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The role of forage genetic diversity in stimulating Africa's agricultural transformation

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Abstract

The catalytic role of agriculture in Africa's structural transformation is generally undisputed. This notwithstanding, climate change, pestilences, poor soil fertility and resource degradation pose serious limitations to the realization of agriculture's transformative potential. To address these challenges, unconventional solutions such as forage genetic resources have been explored as a strategy to mitigate the adverse effects of these drivers of change. This paper reviews the contribution of forage genetic resources to agricultural productivity from the perspective of diversity. In examining benefits and impacts, it highlights the role of forage genetic diversity in enhancing staple crop productivity, livestock productivity and the natural resource base. The review demonstrates that the diversity in forage genetic resources has proven instrumental in combating the aforementioned challenges. Furthermore, the review highlights the important role of forage genebanks in the conservation and distribution of high quality germplasm for research purposes. Policy implications are that the prioritization of forage genebanks by African nations is imperative in the conservation of forage genetic diversity as well as in the distribution of high quality germplasm. The need to explicitly acknowledge the contribution of forage genetic diversity in agricultural policy is also important in creating awareness on the utility of these resources towards Africa's development.

Keywords: Forage genetic diversity, Genebanks, Productivity

1. Introduction

The centrality of agriculture as a catalyst for broad-based transformation, despite a changing global landscape and constant castigation, has almost equivocally been reaffirmed in recent times through rigorous empirical research (Christiaensen and Martin 2018). Moreover, the promising economic performance of African countries invested in agriculture has served to practically assert the prominence of the sector in development discourses (Bachewe, et al. 2018).

Nonetheless, it is well understood that the agricultural sector, in its current state in many African countries is incapable of being a catalyst for economic development. Climate change, biotic and abiotic stresses, poor soil fertility and resource degradation significantly compromise growth in livestock and crop productivity. Climate change is projected to have adverse effects on both the quantity and quality of forages (Ferner, et al. 2018). This is a source of concern not only because drylands form 75 % of the continent's land surface and support 43 % of the population, but also because livestock rearing is the only promising economic activity in many of these areas (Place, et al. 2016) . Climate change is also projected to increase the incidences of biotic and abiotic stresses which in turn will affect cereal productivity (Tesfaye, et al. 2018). Currently, Striga weed infestation and stemborer infestation are some of the major threats to cereal productivity and whose devastation is projected to increase under increasing aridity scenarios (Midega, et al. 2017) (Chepchirchir, et al. 2018).Poor soil fertility, specifically, low soil Nitrogen remains a major challenge to cereal productivity in Africa (Kassie, et al. 2018). Moreover, inherent severe degradation has severely reduced the pools of Soil Organic Matter (SOM) which in turn has had severe adverse effects on food security (Beedy, et al. 2010) .

In recent times, researchers have transcended conventional approaches such as the reliance on productivity enhancing inputs to embrace less prominent, albeit important solutions, such as forage genetic resources. The diversity of forage resources has proven to be of great utility to researchers within and beyond the livestock sector. Browse fodder trees have been recognized as

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an important source of protein for resource constrained smallholder farmers (Franzel, et al. 2014).Moreover, browse tree foliage has been recognized as an important source of soil Nitrogen in many areas of Africa (Mafongoya, et al. 2006) .Forage legumes and grasses, in addition to their nutritive value have been recognized for their ability to rehabilitate vast tracts of degraded lands in arid areas (Yuan, et al. 2016) (Angima, et al. 2002).Researchers have also explored diversity in forage accessions to identify useful genotypes to be incorporated in agricultural technologies geared towards combating pest and weed infestation in cereal crops. (Midega, et al. 2017).

The appeal of forage genetic resources is essentially three fold. Firstly, forage genetic resources offer cost effective solutions to the multiple challenges facing smallholders (Mbow, et al. 2014).This is especially important in a continent where input use is limited due to affordability and profitability (Alene, et al. 2008) (Liverpool-Tasie, et al. 2017). Secondly, forage genetic resources offer a multipronged strategy to simultaneously combat climate change, biotic and abiotic stresses, poor soil fertility and resource degradation. Thirdly, these resources offer environmentally friendly solutions, a key component in achieving sustainable development (Chepchirchir, et al. 2018)

The obscurity of forage genetic resources and their related utility within the agricultural policy landscape can be explained by a narrow, short-term valuation of genetic resources. Forage genetic resources as other genetic material are held in bequest in anticipation to future challenges and as such may not be perceived to be of much utility within short project cycles (Koo, Pardey and Wright 2003). Retaining options for responding to unforeseen challenges is a major benefit that is particularly difficult to estimate, as is bequest value to future generations. Secondly, the impact of genetic resources are often valued through a narrow prism of crop improvements via breeding that serve to further alienate forages which do not have the leverage that popular staples have (Evenson and Gollin 2003). Much of the value of genebank collections accrues in the long-term payoffs from scientific research and knowledge generation, including but not limited to plant breeding. These traditional “explicit” approaches do not accommodate the multifarious pathways through which forage genetic diversity stimulates agricultural development, performing a great disservice to their valuation and appreciation amongst policy stakeholders.

In this regard, this paper endeavors to explicitly drawn attention to the positive role of forage genetic diversity in African agriculture. Specifically, the paper sheds light on three key areas, namely, staple crop productivity, livestock productivity and soil fertility replenishment. Further, the paper highlights the role of forage genebanks in conserving forage genetic diversity. It is hoped that this review will stimulate a broadened conceptualization of the impact of forage genetic diversity, which in turn will be instrumental in enhancing the recognition of these resources in high-level agricultural policy interventions. To the best of our knowledge, few papers have endeavored to explicitly elaborate on the role of forage genetic diversity in stimulating Africa’s agricultural development in recent times.

2. Benefits and Impacts of genetic resources

i) *Increased maize productivity*

Maize is the main dietary staple of Sub-Saharan Africa and as such its availability in this region is indisputably equated to food security and economic stability (Cairns and Prasanna 2018). Moreover, the synonymy of maize and food security is anticipated to hold, fuelled by an increasing sub-Saharan population that is projected to double by 2050 (Jew, et al. 2016).However, production is yet to keep pace with demand, despite improvements in maize productivity. Staple food deficits are a serious source of concern among stakeholders given the role of staple food adequacy in poverty reduction and economic progress (Diao, Hazell and Thurlow 2010).

Pests and parasitic infestations, namely, stemborer and striga weed, pose a serious threat to staple crop productivity in the sub-Saharan region (Kebede, et al. 2018).Moreover, it is anticipated that climate change, a major source of concern currently, will exacerbate the prevalence and lethality of these infestations (Midega, Bruce, et al. 2015).In response to these concerns, researchers at the

International Centre of Insect Physiology and Ecology (ICIPE), developed push-pull technology to combat both stemborer and striga infestation.

The technology capitalizes on both inter and intra species forage diversity to deliver a cost-effective and multi-purpose solution. The original technology involved the intercropping of maize with a perennial fodder legume, Silverleaf Desmodium (*Desmodium uncinatum* (Jacq.) DC), and the use of a fodder grass, such as *Pennisetum purpureum* (L.) Schumach., as the trap plant (Murage, et al. 2015). The push plant repels the stemborer from the maize and suppresses striga infestation whilst the trap plant provides an infeasible environment for the development of stemborer larvae. Researchers further explored forage diversity in adapting this technology to hot and drier areas by using green leaf *Desmodium intortum* (Mill.) Urb. (Leguminosae) as the push plant and drought tolerant Brachiaria spp. (especially *Brachiaria* cv Mulato II (Poaceae) as the trap plant in what came to be known as the "Climate smart push-pull technology" (Midega, Pittchar, et al. 2018) .Further research was conducted in order to identify additional drought tolerant *Desmodium* species to combat striga, and two species were identified namely, *Desmodium incanum* and *D. ramosissimum* (Midega, et al. 2017).

Though a fairly nascent technology, preliminary impact assessment at farm level as well as aggregate welfare impacts show promising results of adoption. Impacts at farm level reveal that the technology had an incremental effect on yields and net income among adopters in Western Kenya; maize yields increasing by 61.9 % whilst net income increased by 38.6 %. Moreover, economic surplus estimations, at varying adoption rates (25-40%) and open and closed economy assumptions, range between 139-250 million dollars for Western Kenya (Kassie, et al. 2018).

The highlight on push-pull technology demonstrates the value of forage genetic diversity in resolving non-livestock agricultural challenges. This is particularly appreciated in the cereals sub-sector, given the economic importance of cereals such as Maize. Diversity has made it possible for researchers to identify forage legumes and grasses amenable to the implementation of this technology. Moreover, the diversity within species' accessions has allowed for the identification of valuable genotypes that exhibit tolerance to a wide range of challenges, namely, pests, weeds and climate change (Hooper, et al. 2015).The appeal for these sorts of ingenious solutions in Africa will undoubtedly increase given the precarious context that entangles agriculture.

b) Soil fertility replenishment

Declining soil fertility has long been acknowledged as a serious limiting factor to food productivity in Africa (Kätterer, et al. 2019).Specifically, low soil Nitrogen has been identified as a key contributor to compromised Maize productvity (Akinyosoye, et al. 2018)This state of affairs is attributed to a number of factors such as soil erosion, weathering and inadequate replenishment of inorganic and organic inputs. The state of affairs is set to be exacerbated by population pressures and climate change, posing serious impediments to the attainment of food security (De Bauw, et al. 2016).Nutrient replenishment through inorganic fertilizers is still very low in Africa, a phenomenon attributed to high transaction costs in input and output markets that limit affordability (Alene, et al. 2008). Moreover, replenishment of organic matter reserves is imperative to an extent in determining crop response to fertilizer; hence a sole emphasis on fertilizer alone would constitute a narrow focus (Kihara, et al. 2016).

In this regard, diverse forages have been found to be amenable to replenishment of soil Nitrogen and soil organic matter reservoirs. A number of browse forages have played an important role in soil Nitrogen replenishment, most notably *Gliricidia sepium* in Southern Africa within maize intercropping systems. Gliricidia's foliage is rich in Nitrogen, estimated to be as high as 4 %, which renders it a good source of green manure (Beedy, et al. 2010). Moreover, the fodder tree, by virtue of being leguminous, is recognized for its ability to biologically fix Nitrogen in the soil (Nyoka, Simonss and Akinnifesi 2012) . The fodder tree's annual biological fixation is estimated at 108 kg/ha (Coulibaly, et al. 2016). Gliricidia-Maize intercrop has been associated with an increase in Soil Organic Matter (SOM), Particulate Organic Matter, Particulate Organic Matter-

Nitrogen and Particulate Organic Matter-Carbon (POM-C), all essential elements for good crop performance (Beedy, et al. 2010).

The commendable uptake of *G.sepium* in Southern Africa is partly attributed to social enterprises such as the Community Markets for Conservation (COMACO).COMACO is a holistic social enterprise venture where farmers living around the Lungwe park (formerly involved in elephant poaching) have been offered alternative income sources through the use of fertilizer trees *(G.sepium)*. The enterprise which works with approximately 180,000, integrates *G.sepium* in its climate smart practices among member farmers, and thereafter purchases produce from members at a premium under *It's Wild!* Brand (Itswild.org 2019).

Forage legumes have also demonstrated a lot of potential in the restoration of degraded lands; a case in point is the vast use of *Medicago sativa* in China. The legume has been widely used as forage grass in the rehabilitation of many degraded areas in China under the "Grain for green" initiative, the largest land restoration project in the developing world aimed at combating soil erosion and degradation (Yuan, et al. 2016) *Medicago sativa*,a perennial dry tolerant legume, is one of the most cultivated forages in the world with cultivation spanning approximately 32 million hectares as of 2009 (Yu, et al. 2018).

The species has sometimes been referred to as "the queen of forages" given that it has the highest yield of free protein per unit, estimated to range between 2000-3000 Kg/hectare, among all forages and grain legumes (Rafińska, et al. 2017) .The legume is appreciated for its ability to fix Nitrogen through symbiotic activity with Rhizobia in its root nodules, thereby improving soil fertility (Zhang, et al. 2016).In addition to its Nitrogen fixation abilities, revegetation with *Medicago sativa* has been shown to increase soil organic Carbon concentration through its large fine litter input and root biomass. Enhancement of soil organic carbon stocks is important for improving soil fertility, reducing soil erosion and mitigating soil carbon dioxide emissions (Yuan, et al. 2016).

The potential for forages in restoration is vast indeed, especially in Africa where an estimated two-thirds of the land is degraded. Degradation is rightfully a source of concern because it compromises food security and poverty reduction gains. (Barrett, et al. 2017).The diversity in forages facilitates the utilization of these resources to restore fragile ecosystems situated in varied agro climatic zones. The aforementioned examples also highlight the manner in which the private sector and public sector can propel adoption and utilization of these resources.

c) Livestock Productivity

Livestock rearing constitutes an important livelihood strategy for an estimated 1 billion poor smallholder rearers and their constituent households (Herrero, et al. 2013). This is especially the case in approximately half of the countries in Africa, whereby 30 % of the population depend on livestock rearing as the predominant livelihood venture (Fikru, et al. 2016). Income, nourishment, traction, manure production and insurance are just some of the multi-functional livelihood benefits that livestock ownership confers to this demographic (Swanepoel, Stroebel and Moyo 2010). Moreover, on a macroeconomic frontier, it is estimated that livestock contribute to approximately 40 % of the global Agricultural Gross Domestic product (GDP) (Ferner, Ferner, et al. 2018).

That said, livestock productivity in Africa stills lags behind that of many countries. Feed scarcity and low feed quality have been cited as some of the major factors limiting ruminant livestock productivity in the tropics (Salem, et al. 2006) (Franzel, et al. 2014) . Natural pastures and crop residues, which constitute the main source of ruminant diets, are of poor nutritional value given their low content of nitrogen and digestible nutrients (Ondiek, et al. 1999, 67).It is within this context that the diversity of browse fodder have been appreciated for their role as cost-effective protein supplements for resource poor farmers.Browse fodder, have been identified as suitable protein supplements to low quality basal diets given their relatively high Nitrogen content (Maasdorp, Muchenje and Titterton 1999, 50). These trees have relatively high protein content compared to grasses; in addition to the fact that their nutritive content does not vary significantly

across seasons, unlike grasses whose nutritional value declines with maturity (Pamo, et al. 2006, 32).
The diversity of browse fodder is especially appreciated to suit contextual variability, namely, altitude range, mean annual rainfall range, feed quality, acidity tolerance and drainage tolerance. To illustrate, *Gliricidia sepium*, is superior to *Calliandra calothrsus* both in nutritive value and agroecological range, yet it is the latter that has enjoyed superior adoption success in East Africa due to its palatability (Stewart, et al. 1998). *Leucaena leucocephala* is also classified as a highly nutritive browse fodder, though its utilization was limited by the leucaena psyllid that led to identification of *G.sepium* and *C.calothyrsus* (Hanson and Maass 1997).*Sesbania sesban* has been widely adopted in Ethiopia, not only for its highly nutritive qualities but also for its tolerance to acidic soils , poor drainage and low rainfall, that compatriot high quality fodder trees such as *Leucaena trichandra and Morus alba* would not tolerate well (Franzel, et al. 2014).The appreciation of diversity extends to accessions within species; a case in point is when researchers would like to identify accessions that have a low tannin concentration (Soliva, et al. 2008). A fodder tree may have a high crude protein content but at the same time have a high tannin concentration that inhibits dry matter intake and protein digestibility. As such diversity within accessions of the species would allow for selection of accessions that maximize nutritive value yet have a low tannin concentration (Mekoya, et al. 2009) .
The appreciation of diversity is also fostered by adverse consequences of a narrowing genetic base as seen with Napier Grass Stunt Disease (NGSD). In the case of Kenya, the disease has adversely affected feed availability and quality; by virtue of its prime position as the dominant forage within intensive and semi-intensive dairy farming systems in East and Central Africa (Wamalwa, et al. 2017). The disease is caused by phytoplasma, a single cell-wall bacterium, and transmitted by an infected insect vector identified as *maiestas banda* (Kawube, et al. 2015). Physical symptoms on infected Napier include yellow leaf symptoms, stunted growth and necrosis (Kawube, et al. 2015).The virulence of the disease has been experienced most in western Kenya where it is estimated that farmers have lost between 40 and 90 % of their crop. The loss of crop has in turn forced farmers to sell their livestock, reduce their herd or purchase feeds from markets (Wamalwa, et al. 2017). The pervasiveness of NGSD across East Africa, as well as the severe livelihood consequences, emphatically underscores the imperative for genetic conservation. The virulence and prevalence of the disease has been partly attributed to the narrowing Napier genetic base (Kawube, et al. 2015).

3. Overview of Forage Genebanks

The discussion of forage genetic diversity is inextricably linked to forage genebanks given that these are the major repositories of forage genetic diversity. The Consultative Group on International Agricultural Research (CGIAR) houses eleven genebanks that conserve a total of 768,576 accessions of varied crops. This is the largest collection under the multilateral system of The International Treaty on Plant Genetic Resources for Food and Agriculture **(ITPGRFA)** agreement**.** The largest forage diversity repositories (within the CGIAR) are located in three genebanks, namely, International Livestock Research Institute (ILRI), International Center for Agricultural Research in the Dry Areas (ICARDA) and International Center for Tropical Agriculture (CIAT).These three genebanks play an important role in the cataloguing, conservation and distribution of forage accessions (www.genebanks.org n.d.)
The International Center for Tropical Agriculture (CIAT) genebank is located in Cali, Columbia. CIAT's mandate involves the conservation of tropical herbaceous forage legumes and grasses adapted to low fertility acid soils with high aluminum. The genebank conserves 66,787 accessions, 22694 of which comprise tropical forages and legumes. The center has one of the largest and diverse tropical legume and forage collections, representing 740 species (www.genesys-pgr.org n.d.). The International Livestock Research Institute (ILRI) genebank is located in Addis Ababa, Ethiopia. ILRI's mandate involves the conservation of high and mid-altitude subtropical forages. The genebank has in its trust approximately 18,643 accessions, 17387

of which constitute forages. It is one of the most taxonomically diverse collections (www.genesys-pgr.org n.d.). The International Center for Agricultural Research in the Dry Areas (ICARDA) was originally located in Allepo, Syria but has since relocated to Morocco and Lebanon. The genebank has in its trust approximately 157,286. The genebank has the largest collection of tropical and forage legumes in the CGIAR spanning over 36,800 accessions. The mandate of ICARDA's collection centers on subtropical and Mediterranean forage legumes adapted to dry areas (www.genebanks.org n.d.).

Forage genebanks are central to the conservation of forage genetic diversity and distribution of superior quality germplasm. The conservation of forage genetic diversity gains greater urgency given the pressure from drivers of change in global endowments of natural resources. Structural transformation and its concomitant repercussions (urbanization, affluence) are predicted to significantly increase the demand for livestock products (Barrett, Christian and Shiferaw 2017). Population increases exert unrelenting pressure on natural resources—leading to the conversion of marginal tracts of land to agricultural use and contributing to biodiversity loss (Pimentel, et al. 1992). Finally, precipitation and temperature invariability, droughts and floods occasioned by climate change underscore the need to have adapted forages that can function in ever-changing ecosystems (Gamoun, Belgacem and Louhaichi 2018). The continued assurance of forage genetic diversity (to adapt to dynamic pressures) is contingent on the existence of a diverse genetic reservoir of forages.

4. Conclusions and Policy Implications

Forage genetic resources, specifically their diversity, play a crucial role in livestock productivity, ecosystem restoration and food security in Africa. This role will be magnified in the future as Africa's endeavors to accelerate her development agenda amidst intense pressure from drivers of change. Forage genetic resources, however, do not receive explicit mention in the broader policy circles determining Africa's development path. The few existent studies have often focused on attributing the value of genetic resources to breeding successes. This narrow approach not only obscures the role of genetic resources to agricultural development in general, but specifically alienates genetic resources such as forages whose success may not be tied to frequent breeding innovations.

The objective of this study was to provide an overview of the contribution of genetic resources to staple food productivity, livestock productivity and ecosystem restoration. Concerning, benefits and impacts, the study documented utilization of forage genetic diversity in combating staple crop productivity threats such as stemborer and striga. The study further documented the role of forage genetic diversity in rehabilitating degraded landscapes and soils. The study reiterated the importance of diversity within the livestock sub-sector; demonstrating how browse fodder diversity has catered to contextual variability. The review also highlighted the consequences of narrow genetic bases as exemplified in the case of Napier Grass Stunt Disease (NGSD).The study also shed light on select genebanks involved in forage conservation, highlighting the diversity in their collections. This is important in order to not only stimulate appreciation for the often "silent" operations of genebanks but also to expand this understanding to a much broader circle of influential policymakers. It is only through such efforts that conservation can be prioritized.

The results of this study present important policy implications. The results of this study demonstrate the multi-impact pathway through which forage genetic diversity can ameliorate Africa's agricultural outcomes. Secondly, this study reiterates the important role of genebanks in the characterization, conservation and distribution of germplasm. It is through these efforts that researchers have access to superior germplasm for evaluation purposes, which in turn has led to the development of innovative solutions. Thirdly, this study highlights the imperative to explicitly acknowledge and prioritize forage genetic diversity conservation within Africa's development agenda. This is important given that Africa's development faces substantial retardation from drivers of change that demand for diverse albeit unconventional solutions as part of the development agenda.

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