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REVIEW ON KNOWLEDGE GAP IN *Brachiaria* GRASS RESEARCH AND UTILIZATION: ETHIOPIAN PERSPECTIVE

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Abstract

Still food security has not been attained fully in many tropical African countries including Ethiopia. However, the issue of food security achievement has been able to realize due to various setbacks among which low productivity of crops and livestock take the lion share. Among the various constraints the parasitic weed Striga, and Stemborer pests are responsible for lower crop yields in the region. Regarding livestock feed, shortage in terms of quantity and quality are the major impediment to the livestock sector. To achieve food security, increasing crop yield and livestock production is vital in Ethiopia and other tropical countries. Crop yields can be enhanced through the control of weeds using biological systems to increase food crop yield apart from chemical inputs. In case of livestock, full production and reproduction potential of animals can be met through fulfilling nutritional requirements of livestock. The major livestock feed resources in Ethiopia are natural pasture and crop residues. Both feed resources; however, are poor in nutritional value and they are listed as low maintenance feed category. Therefore, it is vital to intensify integrated crop-livestock production systems for sustainable economy and environment. Introducing forage grasses in the crop production system has been practiced in the tropics as push pull technology. In Ethiopia, Brachiaria grass is an emerging forage for integrated agricultural production that has been getting considerable recognition as an option to overcome the pests in crop production in the tropics due to its high adaptive and yielding as well as climate smart forages. In the country, Brachiaria is recently introduced by different organization in different agro-ecology of the country mainly as push-pull integrated agricultural system and considering its fodder potential for the livestock feed. Therefore, this review paper aimed to looking for the available research knowledge in Ethiopia and somewhere else in the glob for better utilization of Brachiaria grass in the integrated agricultural system. All available information regarding the research and utilization of Brachiaria grass were reviewed in the published papers. The review reveal that Brachiaria has many advantages over other grass species in terms of adaptation to drought and low fertility soils, ability to sequester carbon; increase nitrogen use efficiency through biological nitrification inhibition (BNI) and arrest greenhouse gas emissions. The knowledge has been established in quantifying the multiple contributions of Brachiaria grass inclusion as push pull technology in different parts of the world (South America, Kenya, Rwanda). Limited report showed that cut-and-carry system is the utilization practice of brachiaria grass grown the push pull integration. The potential of improved Brachiaria grass in Ethiopia to address the challenge of livestock feed scarcity and other environmental managements; however, remain unexploited/limited which calls researchers to work on. The review concluded that B. cultivars could have a significant contribution on both animal and cereal production in the tropics but limited research and utilization in Ethiopia.

Key words*: biological nitrification inhibition, greenhouse gas emissions, push-pull, sequester carbon.*

INTRODUCTION

The majority of the population in Sub-Saharan Africa (SSA) resides in rural areas, and up to 80% are smallholder farmers (Senbet & Simbanegavi, 2017) directly or indirectly dependent on agriculture for their livelihood. It plays a central role in the economic and social life of the many families and is also a cornerstone of Ethiopians' national economy (FAO, 2017; Mengistu et al., 2017; Tekliye et al., 2018). Ethiopia owing the largest livestock population in Africa (Mengistu, 2017; CSA, 2017); the 10th in the world with more than 80 million heads (Temesgen et al., 2014; Mekonnen, 2018; Teweldemedhn, 2018). Despite having a large livestock in number (CSA, 2018), the productivity of livestock is very low due to shortage of feed resources both in quantity and quality (EIAR, 2017; Assefa et al., 2016; CSA, 2018). The agricultural production practices and value chains remain underdeveloped as a result engaging in agriculture in the SSA in general remains less attractive to the young generation (Ströh et al., 2016).

The major feed resources for livestock in Ethiopia are natural grazing and browse, crop residues (CSA, 2018); while improved pasture, forage crops, and agro-industrial by-products do have limited contribution in the country (Mengistu et al., 2017; CSA, 2018). Low quality crop residues and natural pasture are the main source of feed in developing countries including Ethiopia (Abebe et al., 2015; CSA, 2018); which account 95% of the feed biomass in Ethiopia (FAO, 2018). Hence, look for alternative feed resources which can supply required nutrients for livestock to harness the potential of existing livestock sector in the country is mandatory (FAO, 2019). Moreover, integration of improved forage crops in agricultural systems has many advantages including soil conservation; reduced weeds, pests, and diseases, in addition to their primary use as high-quality animal feeds (Mulualem & Molla, 2013; FAO, 2016; Tessema & Feleke, 2018).

Currently getting considerable recognition as an option to overcome this problem in tropical areas including Ethiopia is *Brachiaria* grass (Yiberkew et al., 2020); due to its high adaptive and high yielding as well as climate smart forages (Mekuriaw et al., 2020; Mudavadi et al., 2020; Namazzi et al., 2020). *Brachiaria* grass has the potential of meeting the challenges of feed scarcity both in quantity and quality since it provides more forage per unit area and ensures regular forage supply due to its multi-cut nature (Schiek et al., 2018) and it is also well integrated improved forage that has many advantages. Among the most important merits of genus *Brachiaria* grass over others include adaptation to drought and low fertility soils, ability to sequester carbon, increase nitrogen use efficiency through biological nitrification inhibition (BNI), arrest greenhouse gas emissions, thrives well on different soil types (clay to red soils) and distributed across tropical and sub-tropical regions. Moreover, *Brachiaria* grass recently identified as an ideal fodder that can improve livestock production in eastern Africa (Cheruiyot et al., 2020); There are several initiatives in the region aimed at promoting cultivation of this grass to support the emerging livestock industry (Maass et al., 2015). This is due to its high adaptability to low fertility areas, arid, and semiarid zones of sub-Saharan Africa (Boonman, 1993). However, regarding the aforementioned, the grass has much-untapped potential for smallholder crop-livestock production systems including push-pull technology and future commercial oriented animal production in Ethiopia. The works of Clementine et al. (2020) indicated that there are many *Bracharia* genotypes which can be grown in the mixed agriculture of tropical countries. Previous research evidence (Cheruiyot et al., 2020) show that *Brachiaria* grass is transforming the integrated agriculture using the push pull technology and benefited both the crop and livestock sector in terms of crop yield and livestock production in the different part of the world, respectively. Different knowledge has been developed in the exploring the multiple advantages of the *Brachiaria* grass in the context of feeding the world in the sustainable manner without harming the environment. Thus, this paper, therefore, reviews research works carried out in many countries including East Africa (Ethiopia) on *Brachiaria* spp. to increase the current state of knowledge about the research and development efforts on *Brachiaria* grass species in Ethiopia.

MATERIALS AND METHODS

In preparation of the review paper over 173 articles were collected from different published and un-published sources using key words and google scholar was also employed: *Brachiaria* grass, cultivated forages, Ethiopia, feeds, *Striga*, push-pull, and livestock feed. After collection of manuscripts information contained from sources was analysed and used to organize this article.

DISCUSSIONS OF REVIEW FINDINGS

Livestock feed resources in Ethiopia

Livestock feed resources is the prominent constraint for optimal livestock productivity in tropical and sub-tropical countries (Solomon &

Teferi, 2010; Bouazza et al., 2012; Bekele et al., 2017). The bulk of the livestock feed comes from grasses and legume forage that grows on land not suitable to agriculture (O'Mara, 2012); and in many countries livestock do not receive cereal supplements. However, in the tropics, grasses are the most ecologically reliable and economically justifiable feed resources (Pedreira et al., 2011) because of their morphological characteristics which enable efficient water use, and rapid recovery after periods of drought (Batistoti et al., 2012). Due to this water use efficiency, in East Africa, planting these grasses along contours is encouraged for erosion control (NISR, 2013; Klapwijk et al., 2014).

Tropical forage-based livestock production systems differ regionally (Peters et al., 2013). In Latin America and the Caribbean, cattle are reared on planted pastures while in Western Africa natural pastures are used to graze cattle. In contrast, most livestock owners in the eastern-central Africa and tropical Asia, cut-and-carry of forage is a major practice to feed cattle (Peters et al., 2012). However, the common practice of feed dairy cows' poor-quality roughage in tropic, caused to decrease animal productivity and increase methane emissions (Mekuriaw et al., 2020). For these reasons, introducing alternative roughage feeds, such as nutritionally improved forages is essential for improving milk yield, dietary nitrogen utilization, and reducing enteric methane emission from dairy cows.

Effect of season on availability and quality of feeds

In tropics, smallholder ruminant livestock production is threatened by inadequate feed due to seasonal fluctuation of rainfall, poor pasture management and conversion of natural pasture into croplands (Kebede et al., 2016; Melaku et al., 2017). This in turn has spontaneously sparked employment of unsustainable farming methods leading to serious soil fertility decline leading to decline in crop/fodder yields and their susceptibility to pests and diseases (Keesstra et al., 2016; Dagnew et al., 2017). Household monthly milk output affected in tropics by seasonal fluctuation of rainfall. According to Lanyasunya et al. (2006), mean farm household monthly milk output (Lt/farm/month) during wet and dry season at Ol-Joro-Orok location of Kenya was 345.06 and 177.18, respectively. One of the fundamental reason such a high milk yield fluctuations in smallholder dairy farms arise because most farmers, mainly, depend on rainfall for feed production and rarely make provisions for adequate green feed and fodder preservation for the dry season (Nardone et al., 2010). Chemical composition varied significantly on roughage (forage) quality in Kenya (Mudavadi et al., 2020) and among browse species across seasons in Ethiopia (Mekuraiw et al., 2020).

The smallholder dairy industry in Eastern Africa continues to be characterized by seasonality driven milk fluctuations and reproductive performance of dairy cows (Mudavadi et al., 2020); which is determined by feed availability (quantity) due to seasonal variability (Phelan et al., 2015; Kebede et al., 2016; Ali et al., 2019). Seasonal feed fluctuation is the common problem among livestock keepers in the tropics particularly in East Africa (Shapiro et al., 2017). In Ethiopia, seasonal fluctuation in its availability and quality is a common phenomenon that natural pasture/forage do not available all year round since the gains made in the wet season are totally or partially lost in the dry season (Mutimura & Everson, 2012; Njarui et al., 2016; Adnew et al., 2018). Thus, one of the potential strategy for better feeding of livestock during periods of critical feed shortage particularly in the dry season might be using improved forage varieties and enhance the quality of available crop residues (Shapiro et al., 2017).

Cultivated forages in the livestock feed supply

The global demand for livestock product is projected to increase by 70% in 2050 due to growing population, rising affluence, and urbanization (FAO, 2016; Ritchie & Roser, 2017). The exploitation of this opportunity severely constrained by limited supplies and high cost of good quality feed (Balehegn et al., 2020). In many of tropic countries, feeds and feeding related issues are often ranked as the primary constraint to livestock production and increased consumption of animal-source foods. Among feed resources, forage crops, especially grasses have shown unique characteristics in different agricultural systems in tropics.

Forages are a large component of agro-ecosystems worldwide, and contribute significantly to world food production. A wide diversity of plants are cultivated as forages, from succulent legumes (alfalfa and clovers), to cool and warm-season perennial grasses and annual crops such as corn and oats.

Forage can be grown in harsh environments, utilised as functional components in providing environmental services in soil erosion control and greenhouse gas emission mitigation efforts (Liebig et al., 2005) and income generation as basic animal feed (Sanderson et al., 1996; Wright & Turhollow, 2010). This situation encourages the cultivation of suitable and adapted improved forages to the tropical regions such as brown midrib sorghum in Central America (Rodriguez, 2013), Napier grass (*Pennisetum purpureum*) in different tropical countries (Tessema & Baars, 2006; Mutimura et al., 2018); Rhodes grass (*Chloris gayana* L.) in Kenya (Njaruiet al., 2016), *Desho* grass in Ethiopia (Asmare et al., 2016), *Brachiaria* in different countries (Ghimire et al., 2015; Mutimura et al., 2018; Adnew et al., 2019a; Maina et al., 2019; Yiberkew et al., 2020), cowpea in West Africa (Tarawali et al., 2002), and *Ficus thonningii* trees in Northern Ethiopia (Balehegn et al., 2014).

Among the aforementioned forage crops, Napier grass is a fast-growing perennial grass widely grown for smallholder dairy production in tropical and subtropical regions (Teressa et al., 2017; Mutimura et al., 2018). However, in the smallholder mixed crop livestock system, Napier grass (*Pennisetum purpureum* Schum.), the most widely grown fodder for the cut-and-carry production system, is threatened Napier stunt and smut diseases which cause total loss of the crop in severe cases (Khan et al., 2014). Rhodes grass (*Chloris gayana* L.), one of the cultivated pastures has a narrow genetic base and limited ecological adaptation. Recently, *Brachiaria* grass species becoming as a options for improving productivity in semi intensive systems, and some of these cultivars are high-yielding, nutritious, and eco-friendly (Creemers & Aranguiz, 2019) and probably the most widely grown forage grass species in the tropics Maass et al. (2015). However, in Ethiopia, information on the potentiality of *Brachiaria* grass to use as an option is very limited (Adnew et al., 2018).

***Brachiaria* grass**

Brachiaria grass is an important tropical forage of African origin that supports millions of livestock and wildlife in the tropics (Namazzi et al., 2020); which is probably the most widely distributed sown pasture in the tropics (Maass et al., 2015; Namazzi et al., 2020) particularly in Latin America (Holman et al., 2004; Silva et al., 2013; Cezário et al., 2015; Teixeira et al., 2018), South-East Asia (Hare et al., 2015; FAO, 2015), Australia (Miles et al., 2004) and East Africa (Ndikumana et al., 1996; Maass et al., 2015), with an estimated acreage of 99 million hectares in Brazil alone (Jank et al., 2014). The role of *Brachiaria* grass in the transformation of livestock agriculture has been well valued across the tropics, creating a high demand for improved cultivars adapted to different agro-ecological zones (Adnew et al., 2019b; Namazzi et al., 2020). Recently, this genus grass is increasingly renovating integrated crop-livestock production systems in East Africa (Cheruiyot et al., 2020) including Ethiopia (Yiberkew et al., 2020). It is adaptable to a wide range of habitats from swamps and light forest shades to semi-deserts. It is an important constituent of Savannah grassland ecosystem that has been supporting millions of African herbivores for thousands of years (Kelemu et al., 2011); there has been considerable interest also in *Brachiaria* grasses in Africa, and several initiatives are ongoing to promote *Brachiaria* to support the emerging livestock industry in the region, especially in the dry season (Maass et al., 2015). However, for the potential of this species to be realised, it is important that varieties are tailored to the particular demands of each environment in which it is grown (Bailey-Serres et al., 2019).

Brachiaria grass is appreciated for water stresses and shade tolerance, high biomass production potential, low fertility soils, soil stabilization, ability to sequester carbon, increased nitrogen use efficiency through biological nitrification inhibition (BNI), and subsequently the ability to reduce greenhouse gas emissions and ground water pollutions (Subbarao et al., 2009; Arango et al., 2014; Djikeng et al., 2014; Moreta et al., 2014; Rao et al., 2014; Ghimire et al., 2015). All *Brachiaria* species show greater tolerance to Al^{3+} toxicity than most other grass crops, including maize (*Zea mays*), rice or wheat (*Triticum aestivum*) and resistance to major diseases (Kochian et al., 2015; Arroyave et al., 2018; Worthington et al., 2020). In addition to all these merits, *Brachiaria* grass has gained large uptake in East Africa where the grass has been incorporated as a trap plant in the 'push-pull' pest management system (Khan et al., 2014; Midega et al., 2014).

***Brachiaria* grass in Ethiopia**

The push-pull-system has been developed and promoted by the International Centre of Insect Physiology and Ecology (ICIPE) (Khan et al., 2014). This smart technology successfully harnesses agro-biodiversity for improving the productivity of cereal crops while providing fodder for livestock. According to Maass et al. (2015), the hybrid *Brachiaria* cultivar Mulato II has been distributed since 2001 to Eritrea, Ethiopia, Nigeria, DR Congo, Uganda, Rwanda, Burundi, Kenya, Tanzania, Malawi, South Africa, and Madagascar as multipurpose especially for push-pull technology. Regarding Ethiopia, the push-pull technology has progressed tremendously since its introduction in the country ten years ago, with over 8,000 farmers now using the technology by ICIPE collaboration with various partners (ICIPE, 2017; Adnew et al., 2018; Kumela et al., 2019). In addition to push-pull technology, *Brachiaria* grass introduced in some parts of Ethiopia as animal feed and soil conservation by LIVES Project (Livestock and Irrigation Value chains for Ethiopian Smallholders), Wollo University and MoANR (Ministry of Agriculture and Natural Resources of Ethiopia) (BoANR both Amhara and Oromiya regions) (Adnew et al., 2018). Evaluation of *Brachiaria* species (*B. brizantha*, *B. decumbens*, *B. ruziziensis*, and *B. mutica*) and their different cultivars and ecotypes (Adnew et al., 2019b; Hunegnaw et al., 2020; Zemene et al., 2020; Mekuriaw et al., 2020; Yiberkew et al., 2020) for pasture production have been done in Ethiopia focusing on dry matter yield, nutritive value, agronomic qualities, and livestock productivity. Moreover; field assessment of *Brachiaria* grass on the performance of push-pull technology in different areas of Ethiopia. However, farmers' perception and utilization status of *Brachiaria* grass in Ethiopia is at infancy stage despite its potential and multipurpose grass.

All the studied *Brachiaria* grass (hybrid, cultivars and ecotypes) in different parts of the countries had a CP content that fulfil the minimum requirements of ruminants for maintenance, beef production and milk production in Ethiopia as stated by Humphreys (1978) that CP content from all the plant materials analysed met the minimum requirements for ruminants (>7%), i.e., 6.9% for maintenance, 10.0% for beef production and 11.9% for milk production and also relatively lower fiber fractions. Examples include in three altitudes (low, mid and high altitude of Tach Gayint, Debre Tabor, and Fogera) with both cultivars (Mulato II, Marandu and La Libertad) and ecotypes (Eth. 13726, Eth. 13809 and Eth.13777) (Wassie et al., 2018), *Brachiaria* Hybrid Mulato II Grass Grown in Lowlands of Metekel (Yiberkew et al., 2020), *Brachiaria mutica* in Bahir Dar city (Zemene et al., 2020), cultivars Mulato II, Marandu and La Libertad, Mutica and *B. decumbens* in Mecha district and Andassa Livestock Production Center (Hunegnaw et al., 2020). Besides aforementioned, *Brachiaria* hybrid (CIAT 36087) Mulato II grass cultivation evaluated encourages in Ethiopia as it suitable and well adapted improved forages to fulfil the nutrient requirements of sheep for meat production (Adnew et al., 2018) and dairy cows for milk production (Mekuriaw et al., 2020) in the country. This hybrid Mulato II has comparable or greater drought persistence than both *Brachiaria brizantha and Brachiaria decumbens* cultivars, from which it is bred (Phengpet et al., 2016) and higher yield potential than other *Brachiaria* species (Philp et al., 2019). Despite a broad adaptation, high nutritive value, and positive gains in livestock productivity, the use of *Brachiaria* grass especially hybrid Mulato II for pasture production was limited in Ethiopia.

Productivity and nutritive value of Brachiaria species

Regarding productivity and nutritive value, several authors have previously reported that grasses in the genus *Brachiaria* have advantages over those in other genera, including production of high dry matter yield

(Rodrigues et al., 2014); especially Mulato II cultivar has excellent herbage production performance and benefits to livestock productivity (Peters et al., 2012; Nguku et al., 2016; Ondabu et al., 2017; Adnew et al., 2019b; Mekuriaw et al., 2020; Yiberkew et al., 2020); which is reported that *Brachiaria* hybrid Mulato II grass produces up to 25 t/ha DM in Tabasco (Cook et al., 2005) in different areas. This superior dry matter production confirms why *Brachiaria* grass is now the most commonly (extensively) grown as livestock forage in South America (Cezário et al., 2015) and East Asia (FAO, 2015). A recent study in Ethiopia also revealed that *Brachiaria* grass species adapted well and have high CP content in the range 8.57-14.93% in six different hybrid, cultivars and ecotypes of *Brachiaria* grass (Adnew et al., 2019b; Zemene et al., 2020; Yiberkew et al., 2020) at lowlands of Metekel; Mutica (10.3 and 10.78%); Mulato-II (13.21 and 13.04%); Mulato-I (12.6 and 12.7%); Marandu (14.02 and 13.78%) and La liberated (11.31 and 11.6%) in Red and Black respectively with fertilizer application (Hunegnaw et al., 2020) in north-western of Ethiopia. Dry matter yield and CP mean value recorded by all *Brachiaria* grasses species studied in Ethiopia have higher than the natural pastures grown in Ethiopia as most of the natural pasture lands produce about 2 tons DM/ha/year with low nutritive value (Abebe et al., 2015). Similarly, CP mean value of Mulato I (17.5%) and Mulato II (14.6%) in Thailand reported by Hare et al. (2007) and 7-10% reported by Nguku et al. (2015) in the semi-arid region of eastern Kenya shown that all tested *Brachiaria* grass species at different altitudes and countries met the minimum requirements for ruminants (>7%) (Humphreys, 1978).

Roles of *Brachiaria* grass in Agricultural Systems and Environmental amelioration

Brachiaria as a feed resource for livestock

Brachiaria grass species are productive warm-season perennial grass with superior nutritive value to other warm-season grasses (Vendramini et al., 2014), and can be used for grazing (Inyang et al., 2010; Modernel et al., 2019) or harvested and conserved for feeding when needed (Vendramini et al., 2010). Data on nutritive value indicate that forage from *Brachiaria* is highly palatable to livestock, leading to high intake, whether fed fresh or grazed in the field. It is ideal forage for improving livestock productivity both for cut-and-carry and grazing systems and yields between 5-36 t/ha (Bogdan, 1977). The research at International Centre for Tropical Agriculture (CIAT) and the Brazilian Agricultural Research Corporation (Embrapa) on naturally occurring germplasms from Africa have developed several improved *Brachiaria* cultivars and a few interspecific hybrid cultivars for South America (Argel & Keller-Grein, 1996; Kuwi et al., 2018). Over the past few years, some of these cultivars have been evaluated for pasture production in Africa focusing on biomass production, nutritive values, livestock productivity, and adaptation to biotic and abiotic stresses (Maass et al., 2015). Results of evaluations have shown the great potential of *Brachiaria* cultivars in Africa to alleviate livestock feed shortage, increase the availability of quality feeds and improve livestock productivity and income of livestock farmers in Africa (Njarui et al., 2016).

Recent experiments elucidate that adoption of *B. brizantha* cultivars have the potential to increase milk yield from 3 to 5 liter per cow per day at farmers' condition in Kenya by 15-40% (Ghimire et al., 2015) and up to a 100% increase (average of 36%) in Rwanda (Schiek, 2018). In Rwanda, a controlled feeding experiment using heifers showed an increase in average body weight gain of 205 g per day over 12 weeks when *Brachiaria* grass was fed compared with Napier grass (Mutimura et al., 2015; Njarui et al., 2015). A similar result was obtained from research in Rwanda that showed an increment of milk yield and meat output by 30% and 20%, respectively (CSB, 2016) and also higher meat (Adnew et al., 2019c) and milk yield (Mekuriaw et al., 2020) in Ethiopia. *Brachiaria* now becomes the most preferred grass among these farming communities in east Africa because of its high levels of drought and diseases resistance coupled with palatable and nutritious biomass that increased milk (Ghimire et al., 2015; Schiek, 2018; Mekuriaw et al., 2020) and meat production (CSB, 2016; Adnew et al., 2019c).The studies finding highest DMY and CP and the lowest NDF and

ADF concentrations recorded in East Africa (Kifuko-Koech et al., 2016; Adnew et al., 2019b; Yiberkew et al., 2020) and also found considerable improvement in on-farm feed availability, body weight gain of cattle, and milk yield increases owing to the recent re-introduction of *Brachiaria* grass in Rwanda and Kenya (Ghimire et al., 2015) and in Ethiopia (Adnew et al., 2019c; Yiberkew et al., 2020) shown that *Brachiaria* grass offer opportunities to address the challenge of feed scarcity, improve livestock production and livelihoods in African farming systems (Mutimura & Everson, 2012; Maass et al., 2015).

Brachiaria as a push-pull-system in crop production

Cereals, which include maize, sorghum, millet, and rice, are the main staple and cash crops for millions of small-scale farmers in most of Sub-Saharan Africa (Midega et al., 2018). However, their production is hugely constrained by insect pests, notably stemborers and the parasitic weed *Striga* (Khan et al., 2011; Cairns et al., 2013). Among the various constraints responsible for lower yields of cereal crops are the parasitic weed *Striga*, and stemborer pests whose control has remained a challenge in the region (Murage et al., 2015). One of the most effective ways of managing these pests and the parasitic weed *Striga* are through the use of a companion cropping system, the push-pull technology, which was developed by the International Centre of Insect Physiology and Ecology (ICIPE) and partners through exploiting behavior-modifying stimuli to manipulate the distribution and abundance of stemborer pests and the parasitic weed *Striga* (Khan et al., 2014). The technology uses carefully selected plants as intercrops that either repel or attract stemborer moths and also control striga, resulting in significant improvements in yield of cereal crops (Khan et al., 2014; Midega et al., 2014; ICIPE, 2017).

Push pull technology conventionally, it involves use of insecticides and intercropping maize with a repellent plant, such as *Desmodium, Desmodium uncinatum* Jacq. (Leguminaceae) (push), and planting an attractive trap plant, such as Napier grass, *Pennisetum purpureum* Schumach (Poaceae) (pull), as a border crop around this intercropped field (Midega et al., 2018; ICIPE, 2017). However, efforts to control the fall armyworm through conventional methods, such as use of insecticides is complicated by the fact that the adult stage of the pest is most active at night, and the infestation is only detected after damage has been caused to the crop. The pest also has a diverse range of alternative host plants that enables its populations to persist and spread (ICIPE, 2018). In addition, the sustainability of the conventional push-pull technology, which uses Napier grass (*Pennisetum* spp.) as the trap crop and silver leaf (*Desmodium* spp.) as the intercrop has been affected by the global effects of climate change and Napier grass is also threatened by the emergence of stunt and smut diseases (Mureithi & Djikeng, 2016); which can damage up to 100% of the grass (Kawube et al., 2015) and has also limited its expansion to drier areas. In a new strategy termed 'climate-smart push-pull', the cereal crops are intercropped with the drought-tolerant green leaf *Desmodium* (as the intercrop) and *Brachiaria* hybrid cv. Mulato II species (as the trap crop) which can withstand heavy grazing than Napier grass (Khan et al., 2014; ICIPE, 2018).

Brachiaria grass in the system of push-pull technology has widely been disseminated and accepted by smallholder cereal farmers in East Africa including Ethiopia (Khan et al., 2014), and it has been termed as a low-cost conservation technology (Murage et al., 2015). It is evident that *Brachiaria* grass is represented by *Brachiaria* hybrid cv. Mulato II has a potential in the implementation of the push-pull technology effect with the added advantage of climate-smart agriculture. This technology has been the most successful control strategy for integrated management of the aforementioned two important constraints to cereal cultivation, with the added advantages of simultaneously improving soil fertility, agro-ecosystem integrity (Khan et al., 2014). This revealed by the different reports from field implementation of the technology in different countries of Africa that it effectively limits stemborer infestation and *Striga* (*Striga hermonthica* (Del.) Benth. (Orobanchaceae)), a devastating parasitic weed of cereal crops in Africa, resulting in significant increases in maize grain yields (Midega et al., 2015; Kumela et al., 2019) and its impacts particularly in three

Countries (Kenya, Uganda and Tanzania) (Midegaa et al., 2018) (Table 1).

***Brachiaria* as a soil and water conservation**

Soil erosion is a major threat to the soil resource, soil fertility, productivity, and, lastly, to food and fiber production (Addis et al., 2016). Nowadays, soil erosion is the biggest worldwide environmental problem (Ighodaro et al., 2013). Different soil conservation practices (*i.e.*, cover crop, complementary soil amendments, physical conditioning) applied together as a conservation farming system can improve soil physical properties and reduce plant water stress (Silva et al., 2019).

Table 1. Mean (± S.E.) number of fall armyworm larvae and proportion of maize plants damaged in plots of maize planted in sole stands (monocrop) or in climate-adapted push–pull treatments in different sub-counties in Western Kenya, Eastern Uganda and Northern Tanzania

Country	Sub-county	Cropping System	% plants damaged	t-value	% reduction	Number of larvae/plant	t-value	% reduction
	Bungoma	Push-pull	5.2(1.0)			0.003(0.002)		
		Monocrop	95.4(1.0)	32.7	94.6(1.0)	0.49(0.04)	11.4	82.7(6.3)
	Busia	Push-pull	18.6(1.5)			0.18(0.02)		
		Monocrop	94.3(0.8)	30.3	80.2(1.6)	2.07(0.08)	30.7	90.7(1.1)
	Siaya	Push-pull	4.1(0.9)			0.008(0.004)		
Kenya		Monocrop	80.0(1.5)	34.4	95.0(1.1)	0.23(0.08)	3.01	96.5(1.6)
	Vihiga	Push-pull	4.7(0.6)			0.003(0.002)		
		Monocrop	85.2(1.3)	32.1	94.4(0.7)	0.36(0.04)	10.7	99.3(0.4)
	Migori	Push-pull	3.2(0.7)			0.002(0.001)		
		Monocrop	91.3(1.4)	27.6	95.5(0.7)	0.69(0.03)	30.4	99.6(0.2)
	Homabay	Push-pull	9.5(2.2)			0.06(0.03)		
		Monocrop	84.4(2.7)	16.2	88.2(2.6)	0.95(0.08)	12.9	94.6(2.5)
	Iganga	Push-pull	27.3(2.1)			0.15(0.23)		
		Monocrop	94.0(2.3)	13.2	70.9(2.2)	0.60(0.02)	12.2	75.2(4.7)
	Bugiri	Push-pull	23.8(3.2)			0.13(0.04)		
Uganda		Monocrop	88.0(3.3)	10	72.6(3.9)	0.52(0.05)	6.01	72.4(8.7)
	Tororo	Push-pull	22.0(4.0)			0.14(0.04)		
		Monocrop	80.0(5.0)	7.9	71.1(6.8)	0.56(0.06)	5.93	68.1(11.5)
	Bukedea	Push-pull	26.0(2.8)			0.17(0.03)		
		Monocrop	86.0(4.7)	7.3	68.4(4.3)	0.83(0.12)	6.01	76.2(6.1)
Tanzania	Tarime	Push-pull	5.4(1.6)			0.02(0.01)		
		Monocrop	67.1(3.5)	12.7	92.3(2.1)	0.38(003)	15.8	96.5(1.6)
Average	Reduction				86.7(0.8)			82.7(1.9)

In each sub-county and district, means represent data averages of 30 farmers in Kenya, 10 in Uganda and 30 in Tanzania. Figures in parentheses are standard errors. All t-values were associated with p < 0.0001 except in Siaya where the t-value under mean number of larvae per plant was associated with p = 0.004. a The regions are known as sub-counties in Kenya and districts in Tanzania and Uganda.

In addition to crop rotation, the introduction of intercropped perennial grass species, such as *Brachiaria* grass, along with crops, such as corn (*Zea mays* L.), soybean (*Glycine max* L.) and rice (*Oryza sativa* L.), seems to be a key strategy to increase duration of residue cover on the soil (Pariz et al., 2017; Silva et al., 2019). Intercropped *Brachiaria* also improves soil structure and soil physical quality as water loss is reduced due to low evaporation and improved infiltration rates (Calonego et al., 2017; Pariz et al., 2017), possibly as consequences of increments in soil porosity and organic matter content.

Grasses with robust and strong root systems, such as *Brachiaria*, can penetrate dense soil layers with large penetration resistance values (Calonego & Rosolem, 2011), forming neobiopores that favor water movement and gas diffusion in the soil (Williams & Weil, 2004). Additional advantages of using the *Brachiaria* genus in the integrated systems are that the species produce abundant roots which contribute to the collection of water, soil aggregation and aeration (Kluthcouski et al., 2014). According to a report by Dereje et al. (2014) some volunteer farmers in some villages of Diga district (East Wallaga zone), were increasingly engaged in producing fodder crops such as Rhodes grass (Chloris gayana), Napier grass (*Pennisetum purpureum*) and Chomo grass (*Brachiaria humidicola*) on their fields. In addition to their major significance as animal feed, these perennial grasses serve to rehabilitate the degraded soil which has developed as a result of improper land management and termite infestation (Debelo, 2020). According to this author, the Ethiopian Evangelical Church Mekana Yesus-Development and Social Services Commission (EECMY-DASSC) plants *Brachiaria* grass as a project in closing areas as one of its strategies to promote environmental rehabilitation of degraded termite lands in Mana Sibu district and the project considers the grass as an excellent innovation that enables the rehabilitation of closed areas as it grows easily on degraded lands and is highly resistant to termites. Large areas of idle farmland, back yards, hills, sloping land, upper terraces, bunds, and building foundations would be an opportunity for intensification of livestock provided the land is rehabilitated with tolerant grass species that have high biomass production potential and resilience capacity to adverse biotic and abiotic factors often prevailing in the village.

Brachiaria humidicola (Dereje et al., 2014); *Brachiaria* hybrid Mulato II and Panicum maximum (Philp et al., 2019), which is often used to grow drought-tolerant, are some of such grass species expected to reclaim the degraded land because of its creeping nature that anchors its lower nodes to the ground and its resistance to intermittent attack by termites. In these environments, deep-rooting characteristics allow the forages to access subsoil water and minimize drought exposure during the dry season, potentially delaying or preventing the onset of yellowing leaves and loss of productivity. Generally, *Brachiaria* radicular systems are known for promoting pore formation and organic matter accumulation, reducing soil compaction and increasing introduced the least limiting water range (Calonego et al., 2011; Pariz et al., 2016), improving soil fertility and increasing crop yield (Balbinot et al., 2017). Therefore, they can act as alternative root channels for subsequent crops, reducing the negative effects of soil compaction (Chen et al., 2014; Ajayi et al., 2019).

Brachiaria as biological nitrification inhibition (BNI)

Nitrification is the soil microbial transformation of ammonium (NH_4^+) to nitrate (NO_3^-) that can result in soil nitrogen (N) losses via NO_3^- leaching, promoting eutrophication in aquatic ecosystems (Egenolf et al., 2020). Furthermore, N inputs can be lost to the environment as an intermediate by-product of nitrification or via denitrification causing emissions of nitrous oxide (N_2O), potent greenhouse gas that contribute to global warming and depletion of the stratospheric ozone (Canfield et al., 2010; Zakir et al., 2014). It is estimated that up to 70% of N applied to crops is lost due to nitrification and subsequent denitrification (Subbarao et al., 2017; Coskun et al., 2017). Due to these nitrogen losses, a major portion of the soil nitrogen and applied fertilizer nitrogen (>60%) is lost, in low nitrogen-use efficiency of agricultural systems (Galloway et al., 2008; Schlesinger, 2009). The N losses from agricultural systems are not only a major environmental concern but also an economic loss for farmers as they increase inefficiencies in N-fertilizer use (Nuñez et al., 2018).

Nitrification can be controlled through different approaches, limiting NH_4^+ availability (i.e., managing fertilization) or inhibiting nitrifiers with either synthetic or naturally released compounds (Norton and Ouyang, 2019). Byrnes et al. (2017) and Beeckman et al. (2018) reported that the use of nitrification inhibitors, either synthetic or plant -based BNIs reduces soil nitrification rates and, thus, NO_3^- leaching and N_2O emissions, and that contributes towards increasing crop N use efficiency (Yang et al., 2016). BNI is the natural ability of certain plant species to release nitrification inhibitors from their roots that suppress nitrifier activity, thus reducing soil nitrification and N_2O emission. Abalos et al. (2018) also suggested that plants with acquisitive resource-use strategies (i.e., successful in nutrient-rich environments) reduced emissions of N_2O compared to conservative species and proposed that root length density and specific leaf area were key traits that regulate N_2O emissions and biomass yield in managed grasslands. Similarly, Meier et al. (2017) observed that root exudates of the loblolly pine stimulated the microbial degradation of fast-cycling N pools increasing N availability.

The root is known to directly modify the rhizosphere population by altering the chemical constituents of root exudates (Nuñez et al., 2018). Nitrification inhibitors have been identified in root exudates from several legumes and grasses including sorghum and rice, but by far the largest activity was detected in the tropical grass *Brachiaria* (Subbarao et al., 2009; Byrnes et al., 2017) and the ability of *Brachiaria* grass species to suppress nitrification in soil by releasing an inhibitory compound called 'brachialactone' (Cardoso et al., 2017). The roots of the tropical grass

Brachiaria specifically produce a chemical shown to inhibit nitrifying bacteria (Souri & Neumann, 2017) and to specifically block ammonia-oxidizing pathways in soil bacteria (Byrnes et al., 2017; Nuñez et al., 2018; Egenolf et al., 2020).

Brachiaria grass species were reported to have a high adaptation to the low-N production in the environments of South American savannas (Miles et al., 2004), showed the greatest BNI capacity among the tropical grasses evaluated (Subbarao et al., 2009; Nuñez et al., 2018). In addition to this, recently, the assessment of different plants for their BNI capacity performed in 18 species of pasture grasses, and cereal and legume crops by Villegas et al. (2020) revealed that significant BNI only in the grasses *Brachiaria* species reduced nitrification up to 90%, and suggested the absence of such trait in the other species. Similarly, Cardoso et al. (2017) reported that both greenhouse and field experiments, rates of nitrification were lower in *Brachiaria*-cultivated soil than in bare soil. According to this authors, the symbiotic association of *Brachiaria* grass with fungal endophyte stimulates release of BNI compounds and suppress nitrification in soil. Studies of regulation of N soil dynamics associated to plant and soil microorganism interaction such as BNI and more recently the biological denitrification inhibition (BDI), have increased since they represent an ecologically friendly, sustainable and cost-effective strategy compared to the use of synthetic inhibitors (Subbarao et al., 2017).

Brachiaria as a means to mitigate greenhouse gas (GHG) emissions

Global demand for livestock products, principally milk, and meat, is expected to double by 2050, particularly in developing countries (Herrero et al., 2013; FAO, 2016). However, livestock production is also associated with GHG emissions (Ripple et al., 2014; Rao et al., 2015). Agriculture contributes 14% to global GHG emissions (World Bank, 2010), 50% of these are attributed to livestock production (Steinfeld et al., 2006; Herrero et al., 2013). The other major agricultural effect that increase soil GHG emissions, rather than further stimulate crop yield is excessive N fertilizer application (Cui et al., 2018; Ren et al., 2020; Zhang et al., 2020).

Climate-smart agriculture (CSA) aims to improve global food security while promoting adaptation to climate change and contribute to its mitigation (FAO, 2016). With respect to CSA, a greenhouse experiment, using pots with the same treatments as in the field experiment, suggested that this could have been due to lower soil nitrate levels under *Brachiaria* forage compared to guinea grass, indicating that BNI could be a possible mechanism for lower N_2O emissions from *Brachiaria.* The vegetative cover of well-managed pastures enhances ecosystem services by controlling soil erosion and restoring land through increased soil organic matter and better microclimate. From animal nutrition standpoint, well-balanced diets with low fiber and high digestibility decrease energy losses and increase animal performance (Boland et al., 2013); showed that livestock systems in the tropics can contribute to mitigating climate change by reducing GHG emissions and increasing carbon accumulation (Rao et al., 2015).

A comprehensive review by different authors (Subbarao et al., 2009; Peters et al., 2012; Rao, 2014; Hammond et al., 2015; Lionch et al., 2017) has illustrated the potential of well-managed improved forages to mitigate GHG emissions. Methane emissions from enteric fermentation of cattle fed on tropical grasses and browser tree legumes were low compared to other feed resources (Kennedy & Charmly, 2012). Moreover, replacing naturalized grasses with varieties of higher quality and digestibility forage grasses reduces the amount of methane emitted per unit of milk or meat produced (Peters et al., 2013). Thus, in these sense, the value of well managed tropical grasses especially *Brachiaria* species are very crucial not only in animal production but also for environmental protection (Valente et al., 2014).

CONCLUSIONS

Brachiaria grass species are the newest options for improving agricultural productivity in Ethiopia as of the genus of this grass species are high-yielding, nutritious, and eco-friendly. As a results of these benefits, *Brachiaria* grass species have a very crucial role to support the emerging livestock industry in tropical regions particularly in shown a considerable interest in

Africa. Despite the potential of these improved forages in various tropical countries, information regarding their contribution to livestock productivity, environmental amelioration (amendments like carbon sequestration, biological nitrification inhabitation and methane emission), farmers' awareness about *Brachiaria* grass utilization, and research activity about this grass in Ethiopia is sparse. Besides, climate change and global warming become a reality in Ethiopia. Thus, farmers, researchers, governmental and non-governmental organization have to switch to *Bracharia* grass production as integrated crop-livestock production system to boost the agricultural productivity in Ethiopia. It is possible to summarize that research and development efforts in crop-livestock systems in the highlands can benefit from the integration of climate-smart forage species like *Bracharia* grass.

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