Reg Environ Change (2017) 17:1713–1724
DOI 10.1007/s10113-017-1131-7

ORIGINAL ARTICLE

Potential use of forage-legume intercropping technologies to adapt to climate-change impacts on mixed crop-livestock systems in Africa: a review

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Received: 8 May 2015 / Accepted: 18 February 2017 / Published online: 7 March 2017

Abstract This paper summarizes effects of forage-legume intercropping on grain and fodder yield, land equivalent ratio, residual soil fertility, disease and insect pest reduction in mixed crop-livestock systems in Africa. In particular, it discusses the potential benefit of forage-legume intercropping in improving productivity, resource use efficiency and resilience of the system under climate change. Research undertaken in Africa demonstrates that intercropping forage legumes with cereals improves land intensification due to improvement in overall yield and soil fertility, and reduced risk of crop failure owing to rainfall variability, diseases, weeds and pests. Forage from intercropped legumes improves the intake of dietary nitrogen, digestibility of poor-quality feed, animal performance and efficiency of roughage feed utilization by ruminants. The improvement in digestibility alone leads to 15–30% reduction in methane emission per unit of animal product. Additional role that legumes may play includes lowering erosion (20–30%), reducing nitrogen leaching and carbon losses, and promoting carbon sequestration. Nitrogen fixed by legumes was on average 45 kg N/ha, and this ranges between 4 and 217 kg N/ha for herbaceous legumes and 8 and 643 kg N/ha for fodder tree species. Despite the many benefits of forage-legume intercropping, the current adoption rate in sub-Saharan Africa is very low. Future research aimed at selection of compatible varieties, appropriate plant geometry and temporal arrangement of the various intercrops under different locations and management scenarios, and minimizing the confounding effects of water, soil, light, microclimate and seeds could enhance adoption of the technology in Africa.

Keywords Adaptation · Africa · Climate change · Forage legume · Intercropping · Mixed farming

Introduction

Agriculture forms the backbone of the economic growth of sub-Saharan African (SSA) countries, accounting for 40% of gross domestic product (GDP) and employing more than half the labour force (Barrios et al. 2008). In a large fraction of SSA, where most livelihoods depend on rain-fed smallholder agriculture, agricultural production is sensitive to climate change (Barrios et al. 2008; FAO 2016). A general decline in rainfall pattern has been reported in Africa since the first half of the nineteenth century (Nicholson 1994; 2001). Rising temperatures, associated with this decline in rainfall, have a direct negative effect on vegetation cover, which in turn contributes to soil

Editor: Wolfgang Cramer.

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degradation because of the exposure of the soil surface to wind and water erosion. Consequently, Southern Africa is predicted to loose about 14% of cultivable land and about 20% of its pasture production potential by 2080 because of climate change (Shah et al. 2008). It is apparent that an increase in atmospheric carbon dioxide (CO_2) might lead to dichotomous effects, namely stimulating plant growth (Luo et al. 2004) and contributing to the greenhouse gas effect. According to Luo et al. (2004) plant growth demands more nitrogen, water and other essential nutrients, leading to progressive nitrogen limitation (PNL) in the soil, subsequently destabilizing the C/N ratio of organic matter in the soil (Soussan and Lemaire 2014), which in turn suggests that the nitrogen cycle has the ability to regulate climate change through its influence on carbon sequestration (Liang et al. 2016).

In SSA, smallholder mixed crop-livestock systems are more important than any other system in terms of their contribution to total agricultural output (FAO 2010; Soussan and Lemaire 2014). Mixed crop-livestock farming systems are held responsible for large greenhouse gas emissions. However, they could play a significant role in the mitigation of these emissions (Thornton and Herrero 2014). One of the potential mitigation measures that could be adopted in crop-livestock systems is the introduction of forage legumes in areas under grass production as grass-legume mixtures. This is likely to reduce direct and indirect greenhouse gas emissions (Soussan and Lemaire 2014), thereby mitigating and facilitating adaptation to climate change (Luscher et al. 2014) by replacing inorganic nitrogen-fertilizer inputs with symbiotic nitrogen fixation. Thus, legumes may occupy a niche in such systems as intercrops (Sumberg 2002; Sprent et al. 2010), because they have the ability to symbiotically fix nitrogen in the soil (Zahran 1999). This would preclude the occurrence of PNL due to the increase of nitrogen input into ecosystem as a result of symbiotic nitrogen fixation into soil. Hence, this review analyses the potential role of forage-legume intercropping in the mixed crop-livestock system and discusses the potential of these technologies to adapt to and mitigate climate-change impacts in the mixed crop-livestock systems in SSA.

Climate change and agriculture in Africa

Agricultural productivity in SSA is expected to decrease between 15 and 35% in future as a result of climate change (Cline 2007; Fischlin et al. 2007), which would affect crop and livestock production, hydrologic balances, input supplies and other components of the agricultural systems. The impact is expected to be aggravated by rapid human population growth in the region. Although many non-climate factors affect agriculture, climate change overlays and interacts with other factors to worsen conditions (Fischlin et al. 2007). Rain-fed agriculture is sensitive to climate variability and change, because of its direct dependence on the amount and distribution of rainfall. The vulnerability of the system varies from region to region, and countries in SSA region have limited capacity to adapt to and mitigate the impacts of climate change. This problem is aggravated by lack of awareness of climate-change adaptation and of mitigation measures by rural communities (Lobell et al. 2008).

Impacts of climate change on livestock production

Livestock production supports the livelihoods of more than 600 million poor smallholder farmers in the developing world and is an important source of food (meat and dairy products), animal products (leather) and income in the event of crop failure (Seo and Mendelsohn 2007). Climate change is expected to have several impacts on feed crops, grazing systems, animal physiology and health (Thornton et al. 2009), thereby negatively affecting livestock production in SSA (Serdeczny et al. 2016). The impact on crops and forages includes changes in herbage growth and quality, the species composition of pastures, concentrations of water-soluble carbohydrates and nitrogen (N) and N leaching in certain systems because of high rainfall events (Ngongoni et al. 2007). Higher temperatures (in the prevalence of moisture) may increase the rate of development of pathogens and parasites that spend some of their lifecycle outside their host animal (Harvell et al. 2002). In addition, heat stress may decrease cow fertility, fitness and longevity (King et al. 2006), while livestock death associated with recurrent drought is a common phenomenon in the arid and semi-arid rangelands of East Africa (Oba 2001). However, the vulnerability of livestock to climate change varies according to species, genetic potential, life stage and nutritional status of the animals (Thornton et al. 2009).

The role of forage-legume intercropping in adapting to climate change under different agro-ecological zones in Africa

In Africa forage legumes are commonly intercropped with cereals such as maize (Hassen et al. 2006; Carlson 2008; Birteeb et al. 2011; Kabirizi et al. 2012), sorghum (Mohammed et al. 2008; Lithourgidis et al. 2011), millet (Mohammed et al. 2008) and wheat (Astatke et al. 1995), as well as root crops (cassava) (Mba and Ezumah 1985). The forage-legume species that have been successfully intercropped in each of the major agro-ecological zones of Africa (Fig. 1) are discussed below.

Arid to moist semi-arid zones

The net effects of intercropping on grain yield, forage biomass yield of the companion crops and the land equivalent ratio (LER) of the intercropping system for major African climatic zones are summarized in Table 1. It was apparent that intercropping maize with legumes (*Vignia ungulata*, *Lablab purpurius*, *Stylosanthes guianensis* and *Macroptilium atropurpurium*) improved grain and forage yield of maize compared with maize alone planted in sandy loam to loamy sand soils in areas receiving at least 600 mm of mean annual rainfall (Alhaji 2008; Birteeb et al. 2011). The LER in these areas was also more than unity. In contrast, in areas receiving less than 500 mm of mean annual rainfall, maize yield under intercropping was less than when maize was planted alone, though the LER was more than unity (Vesterager et al. 2008), probably because of competition for resources, especially water.

Sorghum–cowpea intercropping studies in the semi-arid regions of Burkina Faso reduced run-off losses of soil by 20–30% compared with sorghum monoculture and by 45–55% compared with cowpea monoculture (Zougmore et al. 2000). This area received mean annual rainfall of 800 mm during the study period and is characterized by high rainfall intensity and therefore high run-off losses (about 40% of the annual rainfall), reducing the effective rainfall. The soil in this study site was reported to be low in N, and no fertilizer application was reported for the study period. Reports from this study showed that the yields of both sorghum and cowpea doubled under intercropping compared with monoculture. In contrast, studies conducted by Oseni (2010) reported lower sorghum yield under sorghum–cowpea intercropping compared with sorghum monoculture in a higher rainfall (970 mm) environment. The observed higher yield for sorghum monoculture was attributed to the inorganic fertilizer that was applied at planting.

Sub-humid to humid zones

The forage legumes commonly used for intercropping with food crops in sub-humid to humid zones are shown in Table 2. Except for maize–lablab and cassava–cowpea

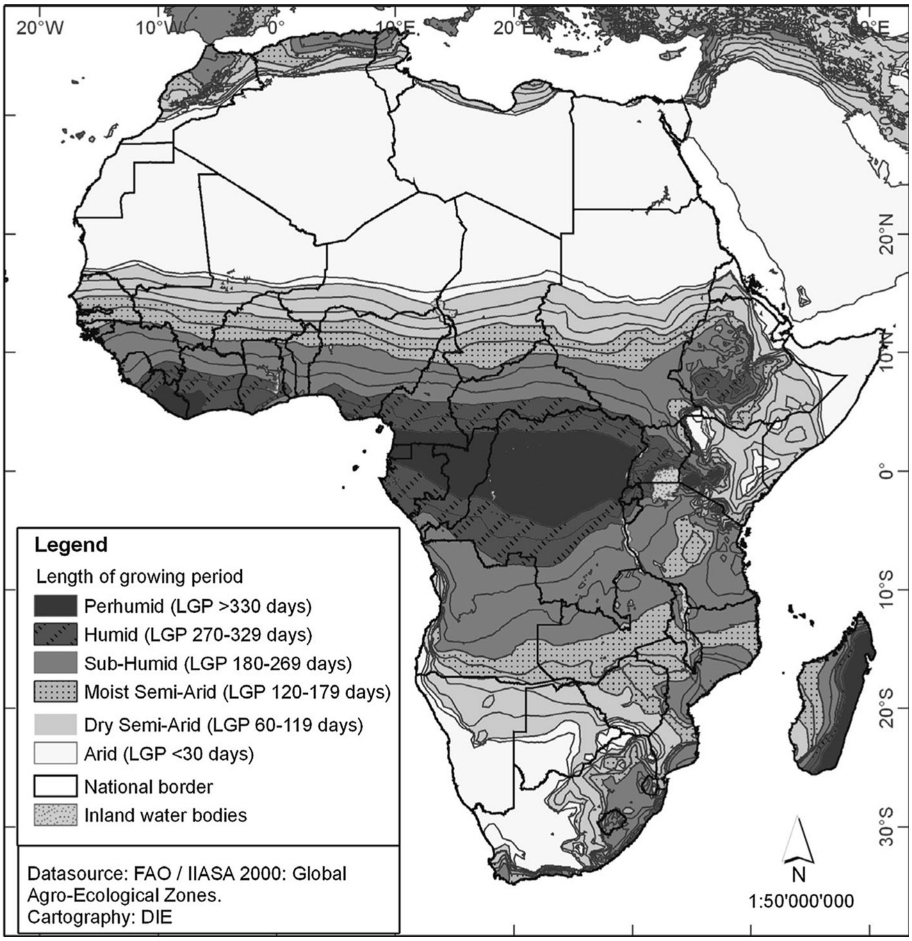

Fig. 1 Major climate zones of Africa based on the length of the growing period (*Source*: adapted from FAO/IIASA 2000)

Table 1 Grain yield, forage biomass yield and land equivalent ratio of legumes intercropping in arid to moist semi-arid agro-ecological zones of Africa

Intercrops	Grain yield	Forage biomass yield	LER	AEZ	Reported benefits	References
Maize-cowpea	+	++	1.40–2.29	Arid (savannah)	Economic advantage is high	Alhaji (2008)
Maize–lablab	+	++	1.12	Arid (savannah)	77.6% ground cover	Birteeb et al. (2011)
Maize-*Stylo*	+	++	1.4	Arid (savannah)	38% ground cover	Birteeb et al. (2011)
Maize-*Siratro*	+	++	1.11	Arid (savannah)	42.9% ground cover	Birteeb et al. (2011)
Maize-cowpea	−	++	1.44–1.63	Moist semi-arid	Weed reduced by 46.2%; *Striga* infestation reduced	Katsaruware and Manyanhaire (2009)
Maize-cowpea	+	++	na	Sub-arid	35% additional monitory value	Carlson (2008)
Maize–lablab	++	++	1.11	Semi-arid	CP of stover improved by 7.6%	Kabirizi et al. (2012)
Sorghum–cowpea	+	++	na	Semi-arid	Reduced run-off by 20–30%	Lithourgidis et al. (2011)
Sorghum–cowpea	−	+	1.08	Semi-arid	Monetary index advantage	Oseni (2010)
Sorghum–cowpea	+++	+++	1.88	Arid	Grain and fodder yield increased	Mohammed et al. (2008)
Sorghum–cowpea	+++	++	na	Semi-arid	9.4% yield advantage	Samuel and Mesfin (2003)
Millet-cowpea	+	++	1.92	Arid	Drought resistant	Hulet and Gosseye (1986)
Maize-cowpea	+	++	1.35	Semi-arid	18% yield advantage	Vesterager et al. (2008)
Sorghum–cowpea	−	+++	1.63	Savannah	Grain yield increased	Zougmore et al. (2000)

LER land equivalent ratio, *AEZ* agro-ecological zone, *na* not available, *RF* rainfall, *CP* crude protein

Grain and forage biomass yield: − (minus) means yield reduced; LER <1 + means yield reduced, but LER above unity (>1); ++ means yield is not affected, with LER above unity (1); +++ means yield improved with LER above 1.5; Stylo-*Stylosanthes guianensis*, Siratro-*Macroptilium atropurpurium*

intercropping systems, grain yield was not affected negatively by intercropping. The reduction in grain yield of maize and tuber yield of cassava when planted with lablab and cowpea in humid regions was attributed to the fast and vigorous growth of legumes (Mba and Ezumah 1985; Hassen et al. 2006). The higher LER of cassava–cowpea intercrops suggests there may still be an economic advantage of this combination, despite the reduction in tuber yields.

Maize grain yield was higher when intercropped with *Vicia dasycarpa,* but in other combinations, yields were not suppressed, especially where delayed planting of the legumes was practised (Hassen et al. 2006).

Tropical to warm-temperate zones

The crops used mainly for intercropping in warm-temperate and tropical zones are indicated in Table 3. Except for maize-velvet bean and wheat-alfalfa intercropping combinations, grain yield was higher or similar in these combinations compared with sole crop. The forage biomass, however, was higher in the intercropping systems than in sole crops for all combinations.

Does forage-legume intercropping have the potential to adapt to climate-change impacts in the mixed crop-livestock farming system in Africa?

Forage-legume intercropping could play a significant role in adaptation to climate change by reducing soil degradation (chemical and physical), improving soil fertility through nitrogen fixation, reducing the prevalence of weeds, pests and disease and improving yield, feed quality and animal performance. In addition, it would provide a co-benefit in terms of reduction of greenhouse gas emissions. Details of the roles of forage-legume intercropping in mitigating and adapting to climate change in the mixed crop-livestock farming system in Africa are presented below.

Table 2 Grain yield, forage biomass yield and land equivalent ratio obtained by legume intercropping in humid to sub-humid agro-ecological zones

Intercrops	Grain yield	Forage biomass yield	LER	AEZ	Descriptors/comments	References
Maize-cowpea	+	++	1–1.4	Sub-humid	Early maturing could be best compatible	Adeniyan et al. (2011), Surve et al. (2012)
Maize-cowpea	+	++	na	Sub-humid	Did not suppress grain yield	Maasdorp and Titterton (1997)
Cassava–cowpea	+	++	1.2	Humid	Improve total yield and starchiness, protect soil	Mustaers et al. (1993)
Maize–lablab	−	++	na	Humid	14–69% forage biomass contribution from legumes	Ngongoni et al. (2007)
Cassava–cowpea	−	++	1.48–2.02	Humid	Late harvesting of cassava	Mba and Ezumah (1985)
Sorghum-*Vicia**	+++	++	na	Humid	Intercrops gave 3.4% more grain yield	Samuel and Mesfin (2003)
Maize–*Lablab**	++	+++	1.46	Humid	Highest lablab yield at later stages of maize growth	Hassen et al. (2006)
Wheat-lablab	++	++	1.35	Sub-humid	At no N level	Astatke et al. (1995)
Wheat-clover	++	++	1.35	Sub-humid	At no N level	Astatke et al. (1995)
Maize-vetch	++	++	1.1	Sub-humid	At no N level	Astatke et al. (1995)

LER land equivalent ratio, *AEZ* agro-ecological zone, *na* not available

Grain and forage biomass yield: − (minus) means yield reduced, LER <1, + (plus) means yield reduced, but LER above unity (>1); ++ means yield is not affected with LER above unity (1); +++ means yield improved with LER above 1.5 Vicia-*Vicia dasycarpa*, Lablab-*Lablab purpureus*

Table 3 Grain yield, forage biomass yield and land equivalent ratio of forage-legume intercropping in warm-temperate and tropical agro-ecological zones

Intercrops	Grain yield	Forage biomass yield	LER	AEZ	Descriptors/comments	References
Maize-velvet bean	−	++	0.77–1.08	Warm temperate	N concentration is 4.9%	Murungu et al. (2011)
Maize-sun hemp	+	++	0.98–1.13	Warm temperate	N concentration is 2.6%	Murungu et al. (2011)
Wheat-alfalfa	−	+	na	Tropics	Reduced incidence of a soil-borne pathogen	Lithourgidis et al. (2011)
Sorghum-*Desmodium*	+	+	na	Warm temperate	100% *Striga* control	Ejeta (2007)
Cassava-pigeon pea	+	++	na	Tropics	Planting date is important	Cenpukdee and Fukai (1992)

LER land equivalent ratio, *AEZ* agro-ecological zone, *na* not available

Grain and forage biomass yield: − (minus) means yield reduced; LER <1, + (plus) means yield reduced, but LER above unity (>1); ++ means yield is not affected with LER above unity (1); +++ means yield improved, with LER above 1.5

Reduction of soil degradation through land cover and soil erosion control

Intercropping forage legumes as cover crops has shown positive effects on soil structure by enhancing the formation and maintenance of soil aggregates (Lupwayi et al. 2011) through better ground cover (Brandt et al. 1989; Tomm and Foster 2001). This leads to an increase in soil organic matter relative to sole crops and increases water infiltration and air circulation (Lupwayi et al. 2011), thus improving soil water-holding capacity (Dovel et al. 1995; Murphy and Colucci 1999; Samuel and Mesfin 2003). For example, 62% ground cover has been achieved by clover species (Tomm and Foster 2001) and 53.2% by *Lablab*

Table 4 Estimates of N_2 fixation (kg/ha) by legumes commonly used for intercropping in Africa

Country	Legume	N-fixed (kg/ha)	Yield (t/ha)	AEZ[a]	References
Ghana	*Cowpea*	200	6.7	Arid–semi-arid	Dakora and Keya (1997)
Zimbabwe	*L. purpureus*	45–60	na	Sub-humid	Mohammed-Saleem (1986)
South Africa	*S. sesban*	28–63	na	Semi-arid	Snap et al. (1998)
Nigeria	*Cowpea*	122	na	Sub-humid	Eaglesham et al. (1981)
Zimbabwe	*Cowpea*	68–138	1.4	Sub-humid	Rusinamhodzi et al. (2006)
Zimbabwe	*Cowpea*	4–29	0.1–0.6	Sub-humid	Ncube et al. (2007)
Namibia	*Cowpea*	13 (30–60%)	0.8	Semi-arid	McDonagh and Hillyer (2003)
SSA	*Cowpea*	9–125	1.5–2.7	Arid–semi-arid	Giller et al. (1997)
Ghana	*Cowpea*	29–179	na	Savannah	Belane and Dakora (2009)
South Africa	*Cowpea*	25–217	0.04–1.5	Semi-arid	Ayisi et al. (2004)
South Africa	*Cowpea*	46–87	1.6–2.7	Semi-arid	Makoi et al. (2009)
Tanzania	*Cowpea*	70	1.2	Semi-arid	Vesterager et al. (2008)
Senegal	*Sesbania sesban*	8–18	2–3.8	Semi-arid	Ndoye and Dreyfus (1988)
Senegal	*Sesbania rostrata*	85–102	4–5.2	Semi-arid	Ndoye and Dreyfus (1988)
Tanzania	*L. luecocephala*	110	0.9	Sub-humid	Hogberg and Kvarnstrom (1982)
Nigeria	*G. sepium*	108	na	Sub-humid	Liya et al. (1991)
Kenya	*Cajanus cajan*	161	8.5	Semi-arid	Onim et al. (1990)
Kenya	*L. leucocephala*	643	9.3	Semi-arid	Onim et al. (1990)
Togo	*Calliandra*	26.5	na	Sub-humid	Schroth and Lehmann (1995)

[a] Agro-ecological zone

purpureus and *Centrosema pubescens* (Birteeb et al. 2011). Such cover crops play positive roles by reducing the impact of rainfall on soil erosion during heavy rain events and of wind erosion (Birteeb et al. 2011). Similarly Murphy and Colucci (1999) and Tomm and Foster (2001) observed similar benefit in studies in Oregon and Brazil, respectively, where a reduction in soil loss of up to 50% (Dovel et al. 1995; Tomm and Foster 2001) was reported under intercropping legumes with grain crops compared to grain crop alone. Similar findings have been reported by Birteeb et al. (2011) and Bryan et al. (2011).

Nitrogen fixation and improvement in soil nitrogen content

A large portion of SSA is situated in belts of uncertain rainfall, thus with uncertain response to nitrogen fertilizer (Kahurananga 1990). In such situations, maximizing biological nitrogen (N_2) fixation by utilizing suitable legumes is crucial. Estimates of the amount of nitrogen fixed by legumes under different agro-ecological zones of Africa under forage-legume intercropping with cereals and other crops are presented in Table 4. The amount of N_2 fixed varied in the range of 4 to 581 kg N_2/ha, depending on nodule formation of the intercropped forage-legume cultivars (Ayisi et al. 2004), the fertility status of the soil and competition between the intercrops.

According to Giller et al. (1997), the amount of N_2 fixed by grain and forage legumes in SSA ranged between 11 and 201 kg N_2/ha for sole-cropped cowpea and intercropped cowpea. Assuming an average N_2 fixation of 45 kg N_2/ha for cowpea, and multiplying these amounts by the land coverage of about 11.1 million hectares, it is estimated that about 500 million kg N_2 could be fixed by cowpea in SSA (Lupwayi et al. 2011). The level of N_2 fixation by forage legumes, however, is influenced by soil fertility status. For instance, Ojiem et al. (2007) observed a 44% decrease in N_2 fixed by legumes under less fertile soil relative to high fertility soils. In such low fertility soils, a starter dose (about 30 kg/ha) of N fertilization could improve N_2 fixation with the legume component (Hassen et al. 2006) as long as other nutrients, especially phosphorus and pH, are not limiting. These natural fertilizers enable smallholder farmers to improve the soil fertility without increasing debt (Murphy and Colucci 1999) due to rising prices of inorganic fertilizers, while reducing the environmental footprint of the agro-ecosystem.

Weed, pest and disease control

Intercropping provides the forage legume and the companion crop with greater competitive advantage against weeds. Increased barley grain yield was reported by Dovel et al. (1995) because of suppression of weeds by interseeded legumes. Other studies by Jeranyama et al. (2000) reported the suppression of weeds in a lablab-cereal intercropping. Similarly, in a sorghum-Desmodium intercropping, 100% control of *Striga* was achieved (Reinhardt and Tesfamichael 2011). Ejeta (2007) reported consistent reduction in *Striga* infestation in maize-cowpea intercropping relative to continuously cropped sole maize.

Intercropping improves crop resistance to pests. Based on a review of more than 150 published field and desktop studies on more than 200 herbaceous species, Lithourgidis et al. (2011) reported that 53% of the pest species were less abundant in the intercrop, 18% were more abundant, 9% showed no difference, and 20% showed a variable response. A separate study conducted by Khan et al. (2001) showed that intercropping Desmodium species with sorghum and maize enhanced soil fertility and increased the effectiveness of applied N in suppressing parasites. Similarly, studies by Skovgard and Päts (1997) reported a reduction in stem borer infestation when *Striga*-tolerant maize variety Acr. 97TZL Comp. 1-W was intercropped with cowpea (*Vigna unguiculata* L.).

Intercropping of forage legumes enhances the disease resistance of companion crops. A general disease reduction of 20–40% because of intercropping has been reported elsewhere (Hauggard-Nielson et al. 2001). Similarly, a review by Lithourgidis et al. (2011) showed that the incidence of pathogens of soil-borne take-all disease was reduced by maize-alfalfa intercropping. Monoculture fields require more chemicals to control weeds, pests and diseases compared with intercropping (Singh and Adjeighe 2002). Intercropping could therefore be useful in reducing the risk of crop failure because of the predicted increases in diseases and pests incidence related to climate change (Jeranyama et al. 2000, Lithourgidis et al. 2011).

Overall yield improvement (grain and biomass) and land equivalent ratio

Forage-legume intercropping improves yield, LER or both, thus improving land-use efficiency. A yield advantage of 20–60% was observed under legume-grain crop intercropping, mainly because of improved soil water-holding capacity in Oregon USA (Murphy and Colucci 1999), reduced pest incidence and more efficient use of nutrients, water and solar radiation (Lithourgidis et al. 2011). Stylosanthes species intercropping improved the grain yield of maize under low fertility soils (Vesterager et al. 2008; Birteeb et al. 2011). Sorghum-*Vicia* species intercropping also showed a higher grain and biomass yield of sorghum (Samuel and Mesfin 2003). Although farmers are not targeting increased stover yield, they could practise legume-cereal intercropping to produce livestock feed without compromising grain yield (Birteeb et al. 2011), while ensuring the stability of both grain and forage yields (Mohammed et al. 2008).

Other studies demonstrated that the grain and stover yields of cereal crops in cereal-legume intercropping systems were lower than yields of sole crops. Nonetheless, the total productivity per unit of land (LER) remained greater for intercropping than for sole crops (Kahurananga 1990; Mpairwe et al. 2002). For instance, high LERs of 1.88 and 1.51 were reported in a sorghum–cowpea intercropping (Mohammed et al. 2008; Surve et al. 2012), indicating the overall yield advantage of intercrops over sole crops in terms of land-use efficiency. Similarly Lemlem (2013) reported higher net return in monetary values from maize–lablab (44.5%) and maize-cowpea (58.9%) intercropping compared to maize alone due to the observed higher LER of 1.65 and 1.71 for maize–lablab and maize-cowpea intercropping, respectively. Cenpukdee and Fukai (1992) also reported that intercropping of cassava-pigeon pea decreased tuber yield slightly, but the overall economic return was higher than the sole crops because of improved soil fertility. In those intercropping systems, pigeon pea was able to fix up to 161 kg N/ha (Onim et al. 1990).

Improvement of feed quality and animal performance

Protein is the most important and expensive supplement for livestock under smallholder conditions in Africa. A protein content of 8–16% in a given feed is usually required to meet the maintenance, growth, production and normal functioning of rumen microflora (Van Soest 1982; Eskandari et al. 2009). Forage legumes provide generally high-quality feed that can be used to supplement crop residues, which are the main source of animal feed in many smallholder farming systems (Nnadi LA Haque 1986). In particular, protein yield of legume intercrops is reported to be higher than that of sole crops (Kahurananga 1990). Increases in CP content of 11–51% have been reported for various intercropping systems compared with sole crops (Tomm and Foster 2001; Lithourgidis et al. 2011). The CP contents of maize + lablab, sorghum + lablab and wheat + lablab were reported to be 4.2, 3.9 and 2.4 times higher than their sole stands (Mpairwe et al. 2002), respectively. Intercropping stylo with sorghum resulted in higher-crude protein content of stylo-sorghum mix compared to sorghum alone (Kahurananga 1990) and showed considerable potential for increasing CP yields per hectare (Birteeb et al. 2011), which improved dry season feed availability and quality (Ngongoni et al. 2007). Most of the legumes used for intercropping had CP content above the minimum threshold (7%) for optimum rumen function and feed intake (Van Soest 1982). An improvement in digestibility and nutritive values of forage has been reported by intercropping clover spp. and cowpea with wheat and cassava, respectively (Dzowela 1990).

The reported higher CP content, digestibility and lower-crude fibre content of forage from forage-legume intercropping systems (Maasdorp and Titterton 1997; Murphy and Colucci 1999) are likely to result in improved fermentation of roughages in the rumen and release of volatile fatty acids that support better animal performance (Birteeb et al. 2011). For example, lablab may possess on average 17% CP (Murphy and Colucci 1999) and could be suitable as a supplementary feed to complement poor-quality roughages such as crop residues often deficient in rumen-degradable nitrogen. Ensuring the supply of rumen-degradable nitrogen in the diet of ruminant through supplementation of lablab forage (Sumberg 2002) will improve rumen microbial fermentation of poor-quality roughages and overall digestibility of the total diet, leading to improvements in ruminant production. Access to higher protein forages will enable better use of low-protein, high-fibre crop residues (Murphy and Colucci 1999). Similarly barley straw was used more efficiently by growing steers when it was supplemented with legume silage (Zhuoga et al. 2016).

Mitigation co-benefits associated with forage-legume intercropping

There are many synergies and trade-offs in food production and climate adaptation and mitigation (FAO 2010). The majority of the studies on intercropping have shown that the impact of climate change could be partly mitigated through integrating forage-legume intercropping into the farming system to improve the quality of forage supplied to the animal, because legume supplementation improves the digestibility of fibrous feedstuffs (FAO 2010). The subsequent increase in digestibility is likely to increase intake and animal performance, but reduce methane emissions per unit of animal product due to more efficient feed utilization. Increasing the digestibility in the diet is the best mitigation measure because most CH_4 emissions are generated from enteric fermentation (Verge et al. 2007). Previous studies by Gurian-Sherman (2011) reported a 15–30% CH_4 emission reduction with the improvement of digestibility.

Because legumes fix nitrogen in the soil (Zahran 1999), the need for industrial nitrogen fertilizer is reduced. The reduced use of fertilizer N in legume-based cropping systems means lower use of fossil fuel (CO_2 emissions) in manufacturing, transporting and applying fertilizer N (Bryan et al. 2011). By reviewing legume-based systems as compared to fertilized annual crops in eastern Canada and north-eastern USA, Gregorich et al. (2005) found that legume crops are grown successfully with little or no nitrogen fertilizer. Subsequently, the emissions of nitrous oxide (N_2O) are expected to be lower in a legume crop than in a fertilized cereal crop (Bryan et al. 2011; Birteeb et al. 2011), thus demonstrating the high mitigation potential of intercropping with legumes. However, excessive nitrogen fixation from legumes monoculture more than its uptake means there will be more soil nitrate that potentially increase the risk of nitrous oxide emission from the area, as its production is compulsive during the denitrification process. Thus, inclusion of cereals in cereal-legume intercrop will minimize the risk of nitrous oxide emission due to more uptake of soil nitrate by the cereal component. Similarly, the introduction of legumes into grass-based forage production systems is expected to further reduce N_2O emission due to the reduction in soil nitrate levels through uptake by the intercropped grass. According to a review study by Jensen et al. (2012), grass-clover intercropping was reported to have lower mean annual N_2O emission (0.54 kg N_2O–N/ha) compared to a N-fertilized pasture grass (4.49 kg N_2O–N/ha) and pure legume stands of white clover (0.79 kg N_2O–N/ha). However, there is little or no information on the level of N_2O emissions from forage-legume intercropping as opposed to sole main crops fertilized with inorganic nitrogen fertilizer in SSA countries (Lupwayi et al. 2011). Recently, Senbayram et al. (2016) reported seasonal N_2O fluxes were 35% lower in a wheat-faba bean mix compared to N-fertilized wheat in Germany, demonstrating the potential for intercropping to mitigate fertilizer-derived N_2O emissions, although work is required to quantify the benefits in SSA rainfall conditions.

According to Fischlin et al. (2007), soil carbon sequestration has a technical potential to mitigate 89% of greenhouse gas emission. The amount of carbon that can be sequestered in the soil depends on the balance between the carbon inputs and losses (Jensen et al. 2012). Cong et al. (2015) reported up to 4% higher soil organic carbon in the top 20 cm for an intercropped system compared to a sole crop system over a seven-year experiment, demonstrating the potential of intercropping to mitigate against climate change. Other studies from various regions of the world show that forage-legume intercropping enhances carbon sequestration. For instance, studies by Tarre et al. (2001) in Brazil showed that the introduction of *Desmodium Ovalifolium* into a Brachiaria sward increased the rate of soil carbon sequestration from 0.66 to 1.17 Mg C/ha per year in the top 100-cm soil layer over a 9-year period. Other studies in Columbia by Fisher et al. (1994) also reported an increase in carbon sequestration by 7.8 Mg/ha per year with the introduction of a legume (*Arachis pintoi*) into a sward compared to sole grass. Studies in the sub-Saharan African country of Malawi, however, showed that the role of legume intercropping with cereal crops on carbon sequestration is dependent on the rainfall and temperature of the study site (Simwake et al. unpublished). Reduced use of insecticides and herbicides as a result of the decreased weed and pest invasion under legume intercropping compared with a sole plot (Singh and Adjeighe 2002) implies less energy utilization (CO_2 emission) in manufacturing, transporting and applying insecticides and herbicides (Bryan et al. 2011).

Adoption of forage-legume intercropping technologies in Africa

Although this review identified the many benefits of including forage legumes as intercrop in crop-livestock systems in SSA, the level of adoption of the technologies by smallholder farmers is very low. A number of constraints, including access to inputs (e.g. seed and fertilizer), yield depression of cereals, low yields and lack of persistence of legumes, and lack of fencing material and access to credit, were identified as core factors limiting adoption of forage-legume technologies (including forage intercropping technologies) in Zimbabwe (Nnadi LA Haque 1986; Mapiye et al. 2006). In addition, gender, literacy level, size of household, land area per household and number of animals per household indirectly affected adoption of forage technologies in Africa (Mapiye et al. 2006; Chijikwa 2016, unpublished report).

Summary

Intercropping forage legumes with cereals and root crop production is well recognized in mixed crop-livestock farming systems of Africa for land intensification, improved grain and forage nutritive value, reduced impacts of diseases and pests and as cover crops to reduce soil erosion and degradation. Within an intercrop system, however, there is a competition for key resources such as water, nutrients and light, depending on the crop species, climatic conditions and management practices. In moisture-stressed zones of arid and semi-arid areas, the influential factors that determine the benefits of intercrops are water and, to a lesser extent, nutrients. In contrast, in humid zones nutrient deficiency and light because of the shading effect are more profound than other factors. Ensuring optimum spatial and temporal arrangements, nutrient availability, population density and cropping pattern of the companion crops for each environment are pre-conditions to enhancing the overall productivity, resource use efficiency and profitability of the intercrops, as well as improving the resilience of the system to adapt to and mitigate climate changes. Future research needs to focus on testing intercrop technologies for each agro-ecological zone across soil types to determine optimum spatial arrangements and geometry of companion crops for efficient utilization of resources (light, water and capital) and improve adoption of forage-legume intercropping technology by smallholder farmers in Africa.

Acknowledgements The authors acknowledge funding received from ANIMALCHANGE, the Department of Science and Technology, and National Research Foundation (NRF), South Africa. The authors also would like to thank Belete Shenkute Gemeda for collecting some literature for the review work.

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