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Climate-smart *Brachiaria* for improving livestock production in East Africa: Emerging opportunities

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ABSTRACT

Brachiaria grass is an important tropical forage of African origin with desirable attributes of agricultural and environmental significance. Brachiaria has been extensively cultivated as a pasture across the tropics except in its endemic provenance of Africa. In 2013, a collaborative research program was initiated in Kenya and Rwanda with the aim of improving the availability of quality livestock feeds adapted to drought and low fertility soils using Brachiaria. The outcomes sought were increased livestock productivity leading to improved farmer income and the development of seed production opportunities. The program has identified five preferred cultivars, and four of them are currently being evaluated on-farm by over 2000 small-holder farmers in Kenya and Rwanda for livestock productivity. Preliminary milk production data has shown a 15 to 40% increase in milk production in Kenya and an average increase of 36% in Rwanda. The substitution of Napier grass by Brachiaria in the feed has increased average daily body weight gain of cattle by 205g during a 12 week period. Kenyan farmers reported increased on-farm forage availability by three months after Brachiaria introduction. The program has also worked to determine the role of endophytes and plant associated microbes for the improvement of biomass production and adaptation of Brachiaria to biotic and abiotic stresses. A diverse group of fungi and bacteria were isolated, identified and characterized, and the role of these microbes on plant growth and plant pathogen suppression is being investigated. This paper discusses the rationale for selecting Brachiaria as potential forage for eastern Africa and highlights current achievements, and identifies areas for future research.

Keywords: Drought, Endophytes, Forage grasses, Mixed crop-livestock systems, Participatory variety selection, Seed production

Introduction

Livestock are important in sub-Saharan African agriculture contributing about 27% of agricultural gross domestic product in the region (FAO, 2010). Livestock are a source of protein rich foods and an income source for the world's billion poorest people allowing them to buy staple foods and other household essentials. Animal manure produced also provides a means of improving soil health and fertility, thereby enabling more sustainable and profitable crop production (Smith *et al.*, 2013). The demand for livestock products has increased in sub-Saharan Africa due to growing population, rising affluence and urbanization. Since the demand for livestock products has outpaced domestic production, Africa has been relying heavily on the importation of basic livestock products over the past three decades (Rakotoarisoa *et al.*, 2012). The gap between demand and supply for livestock products in sub-Saharan Africa is attributed to this region having the world's lowest livestock productivity. However, sub-

Saharan Africa has tremendous potential to boost livestock productivity through the proper utilization of its immense natural resources which includes arable land, diverse animals and plants assets (Rakotoarisoa *et al*., 2012).

Poor feed options of low nutritional quality are among the major factors contributing to the low livestock productivity in sub-Saharan Africa. Forage and crop residues constitute over 90 percent of livestock feed in many sub-Saharan African countries. The shortage of forages in quantity and quality is widespread in sub-Saharan Africa especially during the dry seasons (Djikeng *et al*., 2014). Over 54% of land areas in sub-Saharan Africa which support the majority of livestock in the region occur in arid and semi-arid zones (Jahnke, 1982). However, forage productivity in arid and semi-arid zones can be very low due to drought prone and degraded soils characterized by low fertility and low pH. Further, in most farming systems forages are often relegated to the most degraded and less fertile parts of the land (Njarui *et al*., 2015a) and receive limited or no fertilizer application. Identification and promotion of forage species with improved nutritive value that are also better adapted to drought prone and low fertility soils is a feasible approach for improving animal productivity in arid and semi-arid zones. This will become increasingly urgent in the context of projected weather extremes and climate change. In line with these realities the Biosciences Eastern and Central Africa - International Livestock Research Institute (BecA-ILRI) Hub in partnerships with Kenya Agricultural and Livestock Research Organization (KALRO), Rwanda Agriculture Board (RAB), International Centre for Tropical Agriculture (CIAT) and Grasslanz Technology Limited formulated a Research for Development program entitled *Climate-smart Brachiaria grasses for improving livestock production in East Africa*.

The program has been implemented in Kenya and Rwanda since June 2013 with the following four objectives: (1) Identification of Brachiaria grasses adapted to drought prone and low fertility soils; (2) Integration of Brachiaria grasses in mixed smallholder crop-livestock systems through determining their role in improving milk and meat production; (3) Examination of the role of endophytes and plant associated microbes in enhancing adaptation to drought prone and low fertility soils; and (4) Development of a Brachiaria seed production system that smallholder farmers could use as an additional source of income. This paper describes the rationale of selecting Brachiaria as an ideal forage to increase livestock production in eastern Africa, highlights the major program components and achievements, and discusses emerging opportunities of using Brachiaria in sub-Saharan African agriculture.

Why brachiaria grass?

The genus *Brachiaria* consists of about 100 species distributed across the tropics and sub-tropics of both the eastern and western hemispheres (Renvoize *et al*., 1996). Most *Brachiaria* species are of African origin, and Africa is the center of diversity for Brachiaria (Parsons, 1972). Seven perennial African species; *Brachiaria arrecta, B. brizantha, B. decumbens, B. dictyoneura, B. humidicola, B. mutica* and *B. ruziziensis* are grown as cultivated pasture, particularly in humid tropical regions of Latin America, Asia, South Pacific and Australia (Argel *et al*., 1996; Pizarro *et al*., 1996; Stur *et al*., 1996). Brachiaria grasses form the most extensively cultivated forage monoculture in the world (except in Africa) with an estimated area of 99 million hectares in Brazil alone (Jank *et al.*, 2014). The widespread adoption of Brachiaria is attributed to several desirable traits: adaptation to low fertility and acid soils; tolerance to drought, shade and flooding; high biomass production potential; ability to accumulate carbon into soils; an efficient use of nitrogen (through biological nitrification inhibition); and an ability to minimize greenhouse gases emissions and ground water pollution (Fisher *et al.*, 1994; Fisher and Kerridge, 1996; Rao *et al.*, 1996; Subbarao *et al.*, 2009; Rao, 2014). Moreover, Brachiaria is a palatable and nutritious forage that will support vibrant dairy and beef industries while simultaneously reducing the carbon footprint of livestock production. However, to date its use in eastern Africa has been limited.

Brachiaria is among the most extensively studied tropical forage genera. Research conducted at International Center or Tropical Agriculture (CIAT), Brazilian Agricultural Research Corporation (EMBRAPA), and Australia has identified high performing cultivars and hybrids for different environments. Brachiaria was identified as a potential forage for its native home, east Africa, because of the desirable agronomic and environmental traits described above, and the availability of improved cultivars.

Program components

Identification of Brachiaria germplasm for adaptation to drought prone and low fertility soils: Drought prone and low fertility soils are widespread in the arid and semiarid zone of sub-Saharan Africa and these soils can severely impact on forage biomass production and quality leading to low livestock productivity and poor returns to smallholder farmers. Physiological studies were performed to identify the best commercially available Brachiaria cultivars that were adapted to intermittent and/or terminal drought under low soil fertility conditions. Furthermore, the role of Brachiaria in mitigating climate change through increased soil carbon accumulation, and reduction of greenhouse gas emissions were also examined.

Ten Brachiaria cultivars consisting of *Brachiaria decumbens* cv. Basilisk (CIAT 606), *B. brizantha* cvv. Marandú (CIAT 6294), Toledo (CIAT 26110), Piatá (CIAT 16125) and La Libertad (CIAT 26646), *B. humidicola* cvv. Tully (CIAT 679) and Llanero (CIAT 6133) and hybrid cvv. Mulato (CIAT 36061), Mulato II (CIAT 36087) and Caymán (BR02 1752) were compared with the two control grass species, Rhodes grass (*Chloris gayana*) and Napier grass (*Pennisetum purpureum*) in low fertility soils with simulated drought conditions in a greenhouse at CIAT-Colombia. Shoot and root attributes were measured along with soil carbon accumulation and greenhouse gas (CH_4 and N_2O) emissions.

Results have shown better adaptation of Brachiaria cultivars to drought and low soil fertility conditions than either Rhodes or Napier grasses. Deep roots and stomatal regulation in response to changing water availability were responsible for drought resistance in Brachiaria. These two parameters were used to determine the suitability of different cultivars to different types of drought stresses. For example, Napier grass is better adapted to intermittent drought than terminal drought; *B. brizantha* cv. Piatá is more suitable for terminal drought whereas the hybrid cvv. Mulato II and Cayman are better suited for moderate level of terminal drought and intermittent drought, respectively. Brachiaria roots had higher carbon and lignin contents than Napier grass roots whereas Napier grass roots had higher nitrogen content (Cardoso *et* *al.*, 2015). These results suggest that Brachiaria may accumulate more carbon into soils than Napier grass.

Integration of Brachiaria into mixed smallholder crop-livestock systems: Eight Brachiaria cultivars identified from the greenhouse studies at CIAT- Colombia for adaptation to drought and low soil fertility (*Brachiaria decumbens* cv. Basilisk (CIAT 606), *B. brizantha* cvv. Marandú (CIAT 6294), Toledo (CIAT 26110), Piatá (CIAT 16125) and La Libertad (CIAT 26646), *B. humidicola* cvv. Tully (CIAT 679) and Llanero (CIAT 6133) and hybrid cv. Mulato II (CIAT 36087)) were evaluated in multiple sites across Kenya and Rwanda in comparison with one or two control grasses commonly used by farmers (Napier and/or Rhodes grasses). This work began in 2013/2014 using a farmer participatory variety selection approach. Most of the participating farmers were small scale dairy producers who managed a mixed crop-livestock system. Farmers listed the attributes they consider important when selecting forages for their livestock. The attributes were ranked using a pair-wise ranking matrix and the five top phenotypic traits were used in the selection process. For example, in the mid-altitude eastern region of Kenya, drought tolerance, erosion control, plant height, growth habit and colour were the five top most forage variety selection criteria. Despite site-wise differences in the ranking of cultivars the top performers across all sites were Piatá, Toledo, La Libertad, Marandu, Basilisk and Mulato II. Because of subsequent severe infestations of red spider mites on Mulato II and Marandu, these two cultivars were withdrawn from further on-farm evaluations.

More extensive on-farm evaluation of these four best Brachiaria cultivars (Piatá, Toledo, La Libertad and Basilisk) for livestock milk and meat production was initiated in the latter part of 2014. As of June 2015, 1,513 farmers in Kenya and 525 farmers in Rwanda have been directly involved in the on-farm evaluation of these Brachiaria grasses (Mutimura *et al*., 2015; Njarui *et al*., 2015b). Preliminary data has shown that feeding with Brachiaria increased milk production by 15 to 40% in Kenya and up to a 100% increase (average of 36%) in Rwanda. In Rwanda, a controlled feeding experiment using heifers showed an increase in average body weight gain of 205g per day over 12 weeks when Brachiaria grass was fed compared with Napier grass (Mutimura *et alet al*.., 2015; Njarui *et al*., 2015). About 42 ha of Brachiaria have been established in the mid-altitude eastern region of Kenya with farmers reporting increased on-farm forage availability by three months. Some farmers who are participating in on-farm evaluations have expanded their area planted to Brachiaria using clonal explants, and farmer to farmer dissemination of planting materials has been taking place in both countries. High levels of drought resistance coupled with a palatable and nutritious biomass has led to a concomitant increase in milk production such that Brachiaria is now the most preferred grass among these farming communities. Preliminary data has clearly shown that feeding Brachiaria significantly improves livestock productivity in eastern Africa.

Examining the role of endophytes and plant associated microbes in enhancing adaptation to drought prone and low fertility soils: Endophytes and plant associated microbes are an integral component of plant biology and many of them are known to provide a range of benefits to their host plants (Schardl, 1996; Johnson *et al*., 2013; Ghimire and Craven 2013). Some of these benefits include adaptation to abiotic stresses, enhanced water and nutrient acquisition, protection against plant pests and diseases, improvement in plant growth and an increase in grain and vegetative biomass yields.

Effort has focused on harnessing the ability of endophytic microbes to enhance the adaptation of Brachiaria grasses to drought and low fertility soils. The microbiome research on tropical grasses including Brachiaria is at an early stage of development. Therefore, initial efforts were put into the optimization and development of techniques for isolating microbial populations from Brachiaria, and the identification and functional characterization of these endophytes and plant associated microbes. Methods for isolating endophytic fungi and bacteria from seeds, foliage and roots, and bacteria from the rhizosphere were developed (Ghimire *et al*., 2015; Johnson *et al*., 2015). Similarly, procedures were developed for the functional characterization of these fungi and bacteria, and for bacterial inoculation. Refinements of foliar spray, soil drenching and co-cultivation inoculation methods are being used to achieve effective fungal endophyte inoculation. While the development of in-planta fungal detection procedures are underway.

Isolation of over 500 fungi from seeds and asymptomatic foliage and roots tissues of improved cultivars, genebank accessions and Kenyan ecotypes of Brachiaria grasses has been completed. Similarly, 110 bacterial strains were isolated from asymptomatic tissues and the rhizoplane of Kenyan ecotypes of Brachiaria (Ghimire *et al*., 2015b). The majority of these microbes have been deposited into the microbial culture collections at the BecA-ILRI Hub or AgResearch Limited, New Zealand. Identification and phylogenetic analysis, to determine the relatedness among fungi and bacterial populations revealed a wide range of fungal and bacterial genera associated with Brachiaria grasses. Over 96% of bacteria isolated from Brachiaria grass had a minimum of one trait that was beneficial to plant growth and/or suppression of plant pathogens (Ghimire *et al*., 2015b). Similarly, the previously reported beneficial Brachiaria endophyte *Acremonium implicatum* and related *Acremonium* species were among the frequently isolated fungi (Ghimire *et al*., 2014; Johnson et. al., 2015). Effects of *A. implicatum* inoculation on the drought response of five Brachiaria cultivars (*B. decumbens* cv. Basilisk, *B. humidicola* cv. Tully, *B. brizantha* cv. Marandu, *B*. hybrids cvv. Mulato II and Cayman) under two irrigation regimes in a greenhouse setting showed mixed results suggesting the need for more research to establish if *A. implicatum* in association with these cultivars confers a benefit. Studies on the impact of *A. implicatum* on biological nitrification inhibition in Brachiaria are ongoing (Cardoso et. al., 2015).

Exploring the possibility of Brachiaria seed production as source of income to smallholder farmers: Brachiaria grasses are relatively new to Africa as a cultivated pasture, and the germplasm used to date has been of cultivars specifically selected or bred and adapted to acid soil regions of Latin America. To date, a limited amount of seed has been imported from South America, Mexico and Australia predominantly for experimental purposes. The cost of seed often exceeds US$20 per kilogram, the price that is not affordable for the majority of smallholder farmers in eastern Africa. Systems for the production of forage seed does not exist in most sub-Saharan African countries mainly due to this activity being a low government priority. The unavailability of seed and reluctance by the private sector to deal with an unorganized and dispersed demand for seeds has been a major constraint to the increased use of Brachiaria in eastern Africa. Import restrictions and a lack of clear procedures for importing seed also discourage the private sector from marketing Brachiaria into eastern Africa. The Tropical Seeds LLC, one of the private sector partners of CIAT for the commercialization of Brachiaria hybrids has been supplying the Brachiaria cultivar Mulato II into eastern Africa (Maass *et al.*, 2015) although this has been mainly for experimental purposes. The supply of seed as a commercial operation has to date not happened due to insufficient data being available on the agronomic performance and the resistance or tolerance to pests and diseases of the cultivars of interest.

Availability of quality seed at an affordable price is crucial for the widespread adoption of Brachiaria. Brachiaria can be propagated through both seeds and vegetative cuttings. However, the later method of propagation suffers heavily from pathological and physiological challenges causing a sharp decline in productivity over time. This phenomenon is prevalent for many perennial tropical grass species, and it has been reported that farmers across sub-Saharan Africa are experiencing a high level of productivity losses when Napier grasses have been vegetatively propagated. Therefore, the establishment of a cost effective Brachiaria seed production system is a critical aim of this "Climate Smart Brachiaria" Program. This initiative may also lead to increased income for farmers from the sale of seed. All eight test cultivars were assessed for seed production potential in multiple locations in both Kenya and Rwanda. Initial trials have shown that cultivars differed for both time of flowering and for the production of fertile seeds. However, our observations from the eight test cultivars over past two years have consistently demonstrated that the economic production of seed for Brachiaria in these experimental sites using current agronomic practices will be difficult to achieve. Therefore, current efforts are in place to refine agronomic practices for improved seed production, and towards the development of efficient methods for mass production of vegetative materials. The identification of seed production sites in sub-Saharan Africa that will deliver commercially significant quantities of cost effectively produced seed is on top priority of the program.

Emerging opportunities

Scaling up the use of Brachiaria: Livestock enterprises in sub-Saharan Africa are developing at the fast pace in response to the increasing demand for livestock products. Forages and crop residues constitute a significant proportion of livestock feed in the region. However, forages most frequently used are inadequate especially during the dry seasons and crop residues are of low nutritive quality. Napier grass, one of the most widely cultivated forage in Africa is susceptible to smut and stunt diseases causing a sharp decline in biomass productivity. Moreover, the use of grains in livestock feed has a limited scope as the region suffers heavily from human malnutrition and hunger. The current "Climate Smart Brachiaria" Program has shown that Brachiaria is a most promising option for farmers in east-Africa in improving both feed availability during dry season and nutritive quality leading to a significant enhancement in livestock productivity. The opportunity exists to upscale the use of Brachiaria both in countries where this programme has been focused and in other countries in sub-Saharan Africa. The mobilization of resources to achieve this would have a significant impact in transforming animal production in the region.

Exploration and utilization of available genetic resources: Africa is the center of origin for most Brachiaria species. These grasses are important components of the Savannah grassland ecosystem that is widely distributed across sub-Saharan Africa. Most improved commercial Brachiaria cultivars are the result of selections made from germplasm collected during 1980s from eastern and central Africa. The current inventory in the genebank at ILRI-Ethiopia and CIAT-Colombia consists of about 700 accessions of Brachiaria. As a result of the current program there has been an additional collection of local ecotypes across sub-Saharan Africa. Evaluating these for their agronomic potential and seed production ability will lead to identifying genotypes that are better adapted to eastern African environments.

Improvement of Brachiaria for specific traits: Drought, low fertility soils and prevalent pests and diseases are three major factors that limit Brachiaria productivity in sub-Saharan Africa. The magnitudes of these problems are expected to increase with prevailing climate change scenarios. Therefore, it is timely to identify Brachiaria genotypes with improved drought resistance, larger and deeper root systems for acquisition of nutrients and water, and increased resistance to topical pests and diseases. Our observations on improved Brachiaria cultivars bred in South America have shown that they are susceptible to local pests and diseases prevalent in eastern Africa. Further evaluation of exotic cultivars or collected ecotypes from sub-Saharan Africa is required prior to upscaling of Brachiaria in an African environment.

Promotion of Brachiaria as a multi-purpose grass: The extensive root system of Brachiaria can contribute to the accumulation of significant amounts of carbon into soils, improve soil structure and simultaneously protect soils from erosion. Another root attribute of Brachiaria that will contribute to reducing both greenhouse gas emissions and ground water pollution is biological nitrification inhibition (BNI). High palatability and nutritive value of Brachiaria also significantly contributes in reducing the carbon foot print associated with livestock products. Adaptation of Brachiaria to drought and marginal soils makes it an ideal candidate for restoration of low fertility and degraded soils. The use of Brachiaria in a push-pull system[1] aimed at managing crop pests and contributing to biofuel production (Khan *et al*., 2014) are further attributes of this multi-purpose grass.

Brachiaria Seed Productions: Establishment of a successful Brachiaria seed production system is crucial for both the sustainability of Brachiaria in smallholder production systems and for providing an additional income opportunity for smallholder farmers in sub-Saharan Africa. Some test cultivars produced panicles and set seed in some trial locations, but the amount of seed produced was far below the economic threshold required. Therefore, further research is needed to improve seed production and explore appropriate sites or regions for economic (cost effective) seed production within sub-Saharan Africa. In the meantime efforts to ensure the scaling-up of Brachiaria does occur will be directed towards developing technologies that deliver a rapid multiplication of persistent and healthy clonally propagated materials.

Harnessing microbes for improving plant growth and adaptation: Endophytes and plant associated microbes are known to provide many benefits to the host plants including plant growth promotion and suppression of plant pathogens. The "Climate Smart Brachiaria" Program has initiated research to understand both the range of and significance of microbes residing within Brachiaria leading to improved adaptation to drought prone and

[1] The push–pull technology is a strategy for controlling agricultural pests by using repellent "push" plants and trap "pull" plants

low fertility soils, and improved resistance to pests and diseases. This technology could be an integral part of developing sustainable and eco-friendly solutions to agricultural problems.

Conclusions

Brachiaria, a native flora to sub-Saharan Africa, has transformed livestock industries across the tropics mainly in Latin America and Australia. Although farmers elsewhere have been realizing the benefits of Brachiaria for decades, African farmers have only just started cultivating Brachiaria as a forage crop to support a burgeoning livestock industry. From both agricultural and environmental stand points Brachiaria has several desirable attributes. However, their performance in an African environment needs to be understood because of different climate extremes (mainly drought), the prevalence of low fertility soils, and the anticipated high incidence of topical pests and diseases. A narrow genetic base, attributed to its apomictic mode of reproduction, and cultivar development in a foreign environment (e.g. South America) means that Brachiaria when grown in Africa may need to be evaluated for their resistance to local pests and diseases. Future research on Brachiaria in Africa should be focused on followings areas: (1) Broadening the range of Brachiaria germplasm to be evaluated using the genetic diversity of genebank accessions and collected local ecotypes; (2) Development of cultivars for specific traits e.g. drought tolerance, adaptation to low fertility soils and resistance to local pests and diseases; (3) Identification of economically viable seed production sites and development of cost effective seed production technologies; (4) Exploration and use of endophytes and plant associated beneficial microbes for improved plant growth and resistance to pests and diseases; (5) Development of best practice management systems for growing and harvesting Brachiaria; and (6) Filling knowledge gaps to highlight and promote the agricultural and environmental benefits of growing Brachiaria in Africa, resulting in increased government and private sector support for this new technology.

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References

Argel, P. J. and G. Keller-Grein. 1996. Regional experience with Brachiaria: Tropical America - humid lowlands. In J. W. Miles, B. L. Maass, C. B. do Valle, and V. Kumble (ed.), *Brachiaria: Biology, Agronomy, and Improvement*. International Center for Tropical Agriculture, Cali, Colombia, pp. 205-224.

Cardoso, J. A., J. C. Jiménez, K. Odokonyero, L. M. Pineda, H. Vos, F. Vergara, D. Chamorro and I. M. Rao. 2015. Climate-smart Brachiaria for improving livestock production in East Africa- CIAT. Progress report presented in mid-year review meeting held on 2-3 July 2015 at Rubona, Rwanda.

Djikeng, A. J., I. M. Rao, D. Njarui, M. Mutimura, J. Caradus, S. R. Ghimire, L. Johnson, J. A. Cardoso, M. Ahonsi and S. Kelemu. 2014. Climate-smart Brachiaria grasses for improving livestock production in East Africa. *Tropical Grasslands-Forrajes Tropicales* 2: 38-39.

FAO, 2010. FAOSTAT database collections. Food and Agriculture Organization of the United Nations. Rome. Access date: 2015-08-04. URL:

http://faostat.fao.org

Fisher, M. J. and P. C. Kerridge. 1996. The agronomy and physiology of Brachiaria species. In J. W. Miles, B. L. Maass, C. B. do Valle, and V. Kumble (ed.), *Brachiaria: Biology, Agronomy, and Improvement*. International Center for Tropical Agriculture, Cali, Colombia, pp. 43-52.

Fisher, M. J., I. M. Rao, M. A. Ayarza, C. Lascano, J. I. Sanz, R. J. Thomas and R. R. Vera. 1994. Carbon storage by introduced deep-rooted grasses in the South American Savannas. *Nature* 371:236-238.

Ghimire, S. R. and K. D. Craven. 2013. Endophytes in low input agriculture and plant biomass production. In: *Bioenergy Feedstocks: Breeding and Genetics*. Edited by Saha, M., H.S. Bhandari, and J. Bouton. John Wiley & Sons, Inc.: River Street, Hoboken, NJ, USA, pp. 249-265.

Ghimire, S. R., C. Mutai, J. Njuguna and M. Ahonsi. 2015. Identification and functional characterization of bacterial community of tropical forage grasses *Brachiaria* spp. grown in their natural habitat. Accepted for poster presentation in American Phytopathology Society meeting to be held in August 1–5, Pasadena, CA, USA

Ghimire, S. R., J. Njuguna, L. Kago, C. Mutai, and M. Ahonsi. 2014. Endophytic microbes of Brachiaria grasses from the native home (East Africa) and their roles in host fitness. *Phytopathology* 104 (Suppl. 3):S3.45.

Ghimire, S. R., M. Ahonsi and D. Appolinaire. 2015b. Climate-smart Brachiaria for improving livestock production in East Africa – BecA-ILRI Hub. Progress report presented in mid-year review meeting held on 2-3 July 2015 at Rubona, Rwanda.

Jahnke, H. E. 1982. Livestock production system and livestock development in tropical Africa. *Kieler Wissenschaftsverlag Vauk Postfach* 4403, D -2300 Kiel 1, pp253.

Jank, L., S.C. Barrios, C. B. do Valle, R. M. Simeão and G. F. Alves. 2014. The value of improved pastures to Brazilian beef production. *Crop and Pasture Science*, 65 : 1132-1137.

Johnson, L. J., A.C.M. de Bonth, L. R. Briggs, J. R. Caradus, S. C. Finch, D. J. Fleetwood, L. R. Fletcher, D. E. Hume, R. D. Johnson, A. J. Popay, B. A. Tapper, W. R. Simpson, C. R. Voisey and S. D. Card. 2013. The exploitation of epichloae endophytes for agricultural benefit. *Fungal Diversity* 60: 171-188

Johnson, L. S. Teasdale and J. Caradus. 2015. Climate-smart Brachiaria for improving livestock production in East Africa – Grasslanz Technology. Progress report presented in mid-year review meeting held on 2-3 July 2015 at Rubona, Rwanda.

Khan, Z. R., C. A. O. Midega, J. O. Pittchar, A. W. Murage, M. A. Birkett, J. A. Bruce and J. A. Pickett. 2014. Achieving food security for one million sub-Saharan African poor through push-pull innovation by 2020. *Philosophical Transactions of the Royal Society B* 369 (1639), 20120284.

Khan, Z. R., C. A. O. Midega, J. O. Pittchar, A. W. Murage, M. A. Birkett, J. A. Bruce and J. A. Pickett. 2014. Achieving food security for one million sub-Saharan African poor through push-pull innovation by 2020. *Philosophical Transactions of the Royal Society B* 369 (1639), 20120284.

Maass, B. L., A. O. Midega, M. Mutimura, V. B. Rahetlah, P. Salgado, J. M. Kabirizi, Z. R. Khan, S. R. Ghimire and I. M. Rao. 2015. Homecoming of Brachiaria: Improved hybrids prove useful for African animal agriculture. *East African Agricultural and Forestry Journal* (Accepted).

Mutimura, M. 2015. Climate-smart Brachiaria for improving livestock production in East Africa – RAB Progress Report. Presented in mid-year review meeting held on 2-3 July 2015 at Rubona, Rwanda.

Njarui D. M. G., E. M. Gichangi, M. Gatheru, M. N. Njunie, E. M. Nyambati, K. W. Ndungu, J. G. Mureithi and S. R. Ghimire. 2015a. Niches for forage production and management in smallholder crop-livestock farms in Kenya. Paper to be presented in 23rd International

Grassland Congress to be held on 20-24 November, 2015 at New Delhi, India.

Njarui, D. M. G., E. M. Gichangi, M. Gatheru, M. N. Njunie, C. N. Ondiko, E. M. Nyambati, K. Ndungu, R. W. Muinga and J. G. Mureithi. 2015b. Climate-smart Brachiaria for improving livestock production in East Africa – KALRO. Progress report presented in mid-year review meeting held on 2-3 July 2015 at Rubona, Rwanda.

Parsons, J. J. 1972. Spread of African pasture grasses to the American tropics. *Journal of Range Management* 25:12-17.

Pizarro, E. A., C. B. do Valle, G. Keller-Grein, R. Schultze-Kraft, and A. H. Zimmer. 1996. Regional experience with Brachiaria: Tropical America - Savannas. In J. W. Miles, B. L. Maass, C. B. do Valle, and V. Kumble (ed.), *Brachiaria: Biology, Agronomy, and Improvement*. International Center for Tropical Agriculture, Cali, Colombia, pp. 225-246.

Rakotoarisoa, M. A., M. Lafrate and M. Paschali. 2012. Why has Africa become a net food importer? Explaining Africa agricultural and food trade deficits. FAO RomeRao, I. M. 2014. Advances in improving adaptation of common bean and *Brachiaria* forage grasses to abiotic stresses in the tropics. In: M. Pessarakli (ed.). *Handbook of Plant and Crop Physiology*, Third Edition. CRC Press, Taylor and Francis Group, USA, pp. 847-889.

Rao, I. M. 2014. Advances in improving adaptation of common bean and Brachiaria forage grasses to abiotic stresses in the tropics. In: M. Pessarakli (ed). *Handbook of Plant and Crop Physiology*, Third Edition. CRC Press, Taylor and Francis Group, USA, pp. 847-889.

Rao, I. M., P. C. Kerridge and M. C. M. Macedo. 1996. Nutritional requirements of Brachiaria and adaptation to acid soils. In J. W. Miles, M. B. L., C. B. do Valle and V. Kumble (ed.), *Brachiaria: Biology, Agronomy, and Improvement*. International Center for Tropical Agriculture, Cali, Colombia, pp. 53-71.

Renvoize, S. A., W. D. Clayton and C. H. S. Kabuye. 1996. Morphology, taxonomy, and natural distribution of Brachiaria (Trin.) Griseb. In J. W. Miles, B. L. Maass, C. B. do Valle, and V. Kumble (ed.), *Brachiaria: Biology, Agronomy, and Improvement*. International Center for Tropical Agriculture, Cali, Colombia, pp. 1-15.

Schardl, C. L. 1996. Epichloe species: fungal symbionts of grasses. *Annual Review of Phytopathology* 34: 109-130.

Smith, J., S. Tarawali, D. Grace D and K. Sones. 2013. Feeding the world in 2050: Trade-offs, synergies and tough choices for the livestock sector. *Tropical Grasslands–Forrajes Tropicales* 1:125-136.

Stur, W. W., J. M. Hopkinson and C. P. Chen. 1996. Regional experience with Brachiaria : Asia, the South Pacific, and Australia. In J. W. Miles, B. L. Maass, C. B. do Valle, and V. Kumble (ed.), *Brachiaria: Biology, Agronomy, and Improvement*. International Center for Tropical Agriculture, Cali, Colombia, pp. 258-271.

Subbarao, G. V., K. Nakahara, M. P. Hurtado, H. Ono, D. E. Moreta, A. F. Salcedo, A. T. Yoshihashi, T. Ishikawa, M. Ishitani, M. Ohnishi-Kameyama, M. Yoshida, M. Rondon, I. M. Rao, C. E. Lascano, W. L. Berry, and O. Ito. 2009. Evidence for biological nitrification inhibition in Brachiaria pastures. *Proceedings of the National Academy USA* 106:17302-17307.