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Enhancing yellow maize production for sustainable food and nutrition security in Kenya

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Abstract

Maize is a strategic staple crop serving both as human food and feed in the livestock sector. It therefore has a critical socioeconomic value safeguarding against food and nutrition insecurity. Maize yields are however low especially among smallholder farmers who rely on this crop for their livelihood and sustenance. This has rendered most Sub-Saharan Africa countries such as Kenya to be net importers and depended on food aid mainly in form of maize. Even though white maize variety is nutritionally inferior, it is the most produced and consumed with little regard placed on yellow maize. We reviewed 154 articles and reports to highlight challenges facing maize production and sustainable agricultural practices that should be embraced to overcome them, nutritional benefits of yellow maize, factors hindering its consumption and research gaps that need to be addressed to enhance its production and utilization. Key production challenges identified include shrinking land sizes, declining soil fertility, adverse and unpredictable weather patterns and the devastating striga weed. Intercropping especially cereals with legumes have great potential for efficient land, water and nutrient resource utilization, manage weeds and minimize crop failure and adverse weather effects. This combined with integrated soil fertility management will ensure increased yields. It was found that yellow maize has higher carotenoid content hence superior to white maize and when taken with grain legumes provides a low-cost balanced diet. Despite this, yellow maize utilization is low because it is regarded as poor man's crop, associated with food aid and reserved as livestock feed. This negative perception can be changed through educational campaigns on its nutritional value in order to enhance local production and encourage social acceptability to aid alleviate vitamin A deficiency, a key limiting micronutrient. In conclusion, tapping in the nutritional superiority of yellow maize through legume intercropping should be enhanced for improved food and nutrition security.

Keywords: *Yellow maize; white maize; Vitamin A; intercropping; legume*

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Introduction

Maize (*Zea mays*) is among the most important food crops worldwide ranking third after rice and wheat with nearly 195 million hectare allocated for its production yielding global production of over one billion tonnes (FAO, 2018). Its importance is attributed to the multiple key roles

it plays in the livelihoods of over 900 million people especially in Africa, Asia and Latin America (Shiferaw *et al.*, 2011). For instance in Africa, since its introduction in the 16th century by the Portuguese, the crop has rapidly spread displacing indigenous cereals such as sorghum and millet to become the main staple food and livestock feed predominating most cropping systems (Rapsomanikis, 2015; Shiferaw *et al.*, 2011). The high value attached to maize is because it is versatile, high yielding with multiple purposes and greater returns, have a natural protective leafy cob against depredating birds and easy to process as it does not require dehulling unlike the aforementioned traditional cereals (Smale and Jayne, 2003). Though there are various colored varieties from white, yellow, red and black, however, the maize varieties in Africa are mainly white and yellow, with majority favoring white maize with consumption ranging from 52-328 g/person/day (Ranum *et al.*, 2014).
Yellow maize production and utilization have been restricted and neglected for a long time particularly in Kenya to the extent that there is very limited data and research on the same. This oversight is despite its added nutritious advantage and the integral role it plays in the human diet of improving vitamin A status especially among women and children (Keith, 2003; Muzhingi *et al.*, 2008). It also serves as livestock feed making it an ideal crop in dual efforts of combating food insecurity and widespread malnutrition that is particularly rampart in Sub-Saharan Africa (SSA) (Byerlee and Heisey, 1996; Shah *et al.*, 2016). Furthermore, due to increase human population and thriving livestock sector demand for this crop is growing considerably requiring yield increment to meet the outpaced deficit in order to achieve food security while safeguarding the environment. Yellow maize needs to be specially considered especially among the resource poor households as a means to alleviate hunger, poverty and considerable levels of malnutrition. This review looks at maize production and constraints in Kenya places particular consideration on the important but orphaned nutritious yellow maize variety and sustainable ways of enhancing its production and utilization through soil amendment applications and maize legume intercrop.

Materials and Methods

In order to capture the relevant literature on, a comprehensive literature search was undertaken using Google scholar database. This involved a search with the terms 'Maize or *Zea mays*' "AND Yellow maize AND (food, feed OR nutrition) AND food security AND production AND utilization AND challenges without limitation on the year of publication for studies done in SSA with particular focus in Kenya. Studies from other parts of the world that provided additional insight to the review were included. The literature research extended further to involve terms such as 'soil fertility', 'intercropping', 'Striga weed' and 'legumes'. After scrutinization of the downloaded articles 122 were selected for the review. Additional 32 reports and web pages information were obtained from organizations such as Food and Agriculture Organization and Government agencies including Kenya National Bureau of Statistics.

Maize production and challenges in Kenya

To illustrate the trends in maize production Figure 1 depicts maize yield and harvested area in Kenya for the period 2010 to 2019 in comparison to Uganda and Tanzania. These are neighboring countries that have almost similar climatic conditions and agricultural practices with maize as the most traded commodity across their border trades (EACB, 2020; Nicholson, 2017; Salami *et al.*, 2010). Area under maize production has slowly trended upwards in Kenya, Uganda and Tanzania between the year 2010 and 2018 to stand at 2.2, 1.0 and 3.5 million ha respectively (FAO, 2018). The main reason for this may be due to farmers abandoning other crops to maize since land for agriculture expansion has become limited owing to growing human population pressure and need to preserve natural ecosystems such as forests (Headey and Jayne, 2014; Van Ittersum *et al.*, 2016). Increase in land area for maize production however shows that maize per capita harvests have had no significant change, an indication that this sector is under performing across these countries. Notwithstanding, Uganda's yield over the years though not optimal have been more than that of Kenya and Tanzania with an estimated average of 3 t/ha to Kenya's and Tanzania's 2 t/ha which compares dismally

with over 10 t/ha achieved in America (FAO, 2018). The substantial improved yields in Uganda may be attributed to the fairly fertile deep soils and favorable weather condition experienced in most regions in Uganda with the crop grown for revenue export, being the third staple crop after banana and beans (Ahmed M., 2012; Kaizzi *et al.*, 2017). The crop therefore does not play a significant component of the Uganda's population traditional diet hence mainly grown as a cash crop instead of a food crop (Daly *et al.*, 2016)
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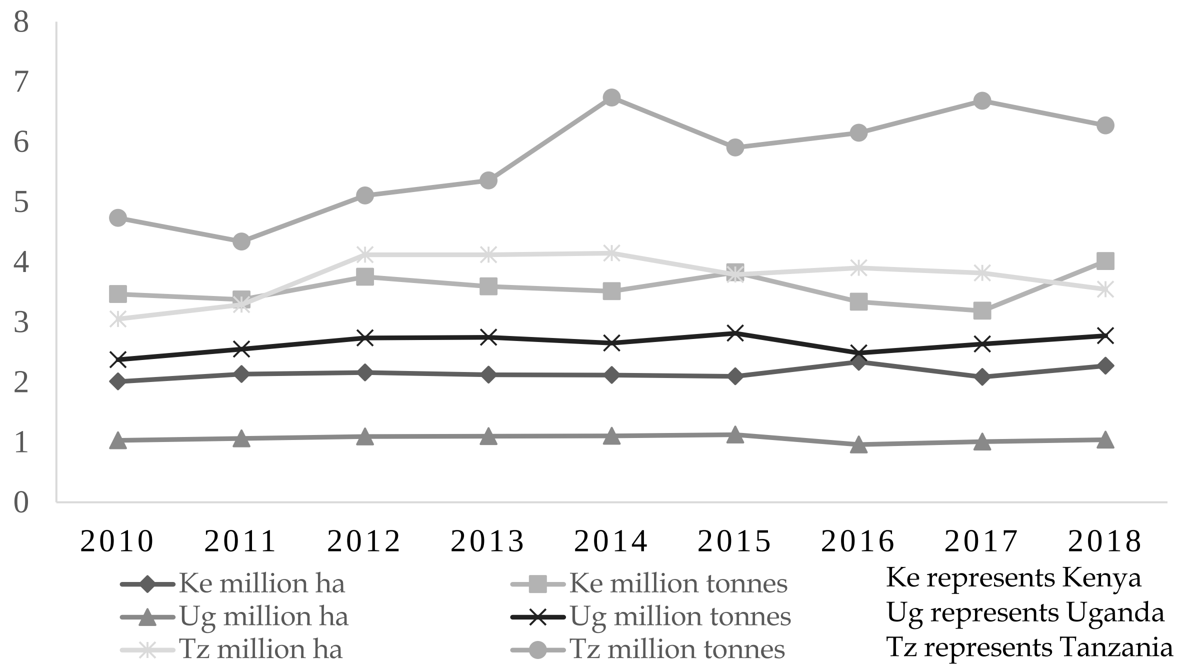

Figure 1: Maize yield and hectarage in Kenya in comparison to Uganda (Source: (FAO, 2018)

The crop therefore does not play a significant component of the Uganda's population traditional diet hence mainly grown as a cash crop instead of a food crop (Daly *et al.*, 2016). These trends however pose a disturbing scenario for Kenya as it shows reduced land productivity amidst rapid human population growth (Headey and Jayne, 2014; KNBS, 2019a). This puts a challenge to the nation's capacity to sustainably supply the volumes of maize needed to ensure food sufficiency and security especially for its low-income rural population.

This is because the crop is highly entrenched in Kenya to the extent of being considered as the "sleeping giant" of Kenyan agriculture and synonymous to food security in the country (Ariga and Jayne, 2011). However, most of the maize produced is the white variety majorly for human consumption, with 70% under smallholder production systems on average 0.5 ha farm relying on minimum external resource inputs (Hans *et al.*, 2017; Rapsomanikis, 2015; Schroeder *et al.*, 2013; Shiferaw *et al.*, 2011). These farmers are able to produce substantial amount contributing more than 65% of the maize consumed by 96% of the population in the country and an important input in the thriving animal industry (Olumeh *et al.*, 2018). There are however few private and state-owned farms with hundreds of hectares of land where maize is grown with highly modern technologies. Due to its high adaptability, production is therefore done across various agro-ecological zones in major counties such as Trans Nzoia, Uasin Gishu, Kakamega, Nakuru, Embu, Nyeri, Kirinyaga, Taita-Taveta and Kwale (Tarus, 2019). Most agricultural regions in the country experience bimodal yearly rainfall pattern consisting of long rain (March-May) and short rain (September-November) with maize growing seasons following this pattern. This enables farmers in hot and sub-humid regions like Western region of Kenya to grow the early maturing maize varieties, averting risks as they are able to evade extreme weather conditions thereby allowing two maize harvests in cases of continuous year round cropping (Hebinck *et al.,* 2015; Rao *et al.,* 2015). Uniquely this region is also involved in yellow maize production taking about three months to mature (Anjichi *et al.,* 2005).

For optimum production, this crop requires favorable weather conditions throughout the growing cycle in deep well-aerated fertile soil. It also calls for good crop husbandry involving timely planting and spacing using appropriate varieties, recommended fertilizers rates, crop rotation and effective control of weeds, pests and diseases. Production is however done under very difficult conditions that has made majority of the smallholder households producers to be net buyers of maize (Holden, 2018). Most of small scale farmers are resource constrained and are therefore not able to adapt to modern technologies to realize increased yields (Onono *et al.,* 2013). Farmers also depend on rainfed agriculture hence liable to extreme unpredictable weather conditions such as droughts and floods. This is further coupled with poor low yielding seeds and high post-harvest losses (Tarus, 2019). Besides this, the cost of production is high compared to other countries in the continent such as neighboring Uganda who produce sufficient amounts to meet the Kenya's deficits. This has made Kenyan maize to be less competitive in the markets and the porous borders have encouraged illegal trade threatening local production (Ahmed, 2012). Furthermore emergence of new devastating diseases (e.g. Maize lethal necrosis), increased pests (e.g. stem borer and army worm) and weeds (e.g. Striga spp.) infestation have greatly hampered yields (FAO, 2018; Olwande and Mathenge, 2012). This has led to very low returns limiting investment in farming activities and inputs to enhance production.

Back in the 1990s, the country used to be a net exporter but due to the current poor yields it has turned into a net importer in order to meet the deficit to the extent of depending on external maize food aid (Rakotoarisoa *et al.,* 2011; Tarus, 2019). Urgent measures are needed to close in on the yield gap and enhance the nutritional quality of this staple crop. Farmers therefore require multifaceted interventions that are viable, sustainable economically and effectual.

Contribution of yellow maize to food and nutrition security

Nutritional benefits of yellow maize

Global burden of malnutrition is mainly concentrated in Sub-Saharan Africa (Fanzo J, 2012; Onyango *et al.,* 2019). This is attributed to factors such as poor diet diversification, poverty, low bioavailability of nutrients in food consumed and starvation/hunger (USAID, 2014). This does not only impact on the health and the future of those affected but also hampers economic and social development of the country (Blössner *et al.,* 2005). The Kenyan government has therefore taken strides to ensure food security and nutrition among its citizens by enshrining it in the constitution of Kenya 2010 in Article 43(c) that assures Kenyans' the right to be free from hunger and to have adequate food of acceptable quality. It is among the four key pillars of the Big Four Agenda aimed at ensuring 100% food security and nutrition by 2022 and further recognized as a long-term goal in Kenya Vision 2030 development blue print. This indicates malnutrition to be a violation of human rights.

One among the major causes of malnutrition is vitamin A deficiency (VAD) which is high in Kenya affecting 60 % of young children and 40 % of women due to their growth and reproduction demands (KNMS, 2011; Keith, 2003). The vitamin is important for vision, growth, reproduction and enhanced immunity system with deficiency resulting to night blindness, reduced immunity predisposing people to infectious diseases thereby increasing mortality rates especially among children and mothers (WHO, 2020; Manjeru *et al.,* 2017). This emphasizes it importance and the need to ensure adequate intake of this nutrient which demands for dietary intake of vitamin A rich foods (WHO, 2020). Major sources are plants such as green, yellow or orange fruits and vegetables and animal-based meat and dairy products, which are however expensive and highly perishable with consumption levels far below recommended levels of 400g/person/day (Zuma *et al.,* 2018). Efforts have therefore been made to enhance nutrient availability through biofortification and supplementations, however these remains inaccessible to many due to high poverty levels (Stein, 2015). For instance, maize flour industrial fortification increases production costs hence expensive benefiting only the urban populations who can afford and mainly consume the processed maize flour unlike the poor rural population who occasionally locally mill their maize produce without further nutrient additions (Manjeru *et al.,* 2017). In particular Kenya, 36 % of its population is poor with an average of 19 % suffering from chronic food insecurity and poor nutrition (FAO, 2016; UNDP, 2018). With the current prolonged droughts and floods, poverty levels have gone up and the number of people depended on relief food have drastically increased (Tarus, 2019). Kenya's hope therefore lies in maize consumption which is a key staple food that is readily available and fairly affordable. It is consumed country wide in various forms (Table 1), forming a major portion of daily dietary intake with average consumption rate of 64kg/person/year which is among the highest in the world (KNBS, 2019b; Ranum *et al.,* 2014). Despite, there being other cheaper alternative sources of calories a study in Kenya by De Groote *et al.,* 2011 showed that 63 % of the people mostly took uji in the morning with the foremost and the second most preferred during lunch and dinner being ugali and *githeri*. It is also a major energy ingredient in livestock feeds especially in the rapidly growing and intensive dairy, poultry and pig sector.

Table 1: *Examples of maize-based foods in Kenya*

Food category	Processing step	local examples
Whole-grain foods	Cooking	*githeri, muthokoi*, roasted and boiled maize
Snacks	Frying	Popcorn
Porridges	Milling, cooking, unfermented	Ugali, uji
	Milling, fermentation, cooking	uji, ikii
Beverages	Non-alcoholic: Milling, soaking, cooking	kirario
	Alcoholic: Germination, Fermentation	busaa, chang'aa

Source: (Ekpa *et al.,* 2018)

In fact, maize is preferred for both humans and animals because of its nutritive composition which tend to vary depending on climatic and soil conditions. On average maize mature kernel is composed of endosperm, pericarp, germ and tip cap (Gwirtz and Garcia-casal, 2014). This consists of 73% starch, 9% protein, 4% oil and 14% fiber among other constituents providing 365 Kcal/100 g of energy (Nuss and Tanumihardjo, 2010; Prasanna *et al.,* 2001; Ranum *et al.,* 2014). The germ contains vitamin E and B complex. It also contains 4% unsaturated fatty acids consisting of 60% linoleic acid, 24% oleic acid and 11% palmitic acid used to produce refined germ oil, a major source of fat in major shopping outlets. This oil subjects the kernel to oxidative and rancidity resulting in off-flavors when poorly handled (Gwirtz and Garcia-casal, 2014).

Maize is, however, deficient in certain essential nutrients such as lysine and tryptophan amino acids, iron and choline mineral content and low in vitamins especially vitamin A which is devoid in white maize (Nuss and Tanumihardjo, 2010; Ranum *et al.,* 2014). This has predisposed most of the low income rural populations that prefer and depend on this variety as their main staple food and infant weaning food to VAD (Manjeru *et al.,* 2017). Yellow maize on the other hand contains carotenoid therefore has superior nutritional value relative to the conventional white maize and other cereals such as rice, wheat, millet and sorghum (Table 2). The carotenoids are contained in the endosperm part of the maize grain hence unaffected by the milling processes (Manjeru *et al.,* 2017). Furthermore, effective vitamin A absorption in the body requires fat which fortunately is naturally available in the maize germ (Muzhingi *et al.,* 2011). This offers a long term potential mechanism for delivering considerable amount of vitamin A in a sustainable and affordable manner to alleviate VAD especially among the vulnerable groups (Simpungwe *et al.,* 2017).

Factors that negatively influence yellow maize production and utilization in Kenya

There is a lot of disparity regarding yellow maize that has greatly limited its production and consumption in Kenya. In developed countries, yellow maize is the most preferred with 70 % utilized as animal feed while in Sub-Saharan Africa except for South Africa white maize is predominantly grown mainly for human consumption and only 18 % serves as livestock feed (Ranum *et al.,* 2014; Shiferaw *et al.,* 2011). The reason why white maize is prevalent in Africa and specifically in Kenya is simply because of familiarity as people are used to producing and consuming it over a long period of time (De Groote and Kimenju, 2008; Pillay *et al.,* 2011). This was particularly influenced by the British colonialists who demanded for white maize for their distilling and starch market at premium price which restricted and saw many producers shift preference to the white variety (McCann, 2005). Yellow maize on the other hand, is not popular due to preconceived notions as it is apparently associated with food aid, an indicator of food crisis when the latter is in short supply, regarded as a poor-man's crop hence inferior to white maize and reserved as livestock feed (Ranum *et al.,* 2014). This has resulted in low level of awareness of its nutritional attributes among the masses. Yellow maize has also a very low

Table 2. Nutrient composition of various cereals (per 100g)

Cereal	Protein %	Calcium (mg)	Iron (mg)	Vit. A (µg)	Thiamin (mg)	Riboflavin (mg)	Niacin (mg)
Yellow maize, immature on cob[b]	5	18	1.8	360	0.16	0.08	1.3
Yellow maize grain[a]	8.3	7	3.9	241	0.5	0.12	2.2
Yellow maize grain boiled[a]	2.7	4	1.3	70	0.08	0.03	0.5
White maize grain[a]	7.94	24	2.6	0	0.25	0.1	2
White maize grain boiled[a]	2.6	9	0.8	0	0.04	0.02	0.5
White Maize meal[b]	10	12	2.5	0	0.35	0.13	2
White maize flour[b]	8	6	1.1	0	0.14	0.05	1
Wheat kernel[c]	10.9	34	3.52	N/A	0.419	0.12	6.74
Whole wheat flour[b]	13.3	41	3.3	0	0.55	0.12	4.3
White wheat flour[b]	10.5	16	0.8	0	0.06	0.05	0.9
Brown rice[b]	7.5	39	2	0	0.32	0.5	4.6
White rice[a]	7.6	21	0.9	0	0.07	0.11	1.1
Millet bulrush flour[a]	10.5	32	32.4	0	0.27	0.17	1.5
Finger millet flour[a]	7.4	344	18.5	2	0.19	0.04	4.6
White sorghum flour[a]	10.8	18	6.4	8.29	0.2	0.11	3.3
Red Sorghum flour[a]	9.3	10	3	0	0.24	0.11	3.3

Source: [a]Kenya Food composition table, 2018; [b]Okoruwa and Kling, 1996; [c]Nuss and Tanumihardjo, 2010 market value despite, Kenya customers demand for nutritious rich diets. This is because while they are willing to pay premium price for white fortified maize meal, they will only purchase yellow maize when offered at discounted price according to the study by De Groote, *et al.,* 2011. While this may be an advantageous to most rural financially constrained consumers, it on the other hand discourages maize farmers whose aim is to maximize on returns on yield investment. A delicate balance needs to be placed on pricing of this commodity to ensure that both the customers and producers are well cushioned. Its negative acceptance as food is worsened due to rancidity and off-flavors with unacceptable taste and smell that is possibly due to poor handling or long storage under unfavorable conditions during importation and transportation as food aid in Kenya (Pillay *et al.,* 2011). It is also disliked due to its color which oddly is the reason it is preferred as animal feed as it gives the poultry meat, egg yolk and animal fat the distinctive yellow color that is attributed with healthiness and tastiness by consumers (Anthony, 2014; Iken and Amusa, 2004). Furthermore, most maize research in Kenya has mainly been focused on yield and biotic and abiotic tolerance with little regard on quality traits such as taste, color and on enhancing maize nutritional value (Hebinck *et al.,* 2015). Odendo *et al.,* 2001 also found that among the most important criteria that farmers use for variety selection are high yield, early maturity and tolerance to biotic and abiotic stresses with grain color that touches on the maize nutritional aspect least regarded. Enhancing yellow maize production and consumption should be considered as cost effective measure of intervening against the burden of VAD and food insecurity.

Ways of enhancing yellow maize production and utilization

Despite the biasness towards yellow maize, its production and consumption can be enhanced to increase availability and accessibility in the country. This is possible to attain since maize is the main staple food crop with ability to meet the basic minimum food nutritional requirements and a prerequisite for socioeconomic advancement. It can therefore can serve as a key driver in aiding the county fulfill its obligations and commitments in ensuring sustainable agricultural development and fight against malnutrition and hunger. In Western Kenya especially the Lake Region, yellow maize is prevalently grown in most farms (Hebinck *et al.,* 2015), a positive indicator offering a glimmering hope that its production can be revived and eventually spread countrywide. Its acceptance and utilization will however greatly depend on farmers' and consumers' perceptions and willingness to adopt and embrace this variety. This can be propelled by i) creating awareness among the masses on its nutritional benefits. Production can be sustainably achieved by ii) intercropping yellow maize with legumes while consumption and utilization as human food and livestock feed attained by iii) complementing yellow maize diets/feeds with legumes to offset protein deficit.

Creating awareness among the masses on the nutritional benefits of yellow maize

Ignorance and lack of awareness are among the factors that contribute to malnutrition in Africa (Bain et al 2013). Educational awareness and campaigns to the general public on the other hand creates interest and empowers people providing them with better and occasionally cheaper nutritional food options to choose from in order to bring about changes in food habits (FAO 2014a). A study by (De Groote and Chege, 2008) have shown that change of perception and social acceptability by the public on yellow maize consumption in Kenya can be enhanced through education campaigns since people are increasingly becoming conscious of their eating habits. This will help people appreciate its nutritive value and understand and recognize its importance as a healthy crop rather than a poor man's crop (Onyango *et al.,* 2019). This is more so considering that customers will substitute an existing product for an alternative one that is considered to be of superior quality. Its sweet taste may appeal to most people especially children (Chomba *et al.,* 2018). Successful adoption and consumption of orange fleshed sweet potato among Kenyan farmers and consumers (Hagenimana and Low, 2000) also offers hope the same will apply to yellow maize and to even courage assimilation of other colored varieties such as the orange maize. *In order* to have more impact, regulatory measures need to be put in place to encourage people to embrace such healthy foods (Onyango *et al.,* 2019). This will greatly help people with limited access to alternative sources of vitamin A rich foods meet their daily dietary requirements to a considerable extend while still maintaining their valued and favorite maize meal (Muzhingi *et al.,* 2008). Taping into nutritional superiority as well as resilience of yellow maize will improve livelihoods of women and youth most of who take lots of their times in farming and marketing activities (FAO, 2011; FAO 2014b). Improved yellow maize production will also ensure adequate supply of nutritious feed/fodder enhancing livestock productivity (Dei, 2017) further improving household diets and alternative sources of income. Homegrown yellow maize production will likewise lessen competition between its use as human food and livestock feed. This will reduce dependence on importation and foreign aids with their associated problems of poor handling, transportation and storage known to produce the unpleasant taste formerly associated with it (Pillay *et al.,* 2011). This will also ensure the large amount of foreign reserves to pay for the imports that drain resources can be put to other better sustainable alternatives and rural transformation to ensure long term food security (Holden, 2018). Overcoming this challenge will see increased demand for yellow maize which will draw more farmers in other maize producing regions to delve into yellow maize production further enhancing and securing the country's food and nutritional status.

Diversification of yellow maize with legumes for food and nutrition security

There is prevalence of food and nutritional insecurity in Kenya affecting 57 % of the population (FAO, 2016). This is mainly attributed to hunger and poverty that has limited many to have diets dominated with starch such as maize (Rao *et al.,* 2015). Such diets over prolonged periods result in protein and vitamin deficiency diseases such as Kwashiokor and Pellagra (McCann, 2005). Human population pressure has also limited land availability that has reduced and hindered food diversity (Manjeru *et al.,* 2017). One recommended solution to securing household diet requirements both as food and feed is through maize and legumes diversification. Depending on the choice of legume, they have different roles on the farm, some are chiefly grown for the grains they produce, others preferred for their leafy edible vegetable, others used for production of plant-based oil or used to provide animals with their protein rich fodder (Snapp and Silim, 2002). Their high competitiveness and short duration enables them to thrive even under adverse environmental conditions of limited inputs application, moisture stress and low soil fertility that is typical of most farms (Das *et al.,* 2018). Legumes are rarely grown as green manure by small scale farmers as the entire crop is ploughed into the soil without grain harvesting, providing no direct benefit to human diet (Jones *et al.,* 2020). Legumes are a second source of food after cereals enabling low income families and rural households to meet their calories and protein requirements improving income while reducing production risk (Smith *et al.,* 2016; Snapp *et al.,* 2013).

As earlier indicated maize regardless of the color is a poor source of proteins therefore families that depend on it as their dietary source are highly vulnerable to protein deficiencies especially children and lactating mothers (Atlin *et al.,* 2011). Although through breeding efforts there is the genetically protein enhanced maize hybrid referred to as quality protein maize, this unfortunately has not yet been adopted in Kenya (Kumar *et al.,* 2019). In order to therefore safeguard against protein deficiencies, maize diet have to be complemented with protein rich food. Animal products that include meat, milk eggs and dairy products contain high proteins, they are however limited and costly beyond reach of most impoverished rural households (Shiferaw *et al.,* 2011). Locally available grain legumes commonly grown in Kenya include chickpea, pigeon pea, cow peas, soya bean, common beans, runner beans and green grams. Some provide edible leaves that can be harvested multiple times during the season especially at times of food scarcity. These legumes are rich in proteins (Table 3) especially amino acids such tryptophan and lysine earning the name 'poor man's meat' and high in minerals such iron, folic and zinc, lacking in staple cereals such as maize providing inexpensive animal protein substitute (Gebrelibanos *et al.,* 2013; Messina, 1999; Snapp *et al.,* 2019). When grain legumes are combined with the staple maize they provide relatively cheap and easily accessible balanced diet with numerous health benefits against chronic diseases such as cancer, diabetes and cardiovascular diseases (Duranti and Gius, 1997; Gebrelibanos *et al.,* 2013).

Although most farmers major on crop production, livestock is also an important component in farming systems and a crucial source of income for many rural small-scale farmers. Intensive livestock production especially in the increasing dairy, pig and poultry commercial sector has put heavy demand on livestock feeds. Feeds accounts for at least 70% of livestock production costs in particular protein concentrates (Kilimo Trust, 2017). Unfortunately most small-scale farmers are not able to afford high cost of protein concentrate and opt to use readily available free local plant resources (Peters *et al.,* 2001). They mostly graze their livestock on pasture grown in communal land or on cereal residues after harvesting which in most cases is inadequate and of poor quality especially during the dry season (Akakpo *et al.,* 2020). Communal lands are diminishing due to subdivision and need for more land for cultivation. Among the best strategy of ensuring high land use efficiency and greater production of total dry matter is by under sowing legumes with cereals such as maize. This encompasses use of legume pastures such as desmodium, lucerne, sesbania, vetch and calliandra among others (SNV, 2017). In case of grain legumes, after maturity and the legume pods harvested, the legume residue can be combined in livestock forage improving the quality and palatability of cereal crop residues. Furthermore, the quality of feed given to livestock has direct influence on the quality of manure (Delve *et al.,* 2001; Mafongoya *et al.,* 2000) which when added to the soil improves the soil fertility levels. This also results in a nutrient cycle that eventually trickles down to improving food or feed production ensuring nutrition enhancement. However, legume yields are very low with an estimated pulse production of 0.4 t/ha which is not in tandem with highly demanded and preferred maize crop (FAO, 2018). This can be optimized and put in check through maize-legume intercrop.

Table 3: Estimated protein and carbohydrates in commonly grown legumes

Legume	**edible plant part**	**% protein**	**% fat**	**% carbohydrates**
Common bean (*Phaseolus vulgaris*)	seed	25	2	69
	pod	22	2	70
	leaf	27	3	50
Cow pea (*Vigna unguiculata*)	seed	26	2	69
	pod	33	5	55
	leaf	36	3	50
Soya bean (*Glycine max*)	seed	39	22	36
	sprout	14	10	43
Groundnut (*Arachis hypogea*)	seed	25	48	8
Mung bean (*Vigna radiate*)	seed	25	1	63
Broad bean (*Vicia faba*)	seed	32	1	55
Lentil (*Lens esculenta*)	seed	30	3	62
Garden Pea (*Pisum sativa*)	seed	28	3	60
Pigeon pea	Seed	22	2	62

Source: (Das *et al.,* 2018; Mulei *et al.,* 2011; Sinclair and Vadez, 2012)

Sustainable maize production for improved yields and livelihood

Soil amendment application under maize crop

Rapid increasing human population, urbanization and demand for economic growth and development have put heavy demand on agricultural products (Hans *et al.,* 2017) especially maize. This crop is among cereal crops with the highest soil nutrient uptake (Table 4) literally leaching the soil off essential nutrients. This exerted pressure on land has eliminated the traditional fallow practice, increased land subdivision and encouraged intensive agriculture production with little or no commensurate replenishment due to high fertilizer costs that has led to rapidly declining soil fertility levels (Mugwe *et al.,* 2009; Odendo *et al.,* 2001; Van Ittersum *et al.,* 2016; Wambugu *et al.,* 2012; Woomer *et al.,* 2002). Impact to this is uneconomical and undermined land productivity threatening food security (Kaizzi *et al.,* 2017; Murage *et al.,* 2000). Maize nutrient component especially N and grain size are also directly influenced by soil nutrient fertility levels and thus its production is unsustainable without fertilizer addition (Feil *et al.,* 2005; Pixley and Bjarnason, 2002).

Table 4*: Comparison on amount of nutrients (N, P, and K) uptake in different cereals*

	Nutrient uptake (kg/t)								
	Grain			crop residue			Total nutrient uptake		
Crop	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
Maize	13	2.4	2.7	5.4	1.8	11	18.4	4.2	13.7
Sorghum	15	2.6	3.1	3.5	0.7	3.7	18.5	3.3	6.8
Wheat	9	1.7	1.8	5.1	1.8	8.3	14.1	3.5	10.1
Rice	12	2.8	5	6.4	0.7	13	18.4	3.5	18

Source: (Nalivata *et al.,* 2017)

Offsetting the declining soil fertility and restoring it to its pre-disturbed productive capacity though difficult requires a substantive investment in fertilizers given that soils health is the agriculture resource base. Following the 2006 African Fertilizer Summit in Abuja, Nigeria, the main avenue that was emphasized was increase in fertilizer use in order to enhance yields and improve the soil fertility status particularly among the small-scale farmers. Basically, the intention was to bring about the green revolution that has been successful in other parts of the world and which is long overdue in Africa.

In order to transform small farmers' agricultural productivity, the Kenya government have supported various development activities in an effort to improve smallholder resource productivity. For example, the government has provided fertilizer subsidization incentives, with the key assumption that this would benefit the small-scale farmers and eventually realize fertilizer use efficiency and change the country's dire food security situation (Onono *et al.,* 2013). However, despite this effort there has been not much significant effect due to corruption, bureaucracy and political interference with the major intended beneficiaries i.e. small-scale farmers displaced, rarely accessing the fertilizer. In most instances the fertilizer are inadequate and untimely availed beyond the optimal recommended fertilizer application time, significantly reducing the yield effect of the fertilizer provided (Ariga and Jayne, 2011; Dorward *et al.,* 2011; Morris *et al.,* 2007). Furthermore, prevalent weather shocks due to dominance in rain-fed agriculture, decade old blanket fertilizer recommendations covering wide regions instead of being based on soil test analysis result in inconsistent results (Kaizzi *et al.,* 2017; Kihara *et al.,* 2015). These have obscured expected yields which have resulted to low marginal returns to fertilizer limited profitability thus making it unpopular and risky affair to invest in fertilizer (Adjognon *et al.,* 2017; Morris *et al.,* 2007). This has forced farmers to further reduce on the already low fertilizer application worsening the soil degradation situation.

The poor soil quality, as is the characteristics of most farms, is also linked to low soil organic matter, the key to soil fertility. Such soils have low nutrients and water holding capacity with the exposed soil susceptible to erosion losses thus imposing additional production constraints by limiting yield response to inorganic fertilizer application (Jayne *et al.,* 2013; Kaizzi *et al.,* 2017; Marenya and Barrett, 2009). Since it is their source of livelihood, farmers have arisen to the challenge and complemented fertilizer application using locally derived farm nutrient sources such as crop residue and animal manure to improve soil water and nutrient holding capacity (Nalivata *et al.,* 2017; Sheahan *et al.,* 2013). Unfortunately farm crop residues are not sufficient having many competing and alternatives applications as fuel, handicrafts and construction materials coupled with burning, which limits its ploughing back into the soil to enhance soil organic matter content (Rware *et al.,* 2017). Another common practice is feeding crop residues to livestock offering a cheap source of forage that is of considerable value among the resource poor farmers (Mcdermott *et al.,* 2010; Apollo *et al.,* 2007). The resultant animal manure is applied in the soil, a significant advantage of crop and livestock mixed farming system aimed at optimizing on farm resources. However, it is of limited supply to meet the recommended application rates and bulky to handle (Bayu *et al.,* 2005; Kihanda *et al.,* 2007). Furthermore during the dry seasons, most livestock are usually grazed away from the homesteads making manure collection difficult and only the small amount collected in the shed at night can be applied in the farms (Thorne *et al.,* 2002). The resultant manure is usually of poor biomass quality with high C:N as it is usually left in the open exposed to rain and sun resulting in soil mineral N demineralization (Bationo and Waswa, 2011; Nalivata *et al.,* 2017). The aforementioned challenges of inefficiencies and bottlenecks facing fertilizer utilization put Kenya in a precarious state threatening national food security status. However, this also provide opportunities for growth and development since the wide yield gap presents a huge opportunity for yield improvement with the increase in human population providing new market opportunities (Hans *et al.,* 2017). There is therefore need to address the plight of small scale farmers by exploring alternative strategies that are cost effective, efficient and sustainable *in order* to promote soil health and fertility necessary for improve yields in light of rain-fed and low input conditions that majority of farmers operate (Andrews *et al.,* 2004). Integrated soil fertility management through combined used of mineral fertilizers with organic nutrient sources is important for efficient soil nutrient utilization due to its synergetic effect ensuring synchronized nutrients release and uptake by plant, improving soil fertility (Mucheru-Muna *et al.,* 2014). Study by (Mucheru-Muna *et al.,* 2014) showed double increase in maize yield in combined cattle manure and inorganic fertilizer compared with control having no fertilizer application. Kihara *et al.,* 2015 observed 6 t/ha increase in yield in the fertilized compared to the non-fertilized treatment. Evidence that improving soil fertility have a direct impact on the maize production and with concerted effort it is feasible to address the yield gap (Vanlauwe *et al.,* 2014). Use of legumes due to their natural nitrogen fixing potential should also be explored as maize intercrop. This is against the background of climate change, limited land and resources and the urgent need to ensure availability of quality food and feed.

Maize legume intercrop system

Intercropping comprises smart combination of two or more compatible complementary crops from different families or species cultivated simultaneous, usually with different growing periods, foliage pattern display and rooting systems in the same field (Bybee-finley and Ryan, 2018). This is to ensure efficient and sustainable utilization of resources such as land, nutrients, light and water (Pereira Cézar *et al.,* 2016; Thierfelder *et al.,* 2012). In most instances, commonly practice is intercropping cereals such as maize as the primary species with legumes as secondary species due to wide recommended spacing of maize allowing for easy legume incorporation (Lithourgidis *et al.,* 2011; Maitra *et al.,* 2020). Among legumes there are long duration legumes like pigeon peas, however most subsistence farmers prefer early maturing grain legumes as they offer immediate benefits and avert risks of crop failure due to unpredictable weather pattern (Adjei-nsiah *et al.,* 2008; Kermah *et al.,* 2018; Snapp *et al.,* 2002).

Increased yields of maize in maize-legume intercrop system is widely reported, for example maize and groundnuts (Yan-hong *et al.,* 2019), maize and common bean (Nassary *et al.,* 2020), maize or millet with soybean (Chapagain *et al.,* 2018; Z. Wang *et al.,* 2014; Yi-ling *et al.,* 2017), maize with cowpea (Chapagain *et al.,* 2018), maize and pigeon pea (Myaka *et al.,* 2006; Ngwira *et al.,* 2012; Snapp *et al.,* 2010), maize and chickpea (Wang *et al.,* 2014). Intercropping therefore aid in coping with climate variability, promotes diet diversification hence food security and nutrition, ensure efficient labor use and high quality livestock fodder production plus other collateral benefits such as increased income (Lithourgidis *et al.,* 2011). All these attributes makes intercropping to be referred to as 'the new green revolution' as it provides a sustainable means of achieving agriculture intensification which is an advantage among smallholder rural farmers operating under constrained finances and resources (Martin-guay *et al.,* 2018). This is more so considering the role it plays in improving soil fertility and management of weeds especially in regard to striga weed that have greatly limited yellow maize production.

Intercropping and soil health

Legumes enhance soil fertility through biological nitrogen fixation (BNF) hence they do not compete with maize for available soil nitrogen but rather contribute to improved soil fertility increasing grain performance (Giller, 2001; Sitienei *et al.,* 2017). This enables such legumes to self-sustain under adverse environmental condition especially in regard to N deficiency considering that they are not sufficiently valued to be fertilized by the low resource input subsistence farmers (Graham and Vance, 2003; Snapp *et al.,* 1998). Legumes such as peanuts, pigeon pea and chickpea have phosphorus solubilizing ability producing organic acid that solubilizes immobilized phosphorus, enhancing P acquisition to the associated non-solubilizing crops (Li and Tang, 2004; Richardson *et al.,* 2011). Legumes can also benefit from cereals intercrop since the latter have the capacity to avail immobilized Zn, Fe and Mn minerals through production of compounds such as phytosiderophores to the companion legume crop which lack the mobilizing ability of these minerals (Stomph *et al.,* 2020). Biological availability of these important minerals enhanced in the intercrop system sustainably increases nutrient use efficiency reducing reliance on the costly mineral fertilizers, producing safe and quality food while lowering production costs (Giller, 2001; Lithourgidis *et al.,* 2011). This is of great importance especially to subsistence farmers with limited resources to access the mineral fertilizers and therefore highly dependent on economically viable and prudent biological processes to sustain yields (Graham and Vance, 2003). BNF contribute little to greenhouse gas emissions as they generate low nitrous oxide compared to the amount emitted with mineral N fertilizer reducing impacts of climatic shocks (Bayer *et al.,* 2016; Sá *et al.,* 2016).

Difference in rooting foraging patterns of intercrops ensures extensive soil exploration enhancing nutrient use efficiency (Richardson *et al.,* 2011). Cereal crops have been shown to alter their rooting pattern by having deeper root distribution with greater root density when grown in association with other crops than they would normally have as a sole crop (Li *et al.,* 2013; Miyazawa *et al.,* 2010). The general distribution and deep roots are also able to aggregate the soil improving the soil structure curtailing erosion, reduce soil crusts and break through soil hardpans minimizing soil resistance to root penetration (Lithourgidis *et al.,* 2011; Valentin, 1993).

In the maize-legume intercrop, maize provides higher canopy structure while legume acts as a cover crop. This provides a naturally buffer against extreme weather events such as during heavy rains by plummeting the velocity of raindrop splash reducing surface runoff curtailing soil erosion and soil organic matter loss (Nyawade *et al.,* 2018a). The cover crop also naturally suppress weeds by creating inhospitable environment for the weeds hindering their germination, growth and development (Nalivata *et al.,* 2017; Silberg *et al.,* 2019). These compound canopies also maintain the relative humidity by shading the soil surface reducing the soil temperature (Nyawade *et al.,* 2018b). The rate of evaporation is minimized in favor of transpiration thereby ensuring soil moisture conservation and water use efficiency especially during adverse moisture stress periods (Stomph *et al.,* 2020). The system also sequester more carbon inform of CO_2 from the atmosphere (Stagnari *et al.,* 2017). Following senescence, the mature dry legume leaves fall and decompose converting into organic matter, mineralized to release nutrients enriching the soil organic component (Nalivata *et al.,* 2017). This improves soil water retention, soil aggregation and tilth reducing leachate losses conferring a positive influence on soil microbial community and biodiversity (Bending *et al.,* 2000; Giller, 2001; Sanginga *et al.,* 2003).

Intercropping and control of Striga weed

Striga infestation is most severe in Nyanza where yellow maize production is prevalent especially *Striga hermonthica*, aggravated by continuous maize cultivation practice and reduced the soil fertility levels due to limited fertilizer use, a common scenario in most farms (Hebinck *et al.,* 2015; Ransom, 2000). The root-parasitic flowering striga weed become intertwined with the cereal roots of susceptible hosts such as maize, millet or sorghum, from where they draw and rob the plant off moisture and nutrients impairing photosynthesis (Silberg *et al.,* 2019). This results to stunted, weak, wilted and chlorotic plants causing extensive damage reducing grain and stover yields even before emergence while the fully bloomed beautiful purple striga flowers signals the impending death of the affected maize plant earning it the name 'witchweeds' (CIMMYT, 2016; Runo and Kuria, 2018). Complete yield losses of 100 % have therefore been reported in highly infested striga fields (Obilana and Ramaiah, 1992). Locally named '*Kayongo*' it has exposed food security and livelihoods of people in this region at constant risk (CIMMYT, 2016; Woomer and Omare, 2005). Farmers have resorted to use of hand weeding to reduce prevalence of the weed, however, this is tedious, time consuming and unsustainable considering the high fecundity and longevity of its seeds in the soil and their ease of dispersal (Khan *et al.,* 2002; Runo and Kuria, 2018). A range of effective component technologies have been identified such as crop rotation, push-pull technology, use of seed coated systemic herbicide, resistant hybrid maize (Kassie *et al.,* 2018; Kling *et al.,* 2000; Mignouna *et al.,* 2010). However, these technologies have cost implications such as high inputs and high labor demands. Furthermore land shortage, scarce resources and limitation in incorporating farmer preferred legumes also restricted their benefits and ease of adaption rendering them impracticable to farmers (Fischler, 2010).

Use of legumes as maize intercrop is therefore a promising option as they increase competition against weeds. Some such as soya bean, cowpea or groundnut can act as a trap plant by excreting root exudates that induces suicidal striga weed seed germination without supporting subsequent growth of the parasitic weed, significantly reducing the weed seed reservoir in the soil (Kureh *et al.,* 2000). The spreading canopy of the undercover legume crop creates a microclimate interfering with Striga weed germination and development (Parker and Riches, 1993; Silberg *et al.,* 2019). Intercropping improves the soil fertility levels limiting development of striga weed as well as depleting the seed reserves in the soil (Khan *et al.,* 2014). This reduces reliance on costly pesticides and agro-chemicals, which are usually beyond the means of most small-scale farmers and further poses major environmental and public health risk (Pickett *et al.,* 2014). Intercropping therefore is able to sustainably tackle myriad of challenges that farmers face to realize increased yellow maize yields in this region.

Gaps in yellow maize production and utilization

Agricultural research has laid major focus mainly on increasing productivity especially of staple crops (McDermott *et al.,* 2015). It is therefore not surprising that most high yielding certified maize seeds available in Kenya are for white maize variety. Research must now put emphasis on quality maize production with regards to taste, color and nutritional attributes *in order* to replace the degenerated yellow maize local varieties with improved varieties. This should be participatory research encompassing farmers, private sectors, donor agents, research institutions, universities, national and county Governments engagement and consultation, *in order* to meet all concerned stakeholders' requirements. Consumer preferences and tastes need to also be factored as this will also determine acceptability and adoption of the new varieties. Such research advances in yellow maize production will propel introduction into the country of more nutritious maize varieties like the yellow or orange maize provitamin A biofortified maize that have been successful in countries like Zambia (Meenakshi *et al.,* 2010). To safeguard against adverse climate change impacts, development of yellow maize simulation models is required to predict yields outcome under different climatic scenarios, farm management practices and soil types.

VAD is highly prevalent among poor people living in remote rural areas with yellow maize holding a considerable potential for addressing this deficiency. Studies to gauge consumer acceptability of yellow maize in Kenya have shown huge disparity among rural and urban consumers brought about due to differences in social economic status (De Groote *et al.,* 2012, 2008). Popularization, education and awareness campaigns are needed which should target the entire household; men, women and children. Men because they are mostly household heads, controlling land dictating what and quantity grown while women in many instances are the caregivers, both of whom strongly influence the children's eating behavior and habits. The highly vulnerable VAD pre-school children, future parents and change agents, can also be encouraged and initiated into shifting consumption preference from white to the nutritious yellow maize need by considering introduction of yellow maize in the school feeding programs. Presence of yellow maize is sighted as impending sign of food crisis in the country, an indication that the Government has failed in ensuring food sufficiency of its citizens. This variety is therefore, not appreciated and rarely promoted. Its importance and relevance require special consideration which needs to be prioritized and supported throughout the maize value chain that supports millions of rural households via creation of favorable policy environment.

Conclusion and recommendations

Food insecurity and malnutrition are major perennial challenges in Kenya, stressing factors that urgently need to be addressed to ensure a healthy and prosperous nation. Focus on yield increment is not enough as this need to be accompanied by ensuring that food produced is of quality with ability to provide prerequisite nutrients needed for growth and development. The rather neglected but nutrient superior yellow maize has considerable untapped potential of improving food security, nutrition and economic status of the country. This is more so, considering that maize is part of people's everyday diet and that cultivation of yellow maize is already being practiced in western Kenya region. To maximize on this, barriers and bottlenecks that has limited full exploration of its potential need to be intercepted while its production and utilization need to be harnessed.

References

Adjei-nsiah, S., Kuyper, T. W., Leeuwis, C., Abekoe, M. K., Cobbinah, J., Sakyi-dawson, O., and Giller, K. E. (2008). Farmers' agronomic and social evaluation of productivity, yield and N2-fixation in different cowpea varieties and their subsequent residual N effects on a succeeding maize crop. *Nutrient Cycling in Agroecosystems*, 199–209. https://doi.org/10.1007/s10705-007-9133-3.

Adjognon, S. G., Liverpool-tasie, L. S. O., and Reardon, T. A. (2017). Agricultural input credit in Sub-Saharan Africa : Telling myth from facts. *Food Policy*, 67, 93–105. https://doi.org/10.1016/j.foodpol.2016.09.014.

Ahmed, M. (2012). Analysis of incentives and disincentives for maize in Uganda (Issue Technical notes series, (MAFAP). FAO, Rome. http://www.fao.org/3/a-at587e.pdf.

Akakpo, D. B., de Boer, I. J. M., Adjei-nsiah, S., Duncan, A. J., Giller, K. E., and Oosting, S. J. (2020). Evaluating the effects of storage conditions on dry matter loss and nutritional quality of grain legume fodders in West Africa. *Animal Feed Science and Technology*, 262. https://doi.org/10.1016/j.anifeedsci.2020.114419.

Apollo, B.O. (2007). Country Pasture/Forage Resource Profiles. https://www.betuco.be/dieren/Pasture%20Forage%20Resource%20Kenya.pdf.

Andrews, S., Karien, D., and Cambardella, C. (2004). The soil management assessment Framework: A quantitative soil quality evaluation method. *Soil Science Society of America Journal*, 68(6).

Anjichi, V. E., Muasya, R. M., Gohole, L. S., Rao, N. K., and MuuiC.W. (2005). Genetic biodiversity assessment and local seed systems of maize landraces among smallholder farmers in Western Kenya. *African Crop Science Conference Proceeding*, 7, 1335–1340.

Anthony, A. O. (2014). Physical Features of Some Selected Nigerian Maize Cultivars. American *Journal of Plant Sciences*, 5, 1352–1358.

Ariga, J., and Jayne, T. S. (2011). Fertilizer in Kenya: Factors Driving the Increase in Usage by Smallholder Farmers. In C. Punam and A. Manka (Eds.), Yes Africa can: Success Stories from a Dynamic Continent (pp. 269–288). Bank, the International The Bank for Reconstruction and Development / The World.

Atlin, G. N., Palacios, N., Babu, R., Das, B., Twumasi-Afriyie, S., Friesen, D. K., De Groote, H., Vivek, B., and Pixley, K. V. (2011). Quality Protein Maize : Progress and Prospects. In J. Janick (Ed.), *Plant Breeding Reviews* 34, 83–130. Wiley-Blackwell.

Bain, L. E., Awah, P. K., Ngia, G., Njem, P. K., Yelena, S., Nsah, B., and Ajime, T.T. (2013). Malnutrition in Sub–Saharan Africa: burden, causes and prospects. *Pan African Medical Journal*. http://www.panafrican-med-journal.com/content/article/15/120/full/.

Bationo, A., and Waswa, B. S. (2011). New Challenges and Opportunities for Integrated Soil Fertility Management in Africa. In A. Bationo, B. Waswa, J. M. Okeyo, F. Maina, and J. M. Kihara (Eds.), Innovations as Key to the Green Revolution in Africa (pp. 3–17). https://doi.org/10.1007/978-90-481-2543-2.

Bayer, C., Gomes, J., Accordi, J., Costa, F., Vieira, B., and Dieckow, J. (2016). Soil and Tillage Research Mitigating greenhouse gas emissions from a subtropical Ultisol by using long-term no-tillage in combination with legume cover crops. *Soil and Tillage Research journal* 161, 86–94. https://doi.org/10.1016/j.still.2016.03.011.

Bayu, W., Rethman, N. F. G., and Hammes, P. S. (2005). The Role of Animal Manure in Sustainable Soil Fertility Management in Sub-Saharan Africa: A Review, *Journal of Sustainable Agriculture*. 25(2), 113-136. DOI: 10.1300/J064v25n02_09.

Bending, G. D., Putland, C., and Rayns, F. (2000). Changes in microbial community metabolism and labile organic matter fractions as early indicators of the impact of management on soil biological quality. *Biology and Fertility of Soils* 31, 78–84.

Blössner, M., De Onis, M., and Prüss-Üstün, A. (2005). Malnutrition: quantifying the health impact at national and local levels / Monika Blössner and Mercedes de Onis. World Health Organization. https://apps.who.int/iris/handle/10665/43120.

Bybee-finley, K. A., and Ryan, M. R. (2018). Advancing Intercropping Research and Practices in Industrialized Agricultural Landscapes. *Agriculture*, 8(80). https://doi.org/10.3390/agriculture8060080.

Byerlee, D., and Heisey, P. W. (1996). Past and potential impacts of maize research in sub-Saharan Africa: a critical assessment. *Food Policy* 21(3), 255-277.

Chapagain, T., Pudasaini, R., Ghimire, B., Gurung, K., and Choi, K. (2018). Intercropping of maize, millet, mustard, wheat and ginger increased land productivity and potential economic returns for smallholder terrace farmers in Nepal. *Field Crops Research*, 227, 91–101. https://doi.org/10.1016/j.fcr.2018.07.016.

Chomba, C., Mwale, M., Ibrahim, A., and Simpungwe, E. (2018). Pathways for Improved Nutrition in Zambia : Lessons from Pro-Vitamin A rich Maize Innovation Platform. FARA research report 2(14) pp 14. https://research4agrinnovation.org/wp-content/uploads/2018/06/FRR-Vol-2-No-14-2018.pdf.

CIMMYT. (2016). Weeding out the losses:Striga

challenges in Kenya. https://www.cimmyt.org/news/weeding-out-the-losses-striga-challenges-in-kenya/.
Daly, J., Hamrick, D., Gereffi, G., and Guinn, A. (2016). Maize value chains in East Africa (Issue F-38202-RWA-1).https://www.theigc.org/wp-content/uploads/2017/03/Maize-value-chains.pdf.
Das, A., Devi, M. T., Babu, S., Ansari, M., Layek, J., Bhowmick, S. N., Yadav, G. S., and Singh, R. (2018). Cereal-Legume Cropping System in Indian Himalayan Region for Food and Environmental Sustainability. In Meena, R. S. et al. (Ed.), Legumes for Soil Health and Sustainable Management (pp. 33–76). Springer Nature. https://doi.org/10.1007/978-981-13-0253-4_2.
De Groote, H., and Kimenju, S. C. (2008). Comparing consumer preferences for color and nutritional quality in maize : Application of a semi-double-bound logistic model on urban consumers in Kenya. *Food Policy*, 33, 362–370. https://doi.org/10.1016/j.foodpol.2008.02.005.
De Groote, H., and Kimenju, S. C. (2012). Consumer preferences for maize products in urban Kenya. *Food and Nutrition Bulletin*, 33(2), 99–110. https://doi.org/10.1177/156482651203300203.
De Groote, H., Kimenju, S. C., and Morawetz, U. B. (2011). Estimating consumer willingness to pay for food quality with experimental auctions: the case of yellow versus fortified maize meal in Kenya. *Agricultural Economics*, 42, 1–16
Dei, H. K. (2017). Assessment of Maize (*Zea mays*) as Feed Resource for Poultry. *IntechOpen*, DOI: 10.5772/65363.
Delve, R. J., Cadisch, G., Tanner, J. C., Thorpe, W., Thorne, P. J., and Giller, K. E. (2001). Implications of livestock feeding management on soil fertility in the smallholder farming systems of sub-Saharan Africa. *Agriculture, Ecosystems and Environment* 84, 227–243.
Dorward, A., Chirwa, E., Dorward, A., and Chirwa, E. (2011). The Malawi agricultural input subsidy programme : The Malawi agricultural input subsidy. *International Journal of Agricultural Sustainability*, 9(1), 232–247. https://doi.org/10.3763/ijas.2010.0567.
Duranti, M., and Gius, C. (1997). Legume seeds: protein content and nutritional value. *Field Crops Research* 53, 31–45.
EACB (2020). East Africa cross border trade bulletin. Volume 28. https://reliefweb.int/sites/reliefweb.int/files/resources/Quarterly_GHA_Cross_Border_Trade_Bulletin_January_2020%20%281%29_0.pdf
Ekpa, O., Palacios-rojas, N., Kruseman, G., Fogliano, V., and Linnemann, A. R. (2018). Sub-Saharan African maize-based foods : Technological perspectives to increase the food and nutrition security impacts of maize breeding programmes. *Global Food Security*, 17, 48–56. https://doi.org/10.1016/j.gfs.2018.03.007.
FAO. (2011). The role of women in Agriculture. ESA working paper No. 11-02. http://www.fao.org/3/am307e/am307e00.pdf
FAO. (2014a). Nutrition, education and awareness raising for the right to adequate food. http://www.fao.org/3/a-i3895e.pdf.
FAO, (2014b). Youth and Agriculture: Key challenges and concrete solutions. http://www.fao.org/3/a-i3947e.pdf
FAO. (2016). FAO 2016. http://www.fao.org/faostat/en/#data/FS.
FAO. (2018). FAOstats 2018. http://www.fao.org/faostat/en/#data/QC.
Fanzo, J. (2012). The Nutrition Challenge in Sub-Saharan Africa. United Nation Development Programme. Working Paper 2012-012. https://www.africa.undp.org/content/rba/en/home/library/working-papers/nutrition-challenge.html.
Feil, B., Moser, S. B., Jampatong, S., and Stamp, P. (2005). Mineral Composition of the Grains of Tropical Maize Varieties as Affected by Pre-Anthesis Drought and Rate of Nitrogen Fertilization. *Crop Science*, 45, 516–523.
Fischler, M. (2010). Impact assessment of push–pull technology developed and promoted by icipe and partners in eastern Africa.

https://www.shareweb.ch/site/Poverty-Wellbeing/Documents/media_-_addressing_poverty_in_practice_ _beneficiary_assessment_(ba)_-_experiencies_-_bapia_icipe_push-pull_2010.pdf.

Gebrelibanos, M., Tesfaye, D., Raghavendra, Y., and Sintayeyu, B. (2013). Nutritional and health implications of legumes. *International Journal of Phamaceutical Sciences and Research*, 4(4), 1269–1279.

Giller, K. (2001). Nitrogen Fixation in Tropical Cropping Systems (2nd ed.). CABI.

Graham, P. H., and Vance, C. P. (2003). Legumes: Importance and Constraints to Greater Use. *Plant Physiology*, 131, 872–877. https://doi.org/10.1104/pp.017004.872.

Gwirtz, J. A., and Garcia-casal, M. N. (2014). Processing maize flour and corn meal food products. *Annals of the New York Academy of Sciences*, 1312, 66–75. https://doi.org/10.1111/nyas.12299.

Hagenimana, V., and Low, J. (2000). Potential of orange-fleshed sweet potatoes for raising vitamin A intake in Africa. *Food and Nutrition Bulletin*, 21(4), 414-418.

Hans, P., Binswanger-mkhize., and Savastano, S. (2017). Agricultural intensification : The status in six African countries. *Food Policy*, 67, 26–40. https://doi.org/10.1016/j.foodpol.2016.09.021.

Headey, D. D., and Jayne, T. S. (2014). Adaptation to land constraints : Is Africa different ? *Food Policy*, 48, 18–33. https://doi.org/10.1016/j.foodpol.2014.05.005.

Hebinck, P., Mango, N., and Kimanthi, H. (2015). Local maize practices and the cultures of seed in Luoland, West Kenya. In Dessein, J. et al. (Ed.), Cultural Sustainability and Regional Development: Theories and practices of territorialisation. *Taylor and Francis* pp. 206–218.

Holden, S. T. (2018). Fertilizer and Sustainable Intensification in Africa. Centre for Land Tenure Studies Working Paper (1/18). https://www.nmbu.no/download/file/fid/40400.

Iken, J. E., and Amusa, N. A. (2004). Maize research and production in Nigeria. *African Journal of Biotechnology*, 3, 302–307.

McCann, J. C. (2005). Maize and Grace: Africa's encounter with a new world crop, 1500–2000. Harvard University Press.

Jayne, T. S., Mather, D., Mason, N., and Ricker-gilbert, J. (2013). How do fertilizer subsidy programs affect total fertilizer use in sub-Saharan Africa? Crowding out, diversion, and benefit/cost assessments. *Agricultural Economics*, 44, 687–703. https://doi.org/10.1111/agec.12082.

Kaizzi, K. C., Mohammed, M. B., and Nouri., M. (2017). Fertilizer Use Optimization: Principles and Approach. In C. S. Wortmann and K. Sones (Eds.), Fertilizer Use Optimization in Sub-Saharan Africa (pp. 9–19). CAB International.

Keith, P. W. (2003). Vitamin A deficiency disorders in children and women. *Food and Nutrition Bulletin*, 24(4).

Kermah, M., Franke, A. C., Adjei-Nsiah, S., Ahiabor, B. D. K., Abaidoo, R. C., and Giller, K. E. (2018). N_2-fixation and N contribution by grain legumes under different soil fertility status and cropping systems in the Guinea savanna of northern Ghana. *Agriculture, Ecosystems and Environment*, 261, 201–210.

Khan, Z. R., Hassanali, A., Overholt, W., Khamis, T. M., Hooper, A. M., Pickett, J. A., Wadhams, L. J., and Woodcock, C. M. (2002). Control of Witchweed Striga hermonthica by intercropping with Desmodium spp., and the mechanism defined as allelopathic. *Journal of Chemical Ecology*, 28(9), 1871–1885.

Khan, Z. R., Midega, C. A. O., Pittchar, J. O., Murage, A. W., Birkett, M. A., Bruce, T. J. A., and Pickett, A. J. (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. http://dx.doi.org/10.1098/rstb.2012.0284.

Kihanda, F., Warren G., Micheni A. (2007). Effects of manure application on crop yield and soil chemical properties in a long-term field trial in semi-arid Kenya. In: Bationo A., Waswa B., Kihara J., Kimetu J. (eds) Advances in Integrated Soil Fertility Management in sub-Saharan Africa: Challenges and Opportunities. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-5760-

1_44.
Kihara, J., Huising, J., and Nziguheba, G. (2015). Maize response to macronutrients and potential for profitability in sub-Saharan Africa. *Nutrient Cycling in Agroecosystems*, https://doi.org/10.1007/s10705-015-9717-2.
Kilimo Trust. (2017). Characteristics of Markets for Animal Feeds Raw Materials in the East African Community: Focus on Maize Bran and Sunflower Oil Seed Cake. https://www.kilimotrust.org/reacts/files/AnimalFeeds_markets_X-tisation.pdf.
Kling J. G., Fajemisin, J. M., Badu-Apraku, B., Diallo, A., Menkir, A., and Melake-Berhan, A. (2000). Striga resistance breeding in maize. In H. BIG, D. Hess, M. Koyama, I. Grivet, H. Rattunde, and H. Geiger (Eds.), Breeding for striga resistance in cereals (pp. 103–118). Weikersheim, Germany margraf Verlag.
KNBS. (2019a). Kenya Population and Housing census Vol. 1: Population by County and Sub-county: Vol. I (Issue November). http://housingfinanceafrica.org/app/uploads/VOLUME-I-KPHC-2019.pdf.
KNBS. (2019b). Enhanced Food Balance Sheets for Kenya Results (2014-2018) (Issue May). https://www.afdb.org/sites/default/files/documents/publications/food_balance_sheets_kenya_full_report.pdf.
KNMS. (2011). Kenya National Micronutient Survey 2011. http://statistics.knbs.or.ke/nada/index.php/catalog/72.
Kumar, P., Choudhary, M., Hossain, F., Singh, N. K., Choudhary, P., Gupta, M., Singh, V., Chikappa, G. K., Kumar, R., Kumar, B., Jat, S. L., and Rakshit, S. (2019). Nutritional quality improvement in maize (Zea mays): Progress and challenges. *Indian Journal of Agricultural Sciences* 89 (6), 895–911.
Kureh, I., Chiezey, U. F., and Tarta, B. D. (2000). On-station verification of the use of soybean trap-crop for control of Striga in maize. *African Crop Science Journal*, 8(3), 295–300. https://doi.org/10.4314/acsj.v8i3.27694.
Li, L., and Tang, C. (2004). Acid Phosphatase Role in Chickpea / Maize Intercropping Acid Phosphatase Role in Chickpea / Maize Intercropping. *Annals of Botany*, 94, 297–303. https://doi.org/10.1093/aob/mch140.
Li, L., Zhang, L., and Fusuo, Z. (2013). Crop mixtures and the mechanisms of overyielding. In Levin, S. A. (Ed.), *Encyclopedia of Biodiversity* (Second, Vol. 2, pp. 382–395). Academic Press. https://doi.org/10.1016/B978-0-12-384719-5.00363-4.
Lithourgidis, A. S., Dordas, C. A., Damalas, C. A., and Vlachostergios, D. N. (2011). Annual intercrops: an alternative pathway for sustainable agriculture. *Australian Journal of crop science* 5(4), 396–410.
Mafongoya, P. L., Barak, P., and Reed, J. D. (2000). Carbon, nitrogen and phosphorus mineralization of tree leaves and manure. *Biology and Fertility of Soils*, 30, 298–305.
Maitra, S., Shankar, T., and Banerjee, P. (2020). Potential and Advantages of Maize-Legume Intercropping System. In Akbar Hossain (Ed.), Maize-Production and Use (p. 13). *IntechOpen*. https://doi.org/http://dx.doi.org/10.5772/57353.
Manjeru, P., Van Biljon, A., and Labuschagne, M. (2017). The development and release of maize fortified with provitamin A carotenoids in developing countries. *Critical reviews in food science and nutrition*. https://doi.org/10.1080/10408398.2017.1402751.
Marenya, P. P., and Barrett, C. B. (2009). State-conditional Fertilizer Yield Response on Western Kenyan Farms. *American Journal of Agricultural Economics*, 91(4), 991–1006. https://doi.org/10.1111/j.l467-8276.2009.01313.x.
Martin-guay, M., Paquette, A., Dupras, J., and Rivest, D. (2018). The new Green Revolution : Sustainable intensification of agriculture by intercropping. *Science of the Total Environment*, 615, 767–772. https://doi.org/10.1016/j.scitotenv.2017.10.024.
Mcdermott, J. J., Staal, S. J., Freeman, H. A., Herrero, M., and Steeg, J. A. Van De. (2010). Sustaining intensification of smallholder livestock systems in the tropics. *Livestock Science*, 130, 95–109. https://doi.org/10.1016/j.livsci.2010.02.014.
Meenakshi, J. V, Manyong, V. M., Tomlins, K., Hamukwala, P., Zulu, R., and Mungoma, C.

(2010). Consumer acceptance of provitamin A orange maize in rural Zambia HarvestPlus Working Paper March 2010 Consumer Acceptance of Provitamin A Orange Maize in Rural Zambia. HarvestPlus, 4, 1–44.

Messina, M. J. (1999). Legumes and soybeans: overview of their nutritional profiles and health effects. *American Journal of Clinical Nutrition*, 70, 439–450.

Mignouna, D. B., Mutabazi, K., Senkondo, E. M., and Manyong, V. (2010). Adoption of a New Maize and Production Efficiency in Western Kenya By. Contributed Paper Presented at the Joint 3rd African Association of Agricultural Economists (AAAE) and 48th Agricultural Economists Association of South Africa (AEASA) Conference, Cape Town, South Africa, September 19th-23rd.

Miyazawa, K., Murakami, T., Takeda, M., and Murayama, T. (2010). Intercropping green manure crops-effects on rooting patterns. *Plant and Soil*, 331, 231–239.

Morris, M., Kelly, V. A., Kopicki, R. J., and Byerlee, D. (2007). Fertilizer Use in African Agriculturer: Lessons Learned and Good Practice Guidelines. World bank Washington, DC.

Mucheru-Muna, B. M., Mugendi, D., Pypers, P., Mugwe, J., Kung'u, J., Vanlauwe, B., and Merckx, R. (2014). Enhancing maize productivity and profitability using organic inputs and mineral fertilizer in Central Kenya small-hold Farms. *Experimental Agriculture*, 50, 250–269. https://doi.org/10.1017/S0014479713000525.

Mugwe, J., Mugendi, D., Odee, D., and Mairura, F. (2009). Effect of selected organic materials and inorganic fertilizer on the soil fertility of a Humic Nitisol in the central highlands of Kenya. *Soil Use And Management*, 25, 434–440. https://doi.org/10.1111/j.1475-2743.2009.00244.x.

Mulei, W. M., Ibumi, M., and Woomer, P. (2011). Grain Legume Processing Handbook: Value Addition to Bean, Cowpea, Groundnut and Soybean by Small-Scale African Farmers. Tropical Soil Biology and Fertility Institute of the International Centre for Tropical Agriculture.

Murage, E. W., Karanja, N. K., Smithson, P. C., and Woomer, P. L. (2000). Diagnostic indicators of soil quality in productive and non-productive smallholders ' fields of Kenya's Central Highlands. Agriculture, *Ecosystems and Environment*, 79, 1–8.

Muzhingi, T., Gadaga, T. H., Siwela, A. H., Grusak, M. A., Russell, R. M., and Tang, G. (2011). Yellow maize with high β-carotene is an effective source of vitamin A in healthy Zimbabwean men. *American Journal of Clinical Nutrition*, 94, 510–519. https://doi.org/10.3945/ajcn.110.006486.510.

Muzhingi, T., Langyintuo, A. S., Malaba, L. C., and Banziger, M. (2008). Consumer acceptability of yellow maize products in Zimbabwe. *Food Policy*, 33, 352–361. https://doi.org/10.1016/j.foodpol.2007.09.003.

Muzhingi, T., Yeum, K. J., Russell, R. M., Johnson, E. J., Qin, J., Tang, G. (2008). Determination of carotenoids in Yellow Maize, the effects of saponification and food preparations. *International Journal for Vitamin and Nutrition Research*, 78(3), 112-120

Myaka, F. M., Sakala, W. D., Adu-Gyamfi, J. J., Kamalongo, D., Ngwira, A., Odgaard, R., Nielsen, N. E., and Høgh-Jensen, H., (2006). Yields and accumulations of N and P in farmer-managed intercrops of maize–pigeonpea in semi-arid Africa. P*lant Soil*, 285, 207–220. https://doi.org/10.1007/s11104-006-9006-6.

Nalivata, P., Kibunja, C., James, M., Tetteh, F., Tarfa, B., Dicko, M. K., Korodjouma, O., Rusanganwa A. C., Maman, K. N., Bayu, W., and Wortmann, S. C. (2017). Integrated Soil Fertility Management in Sub-Saharan Africa. In C. S. Wortmann and K. Sones (Eds.), Fertilizer Use Optimization in Sub-Saharan Africa (pp. 25–39). CABI.

Nassary, K. E., Baijukya, F., and Alois, P. (2020). Productivity of intercropping with maize and common bean over five cropping seasons on smallholder farms of Tanzania. *European Journal of Agronomy*, 113. https://doi.org/10.1016/j.eja.2019.125964.

Ngwira, A. R., Aune, J. B., and Mkwinda, S. (2012). On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under

conservation agriculture in Malawi. *Field Crops Research*, 132, 149–157. https://doi.org/10.1016/j.fcr.2011.12.014.
Nicholson, S. E. (2017). Climate andclimatic variability of rainfall overeastern Africa. *Reviews of Geophysics*, 55,590–635. doi:10.1002/2016RG000544
Nuss, E. T., and Tanumihardjo, S. A. (2010). Maize : A Paramount Staple Crop in the Context of Global Nutrition. *Comprehensive Reviews in Food Science and Food Safety*, 9, 417–436. https://doi.org/10.1111/j.1541-4337.2010.00117.x.
Nyawade, S., Karanja, N., Gachene, C., and Parker, M. (2018a). Susceptibility of soil organic matter fractions to soil erosion under potato-legume intercropping systems in central Kenya. *Journal of Soil and Water Conservation*, 73(5), 567–576. https://doi.org/10.2489/jswc.73.5.567.
Nyawade, S. O., Karanja, N. N., Gachene, C. K. K., Schulte-geldermann, E., and Parker, M. (2018b). Effect of potato hilling on soil temperature, soil moisture distribution and sediment yield on a sloping terrain. *Soil and Tillage Research*, 184, 24–36. https://doi.org/10.1016/j.still.2018.06.008.
Obilana, A. T., and Ramaiah, K. V. (1992). Striga (Witchweeds) in Sorghum and Millet : Knowledge and Future Research Needs. In W. A. de Milliano, R. Frederiksen, and G. D. Bengston (Eds.), Sorghum and millets diseases: a second world review (pp. 187–201). International Crops Research Institute for the Semi-Arid Tropics.
Odendo, M., De Groote, H., and Odongo, O. M. (2001). Assessment of farmers' preferences and constraints to maize production in moist midaltitude zone of Western Kenya. 5th International Conference of the African Crop Science Society, Lagos, Nigeria October 21-26th, 1–12.
Okoruwa, A. E., and Kling, J. G. (1996). Nutrition and quality of maize (IITA Resea). IITA. http://biblio1.iita.org/bitstream/handle/20.500.12478/4491/U96BkOkoruwaNutritionNothomNodev.pdf?sequence=1#:~:text=Of%20these%20crops%2C%20maize%20has,protein%20quality%20in%20the%20diet.
Olumeh, D. E., Adam, R., Jakinda, D., and Willis, O. (2018). Characterizing Smallholder Maize Farmers' Marketing in Kenya : An Insight into the Intra-Household Gender, Wealth-Status, Educational and Credit Access Dimensions. *Journal of Marketing and Consumer Research*, 48, 1–10.
Olwande, J., and Mathenge, M. (2012). Market Participation among Poor Rural Households in Kenya Market Participation among Poor Rural Households in Kenya. International Association of Agricultural Economists (IAAE) Triennial Conference, Foz Do Iguaçu, Brazil, 18-24 August, 1–30.
Onono, P. A., Wawire, N. W. H., and Ombuki, C. (2013). The response of maize production in Kenya to economic incentives. *International Journal of Development and Sustainability*, 2(2), 14.
Onyango, A.W., Jean-Baptiste, J., Samburu, B., and Mahlangu, T. L. M. (2019). Regional overview on the Double Burden of Malnutrition and Examples of Program and Policy Responses: African Region. *Annals of Nutrition and Metabolism*. 75, 127–130.
Parker, C., and Riches, C. (1993). Parasitic Weeds of the World: Biology and Control. *Economic Botany*, 48.
Pereira Cézar, F. L., Mello, L. M. M. de M., Pariz, C. M., de Mendonça, V. Z., Yano, É. H., de Miranda, E. E. V., and Crusciol, C. A. C. (2016). Autumn Maize Intercropped with Tropical Forages : Crop Residues, Nutrient Cycling, Subsequent Soybean and Soil Quality. *Revista Brasileira de Ciencia Do Solo*, 40, 1–20. https://doi.org/10.1590/18069657rbcs20150003.
Peters, M., Horne, P., Schmidt, A., Holmann, F., Kerridge, P. C., Tarawali, S. A., Lascano, C. E., Argel, P., Stür, W., Fujisaka, S., and Wortmann, C. (2001). The role of forages in reducing poverty and degradation of natural resources in tropical production systems. Agricultural Research and Extension Network (No. 117).
Pickett, J. A., Woodcock, C. M., Midega, C. A. O., and Khan, Z. R. (2014). Push-pull farming systems ScienceDirect Push – pull farming systems. *Current Opinion in Biotechnology*, 26, 125–132. https://doi.org/10.1016/j.copbio.2013.12.006.
Pillay, K., Derera, J., Siwela, M., and Veldman, F. (2011). Consumer acceptance of yellow,

provitamin A-biofortified maize in KwaZulu-Consumer acceptance of yellow, provitamin A-biofortified maize in KwaZulu-Natal. *South African Journal of Clininical Nutrition*, 24(4), 186–191. https://doi.org/10.1080/16070658.2011.11734386.

Pixley, K. V., and Bjarnason, M. S. (2002). Stability of Grain Yield, Endosperm Modification, and Protein Quality of Hybrid and Open-Pollinated Quality Protein Maize (QPM) Cultivars. *Crop Science*, 42, 1882–1890.

Prasanna, B. M., Vasal, S. K., Kassahun, B., and Singh, N. N. (2001). Quality protein maize. *Current Science*, 81(10), 1308–1319. https://doi.org/10.1177/156482650602700310.

Rakotoarisoa, M. A., Iafrate, M., and Paschali, M. (2011). Why has Africa become a net food importer ? Explaining Africa agricultural and food trade deficits. http://www.fao.org/fileadmin/templates/est/PUBLICATIONS/Books/AFRICA_STUDY_BOOK_REVISED_low_res.pdf.

Ransom, J. K. (2000). Long-term approaches for the control of Striga in cereals : field management options. *Crop Protection*, 19, 759–763.

Ranum, P., Pe˜na-Rosas, J. P., and Garcia-Casal, M. N. (2014). Global maize production , utilization , and consumption. *Annals of the New York Academy of Sciences*. ISSN, 1312, 105–112. https://doi.org/10.1111/nyas.12396.

Rao, J., Cadilhon, J. J., Midega, C., Atieno, F., O., O. F., Céline, T., Auma, J. O., Mango, N., Okeyo, I., Odhiambo, G. D., and Macdonald, W. (2015). A situational analysis of agricultural production and marketing and natural resources management. ILRI/icipe Project Report. Nairobi, Kenya: International Livestock Research Institute for the Humidtropics CGIAR Research Program.

Rapsomanikis, G. (2015). The economic lives of smallholder farmers: An analysis based on household data from nine countries. http://www.fao.org/3/a-i5251e.pdf.

Richardson, A. E., Lynch, J. P., Ryan, P. R., Delhaize, E., Smith, F. A., Smith, S. E., Harvey, P. R., Ryan, M. H., Veneklaas, E. J., Lambers, H., Oberson, A., Culvenor, R. A., and Simpson, R. J. (2011). Plant and microbial strategies to improve the phosphorus efficiency of agriculture. *Plant Soil*, 349, 121–156. https://doi.org/10.1007/s11104-011-0950-4.

Runo, S., and Kuria, E. K. (2018). Habits of a highly successful cereal killer, Striga. *PLoS ONE*, 14(1). https://doi.org/10.1371/journal.ppat.1006731.

Rware, H., Kaizzi, K. C., Senkoro, C. J., Bayu, W., Oduor, G., and Watiti, J. (2017). Enabling fertilizer use optimization in sub-Saharan Africa. In C. S. Wortmann and K. Sones (Eds.), Fertilizer use optimization in sub-Saharan Africa (pp. 220–224). CABI. https://doi.org/10.1079/9781786392046.0220.

Sá, C. J. D., Lal, R., Clemente, C. C., Lorenz, K., Hungria, M., and Cesar, P. C. F. (2016). Low-carbon agriculture in South America to mitigate global climate change and advance food security. *Environment International*, https://doi.org/10.1016/j.envint.2016.10.020.

Salami, A., Kamara, A. B., and Brixiova, Z. (2010). Smallholder Agriculture in East Africa: Trends, Constraints and Opportunities. Working paper No. 105. African Development Bank, Tunis, Tunisia.

Sanginga, N., Dashiell, K. E., Diels, J., Vanlauwe, B., Lyasse, O., Carsky, R. J., Tarawali, S., Asafo-adjei, B., Menkir, A., and Schulz, S. (2003). Sustainable resource management coupled to resilient germplasm to provide new intensive cereal–grain–legume–livestock systems in the dry savanna. *Agriculture, Ecosystems and Environment*, 100, 305–314. https://doi.org/10.1016/S0167-8809(03)00188-9.

Schroeder, C. T., Onyango K'Oloo, R, Nar Bahadur, R., Jick, N. A., Parzies, H. K., and Gemenet, D. (2013). Potentials of hybrid maize varieties for small-holder farmers in Kenya: A review based on SWOT analysis. *African Journal of Food Agriculture Nutrition and Development*, 13(2), 7562–7586.

Shah, T. R., Prasad, K., and Kumar, P. (2016). Maize—A potential source of human nutrition and health : A review Maize — A potential source of human nutrition and health : A review. *Cogent Food and Agriculture*, 54(1). https://doi.org/10.1080/23311932.2016.1166995.

Sheahan, M., Black, R., and Jayne, T. S. (2013). Are Kenyan farmers under-utilizing fertilizer ? Implications for input intensification strategies and research. *Food Policy*, 41, 39–52. https://doi.org/10.1016/j.foodpol.2013.04.008.

Shiferaw, B., Prasanna, B. M., Hellin, J., and Bänziger, M. (2011). Crops that feed the world 6 . Past successes and future challenges to the role played by maize in global food security. *Food Security*, 3, 307–327. https://doi.org/10.1007/s12571-011-0140-5.

Silberg, T. R., Grace, V., Chimonyo, P., Richardson, R. B., Snapp, S. S., and Renner, K. (2019). Legume diversification and weed management in African cereal-based systems. *Agricultural Systems*, 174, 83–94. https://doi.org/10.1016/j.agsy.2019.05.004.

Simpungwe, E., Dhliwayo, T., Palenberg, M., Taleon, V., Birol, E., Oparinde, A., Saltzman, A., and Diressie, M. (2017). Orange maize in Zambia: Crop development and delivery experience. *African Journal of Food Agriculture Nutrition and Development*, 17(2), 11973–11999.

Sinclair, T. R., and Vadez, V. (2012). The future of grain legumes in cropping systems. *Crop and Pasture Science*, 63, 501–512.

Sitienei, R. C., Onwonga, R. N., Lelei, J. J., and Kamoni, P. (2017). Use of Dolichos (*Lablab Purpureus L.*) and Combined Fertilizers enhance Soil Nutrient Availability and Maize (*Zea Mays L.*) Yield in Farming Systems of Kabete Sub-County, Kenya. *Agricultural Science Research Journal*, 7(2), 47–61.

Smale, M., and Jayne, T.S. (2003). Maize in Eastern and Southern Africa: "Seeds" of Success in Retrospect. http://www.fao.org/docs/eims/upload/166420/Smale,Jayne.pdf.

Smith, A., Snapp, S., Dimes, J., Gwenambira, C., and Chikowo, R. (2016). Doubled-up legume rotations improve soil fertility and maintain productivity under variable conditions in maize-based cropping systems in Malawi. *Agricultural Systems*, 145, 139–149. https://doi.org/10.1016/j.agsy.2016.03.008.

Snapp, S., Aggarwal, V., and Chirwa, R. (1998). Note on phosphorus and cultivar enhancement of biological nitrogen fixation and productivity of maize / bean intercrops in Malawi. *Field Crops Research*, 58, 205–212.

Snapp, S. S., Rohrbach, D. D., Simtowe, F., and Freeman, H. A. (2002). Sustainable soil management options for Malawi : can smallholder farmers grow more legumes ? *Agriculture, Ecosystems and Environment*, 91, 159–174.

Snapp, S., and Silim, S. (2002). Farmer preferences and legume intensification for low nutrient environments. *Plant and Soil*, 245, 181–192. https://doi.org/10.1023/A.

Snapp, S. S., Blackie, M. J., Gilbert, R. A., Bezner-kerr, R., and Kanyama-phiri, G. Y. (2010). Biodiversity can support a greener revolution in Africa. *Proceedings of the National Academy of Sciences of the Unites States of America*, 107(48). https://doi.org/10.1073/pnas.1007199107.

Snapp, S., Kerr, R. B., Smith, A., and Ollenburger, M. (2013). Modeling and participatory farmer-led approaches to food security in a changing world : A case study from Malawi. *Secheresse* 24, 350-358. https://doi.org/10.1684/sec.2014.0409.

Snapp, S. S., Cox, C. M., and Peter, B. G. (2019). Multipurpose legumes for smallholders in sub-Saharan Africa : Identification of promising 'scale out' options. *Global Food Security*, 23, 22–32. https://doi.org/10.1016/j.gfs.2019.03.002.

SNV. (2017). Forage Production and Management. https://snv.org/cms/sites/default/files/explore/download/eth_fomap.pdf.

Stagnari, F., Maggio, A., Galieni, A., and Pisante, M. (2017). Multiple benefits of legumes for agriculture sustainability : an overview. *Chemical and Biological Technologies in Agriculture*, 4(2). https://doi.org/10.1186/s40538-016-0085-1.

Stein, A. J. (2015). The Poor, Malnutrition, Biofortification and Biotechnology. In

Herring, R. (Ed.), The Oxford Handbook of Food, Politics and Society. https://doi.org/10.1093/oxfordhb/9780195397772.013.005.

Stomph, T., Dordas, C., Baranger, A., Rijk, J. Bei, D., Evers, J., Gu, C., and Li, L., Simon, J., Jensen, E. S., Wang, Q., Wang, Y., Wang, Z., Xu, H., Zhang, C., Zhang, L., Zhang, W., Bedoussac, L., and van der Wer, W. (2020). Designing intercrops for high yield, yield stability and efficient use of resources : Are there principles ? *Advances in Agronomy*. 160, 1–50. Elsevier Inc. https://doi.org/10.1016/bs.agron.2019.10.002%0A.

Tarus, C. B. K. (2019). Maize Crisis : A Position Paper on Strategies for Addressing Challenges Facing Maize Farming In Kenya. *East African Scholars Journal of Education, Humanities and Literature*, 2(3), 149–158.

Thierfelder, C., Cheesman, S., and Rusinamhodzi, L. (2012). Field Crops Research A comparative analysis of conservation agriculture systems : Benefits and challenges of rotations and intercropping in Zimbabwe. *Field Crops Research*, 137, 237–250. https://doi.org/10.1016/j.fcr.2012.08.017.

Thorne, P. J., Thornton, P. K., Kruska, R. L., Reynolds, L., Waddington, S. R., Rutherford, A. S., and Odero, A. N. (2002). Maize as food , feed and fertiliser in intensifying crop– livestock systems in East and southern Africa: An ex ante impact assessment of technology interventions to improve smallholder welfare. ILRI (International Livestock Research Institute) Nairobi, Kenya. https://cgspace.cgiar.org/bitstream/handle/10568/505/MaizeImpactAssessment.pdf?sequence=1&isAllowed=y.

UNDP. (2018). UNDP Kenya Annual Report. https://www.undp.org/content/dam/kenya/docs/Annual Reports/UNDP Kenya AR 2018_INTERACTIVE.pdf.

USAID. (2014). Multi-Sectoral Nutrition Strategy Technical Brief: Interventions for Addressing Vitamin and Mineral Inadequacies. https://www.usaid.gov/sites/default/files/documents/1867/USAID_Nutrition_Strategy_5-09_508.pdf.

Valentin, C. (1993). Soil crusting and sealing in West Africa and possible approaches to improved management. In Soil tillage in Africa: needs and challenges. FAO. http://www.fao.org/3/t1696e/t1696e10.htm#P588_47911.

Van Ittersum, M. K., van Bussel, L. G. J., Wolf, J., Grassini, P., van Wart, J., Guilpart, N., Claessens, L., et al. (2016). Can sub-Saharan Africa feed itself ? *Proceedings of the National Academy of Sciences of the Unites States of America*. https://doi.org/10.1073/pnas.1610359113.

Vanlauwe, B, Wendt, J., Giller, K. E., Corbeels, M., Gerard, B., and Nolte, C. (2014). A fourth principle is required to define Conservation Agriculture in sub-Saharan Africa : The appropriate use of fertilizer to enhance crop productivity. *Field Crops Research*, 155, 10–13. https://doi.org/10.1016/j.fcr.2013.10.002.

Wambugu, P. W., Mathenge, P. W., Auma, E. O., and A, H. (2012). Constraints to On-Farm Maize (*Zea mays L.*) Seed Production in Western Kenya : Plant Growth and Yield. *International Scholarly Research*, 2012, 1–7. https://doi.org/10.5402/2012/153412.

Wang, Z., Jin, X., Bao, X., Li, X., and Zhao, J. (2014). Intercropping Enhances Productivity and Maintains the Most Soil Fertility Properties Relative to Sole Cropping. *PLoS ONE*, 9(12). https://doi.org/10.1371/journal.pone.0113984.

WHO. (2020). Micronutrient Deficiencies. https://www.who.int/nutrition/topics/vad/en/.

Woomer, P., Mukhwana, E., and Lynam, J. (2002). On-farm Research and operational strategies in soil fertility management. In B. Vanlauwe, J. Diels, N. Sanginga, and R. Merckx (Eds.), Integrated plant nutrient management in Sub-Saharan Africa. CABI Publishing. Wallingford, in association with the International Institute of Tropical Agriculture.

Woomer, P.L. and Omare, M.N. (2005). Ua Kayongo Hybrid Maize, the Striga Killer: A New Approach to Controlling Parasitic Striga for Kenyan Maize Producers. https://www.aatf-africa.org/wp-content/uploads/2018/11/Ua-

Kayongo_Manual.pdf.
Yan-hong, L., De-yang, S., Guang-hao, L., Bin, Z., Ji-wang, Z., Peng, L., and Baizhao, R. (2019). Maize/peanut intercropping increases photosynthetic characteristics, ^{13}C-photosynthate distribution, and grain yield of summer maize. *Journal of Integrative Agriculture*, 18(10), 2219–2229. https://doi.org/10.1016/S2095-3119(19)62616-X.
Yi-ling, T., Ling-ling, Y. U., Ao-mei, G., Xian-yu, Z., Zhi-guo, W., Yong-gang, G., and Jian-wu, W. (2017). Soil mineral nitrogen and yield-scaled soil N_2O emissions lowered by reducing nitrogen application and intercropping with soybean for sweet maize production in southern China. *Journal of Integrative Agriculture*, 16(11), 2586–2596. https://doi.org/10.1016/S2095-3119(17)61672-1.
Zuma, M. K., Kolanisi, U., and Modi, A. T. (2018). The Potential of Integrating Provitamin A-Biofortified Maize in Smallholder Farming Systems to Reduce Malnourishment in South Africa. *International Journal of Environmental Research and Public Health*. doi:10.3390/ijerph15040805.