture production; forage conservation; feed technology; smallholder dairy farming; dairy nutrition

Introduction

Smallholder dairy farming (SDF) plays a very important livelihood role to about 20% of the world population mostly the rural and peri-urban dwellers (McDermott et al., 2010). In particular, the SDF safeguards food security and enhances access to animal protein (FAO, 2011). In addition, SDF improves household income and empowers the resource-poor rural communities mainly women through selling of surplus milk and dairy products (Paris, 2002). Although smallholder dairy farming systems (SDFS) are characterized by low milk productivity, its major advantage is lower production costs due to use of 'low-tech' and reliance on cheap-feeds which are often locally produced, i.e. low-input-low-yield production system (FAO, 2010). In such systems, the main feed is grass and crop residues which are considerably lower in cost than the predominantly imported grain which is fed to high-yielding dairy cows (high-input-high-yield) in the developed world.

McDermott et al. (2010) described the East African SDF as small farms often comprising less than 5 ha land, keeping one to five dairy cows that are often improved breed (Holstein, Friesian, or Ayrshire mixed with local breeds). The rest of the herd under the East African SDFS comprise few heifers or calves. Feeding in the SDFS is mainly 'cut and carry' whereby crop residues (maize and sorghum stover, rice and bean straws), natural grasses and sometimes weeds are brought to

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the animals at stall. In addition, the mostly established pasture is napier grass (*Pennisetum purperium* Schumach.) and its cultivars. Manure is used for fertilizing crops and to a limited extent pasture. The average milk production per farm under SDFS is about 10 kg per day of which 25% is for home consumption and the rest is for sale to mainly neighbours and to a limited extent to traders and processors.

In Tanzania, the history of SDF dates back to 1983 when Tanzanian livestock policy declared that medium and large-scale dairy farms alone are unable to meet national milk demand. The policy underscored the importance of supporting the initiatives by private, non-governmental and religious organization on efforts towards improving and establishing SDF in various parts of the country with favourable agro-ecology for dairying (Kurwijila & Boki, 2003). In 2011, Tanzania has about 680,000 heads of improved dairy cattle mainly crosses of Friesian, Jersey and Ayrshire breeds with either Boran or Tanzania Shorthorn Zebu (TSZ) cattle. During the same time, these animals contributed about 30% of the annual 1.85 billion litres of milk produced in the country (MLFD, 2011). Most of the improved dairy cattle are kept by smallholder farmers and few in private large-scale commercial farms and government farms (MLFD, 2011).

The performance of the dairy animals in terms of milk yield, calving rate and growth is still very poor in Tanzania (Gillah et al., 2012; Kavana et al., 2005). For example, the average milk production of a crossbred cow (Friesian × Boran) under smallholder conditions in Tanga region was estimated to be 4 and 8 L of milk in the dry and wet seasons, respectively (Cadilhon et al., 2016), while the recommended milk production potential for such animals in East Africa is 15–20 L per cow per day (Lukuyu et al., 2015). Inadequate supply of good-quality animal feeds is among the major hindrances for constant year-round high milk production in Tanzania and East Africa at large (Kabirizi et al., 2013; Njarui et al., 2011; Ogle, 1990; Swai & Karimuribo, 2011).

It is crux of the present paper to derive key lessons on failures, successes, constraints and opportunities of the previous/ongoing interventions towards improving dairy nutrition in Tanzania. This is based on the fact that if sustainable smallholder dairy development is to be achieved in Tanzania learning new lessons on what went wrong or what improvements need to be done towards increased uptake of dairy nutrition technologies is imperative. This information is believed to be of paramount importance for harnessing informed decision-making to a range of stakeholders including dairy farmers, planners and policy-makers in Tanzania and in the developing world at large.

In this paper, key findings to factors or reasons for failures, successes, challenges and prospects for sustainable dairy nutrition in Tanzania SDFS are presented. Also, the major conclusions and recommendations towards sustainable adoption of dairy cattle feeding practices and technologies in the SDFS of Tanzania are provided.

Review methodology

The systematic search of publications was done using online internet-based search engines in March 2017. Procedures for the systematic search of literature described in detail by Phiri et al. (2010) were followed. Four search engines (electronic databases) namely Google scholar, Worldwide Science.org, ScienceDirect and African Journal Online (AJOL) were used in the current study. Search terms (keywords) used were (smallhold* or 'small hold*' or 'small scale'), (dairy*), (cattle or cow), (feed* or pasture or fodder or forage or nutrition or hay or silage), (constraints or failures or opportunities or successes or challenges or sustainable) and Tanzania. Only peer-reviewed journal articles, theses, conference papers, book chapters, project and government reports were downloaded and reviewed. Screening of all papers through reading the titles followed by abstracts was done and if found relevant full paper was read. The references of the read paper were screened to identify relevant papers that might have been missed by the search engine search. From the papers, information particularly facts, evidences or key messages was extracted and included in this review.

Failures in the uptake of dairy cattle feed technologies and practices in Tanzania

The introduction of SDF in Tanzania in the early 1980s mostly was associated with promotion of pasture production, crop residues processing, storage and feeding technologies. However, until now the uptakes by smallholder dairy farmers (SHDFs) of some the promoted technologies and practices are low or non-existent. In this section, previous initiatives towards improved dairy nutrition in Tanzania and related possible reasons for adoption failures are elucidated.

Lack of adoption of urea and alkali treatment for crop residue technologies

Crop residues play a vital role in feed provision to livestock under the tropical crop-livestock mixed farming systems (McIntire et al., 2016; Owen & Jayasuriya, 1989). In Tanzania, the practice of collecting and storing crop residues including maize stover, bean and rice straw from farms after harvest for dry season feeding is widespread among SHDFs (De Groote et al, 2013; Mtengeti et al., 2008; Urio, 1986).

McDowell (1988) reported that crop residues including maize, beans and rice straws contributed about 35–45% of the livestock feed demand in Kenya and about 25% of the energy required by ruminants. However, straw-based crop residues are characterized by low levels of nutrient with crude protein (CP) content of about 260 g/kg dry matter (DM) and metabolizable energy (ME) of 7.5 MJ/kg DM. Also, mineral elements in particular phosphorus and calcium elements tend to be low, thus necessitating supplementation (Mtengeti et al., 2008). In addition, fibrous crop residues have inherently low acceptability, palatability and digestibility due to high fibre content (>18%). Thus, processing of fibrous crop residues for better animal performance is essential.

Nonetheless, research indicating improvement in feeding value (at least 30% increase in DM intake) of poor crop residues in Tanzania following urea and alkali treatments dates back to the early 1980s, whereby adoption of crop residues chemical treatment technologies was reported to be poor due to high costs of urea and sodium hydroxide (Kategile et al., 1981; Lwoga & Urio, 1985). Conversely, the farmer technology uptake of fibrous crop residue urea treatment as a source of ammonia is reported to be remarkable in East Asia particularly in China, where it was introduced in 1985 (Dolberg, 1992). Dolberg (1992) reported that in 1991 about 4 million tonnes of straw were urea treated in China and the plan was to treat 30 million tonnes by 1995. Reasons for higher adoption in China include strong government support, reduced use of expensive grains, improved income to farmers and environment conservation through reducing straw burning habits (Dolberg, 1992).

Lamentably, the uptake of urea treatment of crop residue technologies is still uncommon in Tanzania (Kimambo et al., 2014), despite the recent government fertilizer subsidy programmes that have reduced substantially the fertilizer costs including urea (Jayne & Rashid, 2013). According to Owen et al. (2012), major reasons for this technology uptake failure arguably include poor extension services, high labour demand (poor mechanization) and poor rural infrastructure (dirty rural roads and lack of electricity).

Poor adoption of hay-making technologies

Efforts for enhancing small-scale hay-making practices in Tanzania aiming at reducing dry season feed stresses include promotion of hay making using a simple wooden box (Massawe & Mruttu, 2005). The aforementioned technology aimed at out-scaling hay-making practices which were limited in few governmental and large-scale commercial dairy farms. MLFD (2011) reported that government pasture farms comprised 1542 ha and produced only 403,604 hay bales per annum, while the private large-scale commercial pasture farmlands had a total of 376.4 ha and produced about 500,000 hay bales per annum.

Limited practices of hay making and storage among SHDFs was attributed to inability to afford sophisticated and expensive machines such as tractor powered hay balers (Massawe & Mruttu, 2005). Another initiative for promoting hay making is wet season hay production techniques, whereby grass drying is done through hanging on wooden poles. Wet season hay-making technology using rhodes grass (*Chloris gayana*) was demonstrated to be effective under SDF conditions in Southern highlands of Tanzania (Sundstøl, 2013).

Despite the aforementioned technologies which were proved to be effective, widespread adoption in the SDFS in Tanzania is not encouraging. Constraints related to land shortage, high labour demand (low mechanization level), transport costs, limited storage facilities and low awareness level are reported to contribute into failure for the uptake of hay-making technologies (Kavana & Msangi, 2005; Owen et al., 2012).

Lack of adoption of silage-making technologies

Hay making from thick-stemmed and succulent grass species such as *P. purpureum*, *Tripsacum laxum* (guatemala grass) and *Zea mays* (maize) in wet and cold environments is practically impossible. Alternatively,

cutting of the green grasses at early stages with only 12–15% DM followed by wilting to 30% DM and chopping to small cuttings less than 3 cm thereafter ensiling under anaerobic conditions is advised (Moran, 2005). Therefore, silage-making provide opportunities to store surplus forages even during wet season and allow pasture regrowth (Mtengeti et al., 2013).

Moran (2005) recommends making of silage under SDF conditions using plastic drums, earth pits or nylon bags as silo. Also, recommends addition of locally soluble fermentable carbohydrate and proteins such as maize bran (5–10%) or molasses (3–5%) and legume leaves to the material to be ensiled. Research efforts have revealed that it is possible to make silages of high quality under SDF conditions in Tanzania (Dixon, 1982; Lyimo et al., 2016; Mtengeti et al., 2013; Mtengeti et al., 2014). Despite these evidences, it is disappointing to note that smallholder farmers in Tanzania are yet to adopt silage-making technologies as a strategy for alleviating dry season fodder scarcity problems. Only a few commercial farms have slightly adopted it but most smallholder farmers do feed green chops of napier and guatemala grasses. Peters and Hoffmann (2010) reported limited uptake of silage-making technologies in Honduras whereby higher technological costs and lack of forage choppers were highlighted as key drivers for non-adoption.

Constraints to the uptake of small-scale silage-making technologies include the cost of ensiling materials, high labour demand, absence of forage choppers and unsuitable storage facilities. Inappropriate storage of the ensiled materials resulting to damage by water and pests such as rodents, also discourage farmers from silage production (Owen et al., 2012).

Limited adoption of poor roughage supplementation practices

In Tanzania, efforts to promote proper mixing of concentrates including maize bran, cotton seedcake, sunflower seedcake, leaf meals and mineral–vitamin premixes to supplement the poor roughages have been in place since the earlier 1980s. This practice aims at ensuring that the nutritional requirements of dairy cattle for both maintenance and optimal production are met throughout the year. Previous dairy development programmes such as Heifer in Trust included these technological packages when they were promoting smallholder dairy farming under zero grazing systems (Swai & Karimuribo, 2011). Formulation and proper use of home-made dairy cattle ration were among of the promoted technology and practices. However, the practice is still limited to few commercial dairy farms while most smallholder farmers still do not supplement dairy cattle. Nonetheless, those who are supplementing often provide a small amount of unbalanced concentrates with the intention of calming the cow during milking or improving milk yield (Lukuyu et al., 2015).

Lack of adoption of proper supplementation practices has hindered milk production to further below animal's genetic potential. Reason for failure for smallholder farmers to adopt supplementation practices include higher prices of the concentrates and unreliable supply, for instance dairy meals, molasses, cotton seedcakes and sunflower seedcakes are often not available in areas located distantly to their production places. Quality seeds for establishing fodder legumes for leaf-meal making such as *Desmodium, Calliandra, Leucaena* and *Sesbania* spp. are often expensive and unavailable (Kaliba et al., 1997; Romney et al., 2003).

Failure to modernize leaf-meal making practices

Leaf-meal is composed of dry leaves from protein-rich fodder legumes such as leucaena, lucerne, calliandra, sesbania and acacia fodder tree species. Leaf-meal is essential for supplementing protein poor roughages especially during dry season. Leaf-meal can be easily and locally produced at relatively lower costs than oil seed-based protein concentrates including sunflower and cotton seedcakes which are expensive and proven to be unaffordable to rural resource-poor smallholder farmers (Kakengi et al., 2001).

Franzel et al. (2007) reported that about 61% of the dairy farmers in Tanga region, Tanzania use leucaena leaf-meal as a protein source to their stall-fed dairy cows. Kakengi et al. (2001) reported that when grazing dairy cattle were supplemented with *Leucaena leucocephala* leaf-meal, cotton seed hull and maize bran at a proportion of 2.6, 1.8 and 1.8 kg DM/day increased milk yield by 6.7 L per cow per day in semi-arid Western Tanzania.

Unfortunately, in Tanzania packaging or processing of the leaf-meal into blocks or pellets to maximize animal intake, reduce bulkiness for facilitating transport, handling and storage is not well established. Arguably, reasons for failure include limited research

and entrepreneurial knowledge towards optimization of leaf-meal resources towards improved livestock productivity.

Failure to popularize multinutrient fodder blocks and urea-molasses blocks

Multinutrient fodder blocks (MFBs) are compounded feeds which are moulded into blocks of various sizes depending on target species and technology used. MFBs are formulated to have high energy and protein concentrations, also comprise minerals and vitamins and other essential nutrients. MFBs if well manufactured can supply balanced feeds to the dairy cattle and other livestock. The application of pressure to compress the blocks reduces bulkiness and increases density hence nutrient concentration. Also, blocks reduce bulkiness of loose roughages that are difficult to handle, expensive to transport and consume large storage space (FAO, 2012).

In East Africa, MFBs technology was tested in some farms in Uganda, Kenya, Burundi and Tanzania and 10% milk yield increase was reported (ASARECA, 2013). Plaizier et al. (1999) reported a 1.5-L per cow per day increase in milk yield on smallholder farmers of rural eastern Tanzania when the dairy cattle were supplemented with urea-molasses mineral blocks.

Lamentably, widespread of these technologies to Tanzania SHDFs has never been noticed. Reasons for failure are attributed to poor extension services, high costs and unavailability of molasses in some areas, poor rural mechanization and electrification.

Successes in adoption of dairy cattle feed technologies and practices in Tanzania

Despite the presence of the above-discussed failures in the uptake of technology and improved dairy nutrition practices, it is worthwhile to highlight the current successes and point out the bottlenecks and factors for further acceleration of the adoption process. In this section, the successes of previous efforts for improving dairy cattle feeding practices and technologies in the SDFS of Tanzania are elucidated.

Adoption of pasture establishment technologies

According to Kidunda et al. (1988) pasture research in Tanzania dates back to the 1930s where studies on pasture agronomy, ecology and nutrition were first conducted. Interventions to disseminate pasture production and management technology/practices in Tanzania have been constrained by inadequate funds and poor extension services. Most interventions to disseminate pasture production under SDFS in Tanzania were spearheaded by the dairy development programmes between 1980s and 2000s, whereby, before a new farmer was entrusted with a heifer, evidence of establishment of a fodder plot in particular of *P. purpureum* was a prerequisite for zero grazing system (Swai & Karimuribo, 2011). This led to wider adoption of high-yielding fodder grasses in particular *P. purpureum*, *T. laxum* and *Setaria sphacelata* in the higher rainfall Northern and Southern highlands of Tanzania, as well as in Kagera, Western Tanzania.

Sundstøl (2013) reported that there are a good number of SHDFs who are growing *C. gayana* for both hay and seed production in Njombe region, Southern Tanzania. Moreover, Mwango et al. (2014) reported that most smallholder farmers in the Western Usambara Mountains in Tanzania have planted *P. purpureum* and *T. laxum* in the contour strips for soil and water conservation, and livestock fodder. Growing of multipurpose fodder trees and shrubs including *L. leucocephala*, *Morus alba*, *Calliandra calothyrsus*, *Albizia lebbeck*, *Gliricidia sepium* and *Acacia angustissima* along farm boundaries or on steep hills or uncultivable areas were also encouraged.

Despite these successes, the smaller land sizes of where these fodder production technologies have been adapted render adequate fodder production (Kavana et al., 2005). Also, smallholder farmers' fear of losing croplands to pasture has made adoption of herbaceous legumes such as *Desmodium intortum*, *Centrosema puberscens*, *Clitoria ternatea*, *Lablab purpureus* and *Vigna* spp. being very rare (Kavana et al., 2005). Though, to a large extent SDF in Tanzania in comparison to the agro-pastoralists and pastoralists are better off as far as adoption of fodder production practices is concerned.

Storage of crop residues

In Tanzania, most smallholder farmers store crop residues as a dry season livestock feed (Kabatange & Kitalyi, 1989; Mtengeti et al., 2008). However, it is still in small scale and under poor storage conditions. The most popular stored crop residue is dry maize stover which is the dominant food crop in Tanzania. Other stored crop residues for livestock include rice, sorghum and bean straws. There have been efforts

for improving handling of crop residues through promotion of baling by tractor or small wooden boxes (Massawe & Mruttu, 2005; Urio, 1986). Though, data on the uptake of these technologies in Tanzania are still scanty.

Arguably, most SHDFs in comparison to agro-pastoralists and pastoralists have adopted crop residue storage practices for dry season stall feeding. SHDFs do harvest and carry crop residues for storage on small racks or on the ground at their homestead. In contrary, agro-pastoralists and pastoralists under extensive grazing systems tend to enter livestock into crop fields for *in situ* grazing of crop residues after crop removal.

Therefore, despite constraints related to transport costs, labour and poor storage facilities there is some success with regard to storage and utilization of crop residues by SHDFs.

Challenges to sustainable adoption of dairy cattle feed technologies and practices in Tanzania

Regardless of the above-discussed failures and successes with regard to smallholder dairy nutrition in Tanzania, yet a number of challenges exist. Henceforth, in-depth clear understanding of these challenges is essential for enlightening formulation of solutions towards sustainable dairy feeding under SDFS. These challenges/constraints include:

Limited knowledge and low technical knowhow among the SHDFs

Knowledge on proper feed production, processing and formulation is limited among most SHDFs in East Africa (Orodho, 2005). Moreover, entrepreneurial knowledge for managing dairy farms as 'commercial enterprises' lacks among most Tanzanian SHDFs. The predominant subsistence (small-scale low input–low output) lineage of thinking renders SHDFs from putting effort into learning on improved dairy feed technologies. Similarly, Derpsch et al. (2016) reported a poor adoption of agricultural conservation technologies by smallholder farmers in Paraguay due to lack of entrepreneurial knowledge despite many governmental and international agency technological interventions.

Reasons for the existence of poor technical knowhow among SHDFs include a poor connection between research, extension and farmer (Owen, 2012). Others include intergenerational discontinuity in which children of the better performing farmers leave agriculture and join other sectors often in urban areas (FAO, 2010). Also, short duration taken in dissemination and promotion of proven technologies. For example, Franzel and Wambugu (2007) underscored the role of extension service and duration in facilitating knowledge/innovation uptake by SHDFs whereby, through use of multiple dissemination pathways including demonstration sites, formal extension officers, para-extension trainees and farmer-to-farmer contacts resulted to about 200,000 farmers adopting fodder shrub technologies within 10 years in East Africa.

Unreliable supply and quality of external inputs

Compounded dairy feedstuff composed of protein, energy, mineral and vitamin concentrates for ensuring higher dairy productivity are unpopular in Tanzania (Kavana et al., 2005). This is caused by underlying criticisms that commercial compounded dairy feeds in Tanzania are of unreliable quality, very expensive and with unguaranteed effects to the specified animal class (Laswai & Nandonde, 2013). Expounding on this, Kurwijila et al. (2011) asserted that lack of formal feed quality control inspections in Tanzania leaves a room to some unfaithful compound feed dealers to conduct illicit trade undetected. Henceforth, SHDFs complaints on counterfeit labelling and adulteration of compound feeds including dairy meals and mineral–vitamin premises are not uncommon. The high costs and mistrust by Tanzanian dairy farmers on dairy meals has made usage of commercial dairy meals in Tanzania almost non-existent. In other East African countries, use of commercial dairy meal is at 33%, 12% and 4% for Kenya, Rwanda and Uganda, respectively (Lukuyu et al., 2009).

According to Geerts (2014), the production of compounded feedstuff in Tanzania is constrained by the low quality and seasonality of raw materials, and insufficient credit facilities. Other constraints include limited knowledge and skills on feed formulation, high cost of production and limited production and supply of dual-purpose food-feed cereals and pulses.

Concurrently, lack of certified commercial pasture seeds and formal fodder markets (e.g. hay markets) is a great challenge (Lukuyu et al., 2015). Nonetheless, lack of subsidies for enabling SHDFs access inputs such as quality seeds, fertilizer and pesticides poses

an unformidable challenge to adoption of improved dairy feeding technologies.

Shortage of arable lands

In Tanzania, the average farm size under smallholder farming systems is 0.9 ha (FAO, 2015). Human and cattle populations are projected to increase at rates of 3% and 4% per annum, respectively (NBS, 2012, 2013). This implies that landholdings are diminishing due to human and animal population increase hence increased land use competition. Nevertheless, the growing food-feed-fuel-fibre competition on arable lands poses an unformidable challenge to SHDFs to choose whether to grow crops or pasture in limited land units (Thornton, 2010). For example, in Usambara mountains in northern Tanzania the average farm size is 1.4 ha and farmers have opted to grow food crops and vegetables with pasture being restricted only around farm boundaries and contour strips (Mwango et al., 2014), while in Njombe region in the Southern Tanzania highlands the average farm size is relatively bigger (>3 ha) and SHDFs have devoted plots for establishing pasture (Sundstøl, 2013). Therefore, land shortage challenge poses a question 'where will the farmer grow pasture?' the answer to this question calls for sustainable intensification of SDF.

Farmers' culture and traditions

Smallholder agriculture is highly labour-intensive and frequently heavily reliant on women, who contribute up to 70% of the agricultural labour within Africa (Pretty et al., 2011). McDermott et al. (2010) asserted that with prevailing poor mechanization in the SDFS strong attitude towards hardworking is mandatory for the farming to be successful. In addition, often SHDFs operate under multiple enterprises (mixed farming) determined by risk diversification contrary to commercial farming which is specialized (FAO, 2010). Dairy farming being a secondary enterprise after crop cultivation makes SDF unfocused and sometimes focusing mainly on manure for crop and animal as an asset.

Moreover, it is well known that dairying is not a major part of cultural heritage in Africa and Tanzania inclusive. This poses a huge challenge to sustainable transfer of dairy feed technologies to smallholder farmers who have strong cultural history and traditions of crop cultivation and extensive grazing. For example, Maleko et al. (2015) reported reluctance of livestock keepers in central Tanzania to engage in pasture production initiatives whereby farmers regarded the newly introduced fodder grasses as weeds. Similarly, Kumwenda and Ngwira (2003) stated that in Malawi livestock keepers consider 'pasture and forage as weeds rather than crops, and tend to consider weeds and pasture species as one'. Thus, lack of appreciation by SHDFs to forage as a valuable resource similar to crops like maize and beans poses a challenge to adoption of forage technologies.

Technological costs, low milk prices and limited access to credits

In Tanzania, most rural households are poor with annual income averaging 480,000 Tsh (Aikaeli, 2010), whereby 100 TSh $\approx$ 0.08 USD. Thus, making it difficult for them to afford feed technological costs given the high poverty incidences. For example, due to low incomes most SHDFs are unable to purchase pasture seeds, forage choppers, tractors, balers, ensiling materials and milking machines. This is further exacerbated by the lower productivity of dairy cows and lower milk prices which trap SHDFs on poverty (Cadilhon et al., 2016). As of 2015, Wassena et al. (2015) reported farm gate milk prices ranging between 200 and 1000 TSh/L (100 TSh $\approx$ 0.06 USD) of fresh whole milk in pastoral and SDFS of eastern Tanzania.

Moreover, lack of access to credits by SHDFs renders them unaffordable to purchase improved dairy cattle, manage and feed them properly including feed supplement provision. Similarly, Derpsch et al. (2016) observed in Paraguay medium and large-scale farmers managed to adopt conservation agriculture practices while small-scale failed due to inability to purchase less labour demanding machines such as tractors.

Owen et al. (2012) stated that better milk prices offered to peri-urban dairy farmers prompt them to be more receptive and responsive to new technologies/practices including supplementation than resource-poor rural small-scale farmers. Thus, finance inadequacy (poverty) among SHDFs poses a great challenge towards sustainable adoption of improved dairy technologies.

Unreliable water supply and prolonged droughts

In Tanzania, in particular rural area where rain-fed agriculture is dominant rural water infrastructure

including boreholes, wells and pipelines are poorly developed (Jiménez & Pérez-Foguet, 2011). In addition, most smallholder farms lack water storage facilities such us tanks, dams and underground reservoirs, thus rainwater harvesting and storage is limited. The current climate change that is characterized by erratic rainfalls in Eastern Africa with extended drought periods poses a great challenge to SDF (Adhikari et al., 2015).

It is well known that about 85% of milk is water and without water an animal is incapable of digesting and assimilating feeds. It is also well known a high producing cow can drink up to 60 litres of clean fresh water per day. Nonetheless, water is needed for pasture growth, cleanness, pesticides (acaricides) spraying and in biogas plants. Henceforth, water shortage especially during dry seasons poses a huge challenge in promoting feed technologies such as irrigated pasture and hydroponic fodder.

Poor dairy chain infrastructure

Most rural roads in Tanzania are underdeveloped and that limit market access (outlets) and inputs supply to the farms especially during rainy season. This also limits sharing of farm machinery and technology between dairy farms. Poor rural transport infrastructures hinder sustainable development of dairy sector in rural and remote areas. In which, efficient dairy farming is currently limited to peri-urban and urban areas where access to markets and farm inputs is reliable. Other infrastructural constraints include lack of skilled labour, poor buildings, e.g. cowsheds, lack of processing facilities, e.g. milk cooling tanks, lack of storage facilities, e.g. barns and warehouses. Additionally, lack of electrical power supply, e.g. for driving forage choppers, poor marketing systems, limited advisory and health services do constraint SHDFs towards adoption of improved feed technologies (Kivaria et al., 2005). Hence, under-investment in dairy chain infrastructure in Tanzania is a huge challenge towards sustainable dairy development including adoption of improved feed technologies.

Prospects towards enhanced sustainable adoption of dairy cattle feed technologies in Tanzania

Given the fact that milk requirement in Tanzania is increasing concurrently with human population increase and the emerging of middle-income class (NBS, 2013). Reliable solutions towards sustainable curbing of dry season feed shortages for improved dairy productivity in Tanzania are suggested below.

Promote dairy nutrition awareness creation

Farmer's education level and clear understanding of the basic agricultural production principles influence positively the productivity of a given farming system (Nkonya et al., 1997). For example, awareness creation to SHDFs towards understanding 60–70% of dairy costs is directed to feed is needed, whereby training packages addressing sustainable fodder production, conservation to proper feeding strategies including budgeting for dry season need to be emphasized. Likewise, farmers' mindset change towards growing fodder as cash crops similar to food and commercial crops need to be imparted.

Moreover, entrepreneurial and technical knowledge on the potential for producing high-quality pasture seeds adapted to given local environments needs to be stressed. In particular, the education programmes should focus on sensitizing farmers on potential techniques for improving milk yield and ensuring year-round constant high milk production. For example, use of protein energy-rich concentrates and mineral–vitamin premixes to supplements poor dry roughages. As well as, on how to formulate a balanced home-made dairy meal optimizing locally available feed resources including agricultural byproducts and fodder legumes.

Clear policy for promoting adoption of improved dairy nutrition technologies

Supportive agricultural policies are affirmed to be the key drivers towards sustainable development of smallholder farming systems (Bebe et al., 2002). This encompasses pro-poor investments in institutional capacities and technologies to harness sustainable production. The policy *inter alia* should clearly address the following issues:

*Need for clear policy for empowering SHDFs with access to investment capital***:** The government should state clearly the strategies and resources commitment towards realization of the Tanzania Agriculture Policy 1997, Livestock Policy 2006 and the vision 2025 of commercializing smallholder agriculture. This includes implementation of the Maputo Declaration of July 2003 by the African Heads of States including Tanzanian president who endorsed the

Comprehensive African Agriculture Development Plan (CAADP). CAADP calls for governments to allocate 10% of the national budget to support agriculture sector and recommends at least 6% annual average growth rate of the agricultural sector (AU, 2003). Deployment of this commitment *inter alia* other strategies could ensure how water, input and credit access by SHDFs will be enhanced within a given timeframe. For example, enhancing microcredit access to poor SHDFs who often lack collateral due to informal ownership of land and animals, hence rendering them untrusted with financial institutions which often consider them as high-risk-low-return clients (FAO, 2011).

Need for the formulation and implementation of Tanzania Dairy master plan: According to DDF (2013), there is a need to formulate and implement national dairy master plan emulating that of Kenya which was framed in the 1990s and managed to transform Kenyan dairy sector making it among the most successful in Africa. In which, the stakeholders proposed an increase in the current milk production from 1.8 billion litres per year to 6 billion litres and to increase the dairy cattle population from 0.68 to 3 million in 2025. With dairy master plan, there is a higher chance of bolstering dairy nutrition technologies and practices given clear goals of increasing milk productivity per animal.

Need for clear policy to promote public–private partnership (PPP) approaches: Promotion of PPP approaches aiming at fostering collaboration among the key stakeholders along the dairy value chain is deemed essential for enhancing access to information, inputs and markets among the SHDFs. For example, collaboration between public institutions such as universities and private organizations including input manufacturing/supplying companies, and the farmers' cooperatives have a higher potential to enhance innovation and knowledge sharing. Evidently, PPP has proved to be effective in India through increasing milk yields by 14% in agricultural areas where the new straw-based multinutrient block technology was promoted (FAO, 2012). Similarly, in Uganda a synergy between university researchers and private sugarcane company enabled the innovation and promotion of commercial urea-molasses-based dairy feed supplement (Kabi et al., 2013). Thus, a policy which embraces promotion of PPP models promises to harness innovation and sustainable adoption of feed technologies. PPP is pertinent to Tanzania owing to the fact that most of dairy input suppliers, milk processors and traders are private firms, hence engaging them actively into win–win collaborations with the SHDFs is vital for enhancing sustainable dairy production.

Need for clear policy for strengthening SHDFs cooperative associations or organizations: Cooperative associations are known to be essential for joining the efforts of disadvantaged groups such as smallholder farmers in overcoming unfavourable conditions such as low farm gate prices and poor input supplies. Policy support for SHDFs on the establishment or strengthening cooperatives and their linkage to credit facilities, input suppliers including seeds, fertilizers, feed supplements and machinery is essential. Nonetheless, cooperatives have a high potential for enhancing access and protection of markets for SHDFs' products and services. For example, Ghosh and Maharjan (2001) revealed that advent of dairy cooperatives was concomitant with an increase in milk yields, income and improved household food security among the rural SHDFs in Bangladesh. Likewise, Cadilhon et al. (2016) reported that in northern eastern Tanzania a partnership between the Tanga Dairy Cooperative Union (TDCU) and Tanga Fresh Limited (the largest milk processor in the region) exists. TDCU members are assured of year-round milk market and other benefits including training and access to improved cattle breeds.

Need for clear policy for supporting SHDFs' innovations and appropriate technology transfer: Clear policy for appropriate research and extension infrastructures and methodologies for promoting innovations and appropriate technology transfer in the feed sub-sector among SHDFs is essential. Also, facilitating access to right agricultural information by the SHDFs is important. This will facilitate the development of evidence-based solutions for informing decisions towards selection of most effective interventions for harnessing sustainable growth of the SDFS.

Need for clear policy for promoting sustainable agricultural land and water management: Clear policy to promote sustainable land and water management under the dairy production in which feed production and utilization should cause minimal environmental pollution and promote efficient recycling of resources including manure and water.

Need for clear policy for promoting sustainable intensification of the SDF: Clear policies to promote sustainable intensification of the SDFS through strengthening the land, water and finance rights among the rural poor are needed. Also, for improving the rural dairy

infrastructure from inputs to marketing, for example improving rural roads, electricity supply and milk storage facilities. This policy suggestion is owing to the fact that milk is a highly perishable product.

Increase emphasis on on-farm research

Farmer, researcher and extension personnel long-term interactions are essential given the fact that technology adoption at the community level is a slow process (Lee, 2005). Identifying barriers towards sustainable innovations and adoptions is the key success towards enabling SDF to overcome the production and marketing challenges. According to Lukuyu et al. (2011), the ideal condition defined by researchers is often not related to that of farmers thus on-farm research is needed for co-innovation and technology development. Nonetheless, Pretty et al. (2011) emphasized on combining scientific and farmer input into technologies and practices that combine crops–animals with appropriate agro-ecological and agronomic management. Thus, without bridging the gap between research and farmers (end-users) it is hard for SDF to develop sustainably. FAO (2012) reported 14% increase in milk production and 30% cost reduction as the result of adoption of improved fodder technology in India whereby farmers and researchers were facilitated by the Indian government to co-innovate and utilize the technology.

Enhance rural agricultural mechanization

Imported sophisticated machines including four- and two-wheel tractors are expensive and often cannot be afforded by smallholder farmers in terms of price and maintenance. Consequently, in Africa use of mechanical power in agricultural production is approximately 10%, draught animals 25% while human power using hand tools is about 70% (Kienzle et al., 2013). Forage conservation, feed compounding, manure spreading and slurry spraying are labour-intensive activities. It is obvious that without labour-saving equipment farmers fail to practice despite the know-how or technical merit of the practice.

For example, it is well known that most youths in Tanzania are not interested in agriculture including dairy due to poor equipment and low wage rates. Most youths in Tanzania will rather prefer working on other sectors including doing petty trade in urban areas commonly called 'machinga' (Liviga & Mekacha, 1998), and do motorcycle taxiing commonly called 'bodaboda' and not agriculture due to aforementioned reasons (Bishop & Amos, 2015). As consequent, this shifts more labour burden to children and women in the management of SDF.

Preconditions for enhancing rural mechanization include nurturing of farmers' cooperative associations first, as farmers' need to have access to information, investment capital and technical knowhow for sustainable adoption. Kienzle et al. (2013) asserted that rural mechanization promotion should not go in isolation but a complementary activity related to improvements of farming, storage, transport and market access technologies.

Henceforth, rural mechanization will reduce labour cost and make small-scale dairy farming competitive on the labour market. For example, emphasis to access labour-saving equipment including forage choppers, mowers, balers, milking machines which are cost effective and easily adoptable by rural farmers is essential. Affordable machines for reducing particle sizes of crop residues (simple chopping/chaffing/shredding/grinding machines) are vital for improving dairy cattle feeding practices.

Conclusions and recommendations

We conclude that the major factors contributing to low adoption of dairy nutrition technology and practices in Tanzania include: (i) Farmers' limited knowledge and skills in dairy cattle feed technologies and practices due to poor extension services, (ii) limited access to investment capital, (iii) inadequate input supply including limited pasture seeds, feed concentrates and farm machinery, (iv) shortage of arable lands for growing pasture (v) poor rural infrastructure including dirty roads and lack of electric power, (vi) low farm gate milk prices and (vii) limited capacity for rainwater harvesting and storage among the SHDFs. For sustainable adoption of improved dairy feed technologies and practices among the Tanzania SHDFs, we recommend the following:

(1) There should be promotion of dairy farmers' cooperative associations in order to facilitate smooth access to information, knowledge and skills on dairy feed technologies and practices. As well as, for enhancing access to investment capital, land, water, reliable external inputs (pasture seeds, feed concentrates and farm machinery) and fair markets among the SHDFs.

(2) There should be promotion of holistic/comprehensive PPP approaches in the development of dairy feed technologies by investing on adoption processes as well. This should include incorporating technological adoption time, gender dimensions and organizational/institutional issues in dairy feed technology innovations and growth. For example, promoting evolvement of fodder production and processing technology as well as empowering fodder market entrepreneurs as both associations and private firms (strong input–output service provider and market linkages).

(3) On-farm researches and extension for fostering innovations/development of efficiency and affordable technologies are recommended. These on-farm researches should include fodder production, processing, feeding and marketing to ensure constant year-round availability of high-quality dairy feed resources. Specifically, pluralistic extension approach embracing PPP towards promoting adoption of proven feed technologies and identifying farmers' problems should be supported.

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