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SOIL & CROP SCIENCES | REVIEW ARTICLE

Impediments to agricultural production in Uganda and measures to enhance soil fertility utilizing organic soil amendments: A review

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Abstract: Agriculture is the greatest resource that supports life on earth. The rapidly growing human population has globally escalated the demand for agricultural products including; food, fodder, medicines, and biofuels, but their supply has been limited. This has been attributed to the gradually declining quality and quantity of natural resources. The agricultural sector in Uganda has suffered from the effects of land-use shift as one of the major challenges contributing to land degradation. This has been aggravated by poor soil management practices leading to low soil productivity. The global campaign to adopt fertilizer use has generated significant outcomes in boosting production but with severe consequences of environmental pollution from the bulky fertilizers used. This review paper seeks to identify bottlenecks in the line of agricultural production and environmental sanitation in Uganda, with a proposed alternative of using well-processed organic fertilizers from biomass and nano-fertilizers postulated to eliminate fertilizer bulk. The paper further highlights *Azolla* as one of the high biomass plants with potential agricultural benefits when used as an organic fertilizer. The literature search for this

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The author is a PhD student in the department of Plant sciences, Microbiology and Biotechnology, Makerere University. She is conducting research on improving soil fertility and nutrient use efficiency using a nano fertilizer processed from *Azolla*, an agronomically important aquatic plant. The research involves optimization of standard methods for cultivation of *Azolla* which is a key component in its multiplication. This in turn will enable mainly the smallholder farmer to adopt its cultivation and its application as a green manure. The final product from this research is intended for use as a fertilizer for different crops and as a starting point for the development of other soil organic fertilizers.

PUBLIC INTEREST STATEMENT

Agriculture in Uganda supports livelihoods of over 70% of the entire population. This sector employs 63% of youth, but many are threatening to leave searching for better income. This is due to insufficient food production arising from declining soil fertility, attributed to inefficient farming practices. Monocropping favors attacks by pests and diseases, continuous tillage exposes soil to erosion and consistent use of agrochemicals affects soil properties hence fertility loss. Further still, dependence on rain-fed agriculture has threatened the sector considering the inconsistent weather changes. Drought and floods have severely affected farmers' yields, a scenario that threatens food security and farmers' livelihoods. There is need to adopt better farming practices that allow restoration of nutrients for instance; mixed farming and crop rotation instead of monocropping, minimizing tillage, and application of organic soil manures. Further still, the practice of irrigation could enable continuous yearly harvest thereby enhancing yields and improving farmers' livelihoods.

review paper was based on the information published on the web of science and extracts from interviews. All authors recommended the adoption of safer organic and nano-fertilizer technologies as the alternative solution to improving soil productivity while promoting environmental sanitation in Uganda.

Subjects: Agricultural Development; Agriculture and Food; Soil Sciences

Keywords: agricultural production; Azolla; biomass plants; food security; organic soil amendments; soil fertility

1. Introduction

Agriculture is the greatest human activity and resource from which civilization began. This resource provides food, fodder, fiber, fuel, and medicine to the global community. Following the introduction of agriculture during the Neolithic era which occurred about 10,000 years ago, the human population has progressively increased (Olsson, 2001). The rapidly growing population has escalated the demand for all agricultural resources with food as the major resource, but their supply has been limited (MAAIF, 2016). The insufficient supply of food has severely affected several communities, especially in developing countries. In sub-Saharan Africa, 239 million people were recorded as undernourished, with a prevalence of 22.8 percent as measured by the "Prevalence of Undernourishment (PoU)" (FAO, 2020). According to the Global Hunger Index (GHI) scores of 2018, Uganda was at 31.2 (Bernstein & Wiesmann, 2019). There is no doubt that covid-19 restrictions have escalated the outcomes of food insecurity, especially among the urban poor population that lives hand to mouth (Fews Net Famine Early Warning Systems Network, 2022).

Food insecurity in Uganda has majorly been considered an outcome of low agricultural productivity. This has been attributed to the gradually declining soil fertility originating primarily from anthropogenic causes majorly continuous tillage and mono-cropping as well as reduced agricultural inputs (Andriesse & Giller, 2015; Bernstein & Wiesmann, 2019). There has been a land-use shift from the original tropical rainforests to savannahs and later other non-agricultural activities including construction, charcoal burning, bricklaying, and animal grazing (Andriesse & Giller, 2015). This has significantly contributed to the degradation of soil. Loss of soil fertility has been manifested through loss of organic matter coupled with excessive nutrient mining (Nyombi, 2013). This mainly affects farmers who remove the biomass after harvest leaving the soil unreplenished thereby creating a negative nitrogen balance (Apanovich & Mazur, 2018). Because of the limited arable land available for the rising population, it is no longer possible to apply the old soil management practices of bush fallowing, and shifting cultivation that would restore fertility to the damaged soils (Andriesse & Giller, 2015; Bekunda et al., 2010). Furthermore, issues of soil fertility were aggravated by the political influence which triggered the removal of subsidies on agricultural inputs influenced by donors under the pan African structural adjustment programs in the 1980s. The removal of subsidies coupled with the collapse of national agricultural extension services prevented the smallholder farmer from accessing low-cost agricultural inputs (Andriesse & Giller, 2015). As a result, the economic status of most sub-Saharan countries is unable to sustain commercial agriculture driven by the high cost of agricultural inputs (Raimi et al., 2017).

This review paper seeks to highlight major constraints impeding agricultural development in Uganda. The paper further proposes smart agricultural technologies including the use of safely processed organic fertilizers and nano fertilizers as alternative solutions to one of the major agricultural constraints which is soil infertility. The proposed alternatives are anticipated to increase food production while minimizing environmental pollution in Uganda. The paper also highlights *Azolla* (an aquatic plant) in the category of organic fertilizers as one of the high biomass plants with immense agronomic potential. *Azolla* has the ability to double its mass within 2–5 days (Raja et al., 2012), and its growth can be artificially controlled for farmers to achieve maximum agricultural benefits (Sawant, 2021). Nano-fertilizers are believed to provide excellent agricultural benefits with minimal environmental pollution as compared to conventional fertilizers (Ali et al., 2014; Raja et al., 2012). Therefore, if smallholder farmers adopt these smart technologies, it is anticipated that crop production will increase followed by a boost in their income.

2. Methodology

This review article was based on an extensive literature search from the web of science (WOS), the authors' observations being strengthened with statistical data from the government professional bodies as well as interview records. During this search, we focused on a number of elements including agricultural challenges in Uganda narrowed down from sub-Saharan Africa. Other elements included the land tenure systems, fertilizer use (including both organic and inorganic), attitudes of the youth towards agriculture, the government's commitment to improving the agricultural sector, poverty, and food security in Uganda. Globally, information on the effects of inorganic fertilizer use, the different forms of organic fertilizers farmers use, and the challenges associated with them were all included. The proposed alternatives of using well-processed organic fertilizers with emphasis on high biomass plants were highlighted. The latest technologies of using nano-fertilizers were also discussed, all intended for improving soil productivity and boosting agricultural productivity as a key to attaining a biobased agricultural economy. The authors also quoted one of the publications from their findings on the use of *Azolla* for boosting productivity for terrestrial crops.

3. Agriculture and its challenges in Uganda

Uganda, just like other developing countries, is experiencing several challenges among which is food and nutritional insecurity. In the 1960s, Uganda was considered a "food basket" for East Africa, with sufficient food to sustain its population (Padam et al., 2014; Place & Otsuka, 2002). However, the trend has reversed, resulting in several cases of acute food insecurity (IPC Report, 2019). This phenomenon has turned Uganda into a "begging bowl" of international aid organizations. Land tenure systems in Uganda to a large extent have not favored the agricultural sector. Most of the land in Uganda is owned by the public with the government only acquiring a leasehold (John Ariko et al., 2017). With this ownership by the public, there has been a lot of land fragmentation from; inherited land distributed among family members, as well as property managers who purchase large chunks of land and fragment them into plots for sale (John Ariko et al., 2017). Land fragmentation has been considered beneficial in certain instances of conflict resolution, especially among families as well as crop scheduling for some farmers with large plantations (Veljanoska). However, when land is excessively fragmented it poses danger in the agricultural sector, especially where limited arable land is left and the largest portion is utilized for other non-agricultural practices like construction, and bricklaying among others (John Ariko et al., 2017). This has severely affected the smallholder farmers who largely depend on the small pieces of land which is less than five hectares for survival (Bamwesigye et al., 2020).

Ugandan soils like other sub-Saharan African soils have been severely affected by issues of land use shift. The original tropical rainforests were converted into savannahs which were later turned into; local farms, construction sites, charcoal burning places, and other non-agricultural activities (Andriesse & Giller, 2015). Whenever there is a shift in land use, ecosystem determinants in terms of structure and function become affected as the system stabilizes itself into a new form. The cumulative effect of this form of land use shift has a tremendous influence on land degradation as another driving force for climate change (Andriesse & Giller, 2015). Land degradation has been cited as the major impediment to crop production, with deforestation as the major contributing factor (ROY et al., 2016). Other factors include overgrazing which compacts the soil, poor agricultural practices more so continuous monocropping, coupled with excessive use of chemical fertilizers (ROY et al., 2016). Continuous tillage and monocropping constitute the major soil degradation processes among smallholder farmers in Uganda. These inefficient farming methods negatively impact soil by increasing surface runoff, reducing infiltration, and disturbing soil structure and biodiversity (Fatumah et al., 2020). Further still, monocropping promotes exposure to climate change coupled with pests and diseases due to a reduction in biodiversity. When a particular pest invades the monocrop plantation, the likelihood of its rapid increase is high owing to sufficient availability of the required food reserves. The outcome is the infestation of the entire plantation, a scenario that encourages the continued use of pesticides. This practice promotes chemical soil degradation thereby exacerbating the effects of climate change (Loh et al., 2022). In Uganda, over 97% of farmers rely on rain-fed agriculture (Sridharan et al., 2018). As climate change sets its toll on agricultural systems, smallholder farmers are more likely to get severely affected by climate-related droughts and floods all resulting into reduced yield, a phenomenon that threatens food security in the country (Mubiru et al., 2018).

4. Engagement in agriculture

The agricultural sector in Uganda contributes 24.8% of the country's GDP, with over 70% of the entire population engaged in this sector (World Bank, 2020). A 63% of these are smallholder farmers who are youth below 40 years (MAAIF, 2017) with farm sizes ranging between 0.8 and 1.6 hectares. A 64% of these did not complete their primary education and the majority are women while only 16% advanced through secondary education (Anderson et al., 2016). Despite the dependence of the largest population on agriculture, more so the women and youth, the government has not provided adequate support in terms of training, market, and subsidies for the genuine agricultural inputs to these smallholder farmers (Bamwesigye et al., 2020). This has prompted many youths in rural areas to leave agriculture and engage in other purportedly more profitable services mainly transport and other businesses (Table 1). Over years, there has been a declining trend in the agricultural sector engagement by the Ugandan youth, attributed to the presumably lower income from the agricultural sector compared to other sectors like service and industry (MAAIF, 2017).

Below is another extract from an interview with a bodaboda (motor bike for public transport) rider who left agriculture for transport services.

(Source: Gemma et al., 2013)

Poor harvests due to pests and diseases/ weather changes

"While I initially used to get enough income from agriculture to cater for my family needs, it is no longer possible because for example the banana/matooke species that we used to grow has been affected by banana wilt and droughts and we do not harvest much that is why I am engaging in bodaboda riding to supplement my income"

__________Youth Bodaboda rider /Farmer in Luwero district

A number of youths especially from rural settings fall in this category. There is no doubt that youth engagement in agriculture will continue to decline as soils become more unproductive (hence reduced agricultural outputs) unless affordable measures to enhance soil fertility are adopted. Further still, the need to increase awareness about the dangers of currently practiced farming methods mainly monocropping and continuous tillage is paramount. If this problem is left unresolved, the economy is likely to drop further with elevated poverty levels among the population being worsened by hunger.

Further still, many of the big local investors in Uganda have no interest in agricultural investments. They instead opt for non-export items like commercial apartments, shopping malls, and real estate development moreover with a very low multiplier effect (John Ariko et al., 2017). As authors, we assumed that this could either be due to lack of sufficient information about the sector and its dynamics or the desire to invest in items and services postulated to be more income-generating since these investors are more profit-oriented. Further still, poor quality roads from

Table 1. Below clearly highlights this decline in agricultural engagement and a rise in other sectors within a 4-year period

	2005/06			2009/10		
	Age group		Both	Age group		Both
Broad sector	**18–30**	**31–59**		**22–34**	**35–63**	
Agriculture	73.2	71.6	72.3	64.2	68.2	66.6
Industry	7.3	5.8	6.5	8.5	6.8	7.5
Services	19.5	22.5	21.3	27.3	25.0	26.0
Total	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*	*100.0*

Notes: The dynamics are based on the same cohort of youth i.e. those who were aged 18–30 in 2005/6 and four years later 2009/10 these same youths were aged 22–34 years.
(Source: Gemma et al., 2013)

large farms to major towns are another hindrance that discourages these large investors (John Ariko et al., 2017). All in all, this failure to effectively engage in the market economy has elevated profit repatriation in the country. All the above factors summed up have resulted in high importation of most agricultural produce as a way of meeting the food demands in the country thereby creating an unfavorable balance of trade. Failure to sufficiently export items that could bring foreign currency into the country has significantly contributed to high poverty rates among smallholder farmers in Uganda (John Ariko et al., 2017). Despite these challenges, the government of Uganda is committed to addressing these concerns as per the third National Development Plan (2020/2021-2024/2025). Several government programs under the ministry of agriculture have been put in place to support rural farmers with hopes of improving the agricultural sector (Mbago-Bhunu et al., 2021).

The challenges of agriculture in Uganda are quite many but the driving factors in our view were issues associated with infertile soils. By 2013, the loss of Uganda's Gross National Product (GNP) arising from land degradation practices was evaluated in the range of 4–12%, with 85% from soil erosion (Berry et al., 2003). Nutrient loss from Ugandan soils amounts to 87 kg of nutrients (NPK) per hectare per year; in ratios of 38 kg of nitrogen; 17 kg of phosphorus and 32 kg of potassium (Sunday & Ocen, 2015). Furthermore, Uganda has been cited as one of the countries with very high nutrient mining rates (Bekunda et al., 2004; Nyombi, 2013). Nutrient mining in Uganda arises from the incessant transportation of direct farm harvests from rural farms to urban centers. An example is the banana plant after harvesting where the banana fruits and other byproducts, including leaves, stems, and fibers are all transported from the harvest site to towns. These products are used for various domestic and commercial purposes for instance; banana leaves are used for cooking while the fibers and stems are processed to make ornamentals (Nyombi, 2013). Transportation of this biomass away from the harvest site creates a mineral nutrient deficiency in the soil, unlike in the past (over 30 years ago), where this biomass would be left on the farm as mulch to replenish the soil after harvest. Currently, there are few farmers involved in integrated farm practice. This leaves other farmers with no alternative except the use of inorganic fertilizers (Nyombi, 2013). Failure of the government to provide adequate support to farmers more so through subsidized rates of genuine fertilizers and pesticides has prompted the business fraternity to uncontrollably invest in this sector. (Mbowa et al., 2021) cited "Container village" (a local collection market for agricultural inputs) as the leading supplier of counterfeit agricultural inputs in Kampala. These researchers confirmed that most of the fertilizer brands on the market were substandard with false labels in relation to the actual composition inside the package. As smallholder farmers struggle to replenish their soils, they ignorantly purchase these inputs thought to be affordable in cost. The outcome after their use is damage to the soil and eventually low yields followed by economic losses.

5. Organic fertilizers and soil amendments

Organic fertilizers are highly recommended globally due to their ability to preserve nature by minimizing the negative effects on the environment. Besides improving food quantity in terms of yield and quality through added nutritional value, organic fertilizers exhibit stability and resilience to the changing climate (Raimi et al., 2017). This is an important quality that is needed in this era following the devastating effects of climate change affecting the global community. Organic fertilizers also have a beneficial effect of increasing organic matter and soil fauna at large thus improving soil quality. Furthermore, organic fertilizers tend to maintain the natural pollinators such as insects and birds which improves crop variability. This occurs through the preservation of their natural habitats leaving them undisturbed thereby maintaining a favorable environment for those pollinators (Bernstein & Wiesmann, 2019). The use of organic fertilizers has also significantly contributed to food security, especially among smallholder farmers who primarily engage in subsistence agriculture. This has ensured a sustainable supply of food for home consumption (Mupambwa & Mnkeni, 2001). Organic products have a high demand globally which has generated enormous profits for farmers mainly through exports thus improving their economic wellbeing. The increasing demand comes as a result of the population getting more concerned with their health thus making an informed consent of what they consume.

Several organic approaches to boost food productivity have been attempted with excellent benefits but also with challenges associated. Several farmers globally have adopted the use of animal manures, sludge, municipal solid waste, and agricultural waste among others (El Barnossi et al., 2020; Chew et al., 2019) . These organic soil amendments options have advantages of minimizing groundwater contamination and also assist in replenishing contaminated soils through immobilizing these metal ions, thereby enhancing mineral nutrient uptake with minimal leaching. However, to achieve this, these organic soil amendments have to be first processed through composting and/or digestion to obtain a fine product, free from pathogens that may be transferred to plants (Chew et al., 2019; Weithmann et al., 2018). Otherwise, the high level of pathogens they harbor can become detrimental to plants and may pose potential health hazards to man (El Barnossi et al., 2020). Organic fertilizers also tend to be costly to those farmers without integrated agricultural systems making their availability difficult and costly. The issues of difficulty in transport because of bulk coupled with a bad odor have also raised major concerns for farmers hence there is a need for processing to reduce bulk and eliminate the odor prior to application (Babasola et al., 2017). The use of microbial inoculation is an excellent method for bio-fertilization with potential benefits. However, certain anomalies tend to occur when these microorganisms develop mechanisms that impose negative effects on other soil organisms, a case of antibiosis (Piehl et al., 2018a; Zhu et al., 2019) Vermicomposting is also another fertilizer alternative that has been adopted by some farmers. This technology mainly utilizes different species of worms like earthworms coupled with microorganisms to mechanically digest the organic matter (raw material) thereby enhancing mineralization. However, there is a need to supply the organic waste as the raw material to be digested, therefore an interplay of organic waste and the vermicomposting organisms is needed to achieve the mineralization (Mupambwa & Mnkeni, 2001).

There is a big concern about some organic manures mainly biowaste being carriers of microplastics into the environment (Weithmann et al., 2018). Microplastics are plastic fragments less than 5 mm in size. These particles have been observed as contaminants in organic manures including sludge, municipal solid organic waste and agricultural plastic film (Zhu et al., 2019). Microplastics found in organic waste are usually from household waste. Processing would reduce these contaminants through sorting and sieving but it is quite difficult to eliminate all since some of it is already fragmented by the time of processing (Weithmann et al., 2018). According to Zhu et al., 2019, microplastics have had detrimental effects on soil macro and other organisms. In research by (Veljanoska,), which compared levels in microplastics in different manures (Table 2), biowaste was observed to harbor a number of microplastics at all stages of processing as compared to energy crops and agricultural waste. This implies that in order to minimize further effects of environmental pollution, more clean and pure materials need to be collected and processed before application as organic fertilizers.

Following this, our review paper singled out an aquatic plant called *Azolla* which was discovered to offer excellent agricultural benefits with minimal environmental pollution. *Azolla* belongs to the pteridophytes (spore dispersing plants), family *Salviniaceae*, order *Salviniales* and genus *Azollae* (Kumar et al., 2021). *Azolla* thrives in a symbiotic association with the nitrogen-fixing

Table 2. Below highlights the amount of microplastics that were found in biowaste, energy crops, and agricultural waste after several stages of processing. Overview of plants & compartments. The total number of particles is shown as particles >1 mm per dry weight

	Plant A		Plant B				Plant C	Plant D	Plant E to N
Type	Biowaste composting		Biowaste digestion				Energy crop digestion	Biowaste digestion	Agricultural digestion
Sampled	CP 8 mm	CP 15 mm	Digest A	Digest B	Digest C	Digest D	End of process	Commercial binding	End of process
Particles/kg	20	24	70	122	146	14	0	895	0 to 11

Source (Veljanoska).

cyanobacterium *Anabaena azollae. Azolla* is an agronomically important plant because of its bio-fertilization potential arising from the symbiotic association. It has the ability to rapidly grow and double its biomass in just 2–5 days (Raja et al., 2012). *Azolla* can be artificially cultivated in a pond where all the necessary growth requirements are met, including a shady environment; appropriate temperature and pH; as well as some nutrients including phosphorus, potassium, molybdenum, calcium, and magnesium among others (Moore, 2016). *Azolla* can also be applied to terrestrial plants as a green manure with excellent results of boosting terrestrial crop production (Ssenku et al., 2022). The nitrogen-fixing cyanobacteria associated with *Azolla* absorb atmospheric nitrogen reducing it to ammonia. When *Azolla* decomposes, it releases nutrients like nitrogen, phosphorus, and potassium into the soil for uptake by the plants in the field (Arora & Singh, 2003). The released nutrients in turn enhance both the growth and yield of the crops dually planted with *Azolla* (Raja et al., 2012). The *Azolla-Anabaena* association causes substantial changes in the general properties of soil, including the physical, chemical, and biological properties. This generates a boost in soil fertility (Mandal et al., 2016) by increasing total nitrogen, organic carbon, and available phosphorus (Raja et al., 2012). The *Azolla-Anabaena* symbiont bio-fertilizer system has been utilized in South-East Asian countries including India, China, Philippines and Indonesia where it exhibited an elevation in the biomass when applied as a dual or basal crop with paddy rice (Bhuvaneshwari & Singh, 2015; Bocchi & Malgioglio, 2010). In paddy fields, under normal semi-tropical climate, *Azolla* is able to produce an average of 300 tons of green manure per hectare per year. This value is comparable to 800 kg of nitrogen, an equivalent of 1800 kg urea (ROY et al., 2016). The result is a boost in crop production (Raja et al., 2012). When *Azolla* is incubated in waterlogged soils, mineralization is accelerated and about 60–80% of nitrogen is released into the soil in a period of 2 weeks (Raja et al., 2012). *Anabaena azollae* reduces atmospheric nitrogen to ammonia which is taken up by *Azolla* that supplies assimilated products of photosynthesis to *Anabaena azollae* (Van Hove & Lejeune, 2002). The overall effect is enhanced yield and nutrient quality of the crops (Moore, 2016).

6. Use of nano-fertilizers

Another alternative approach is the transformation of these organic fertilizers into nano fertilizers during processing to reduce bulk and improve nutrient use efficiency. Transformation of organic fertilizers into a more usable form by plants is key in promoting nutrient use efficiency a characteristic that sustains environmental health. Nanotechnology is basically a scientific approach that involves designing, developing as well as applying materials and devices at molecular level using a nanometer scale (1–100 nm size) (Ali et al., 2014). This science may employ nano-scale devices which serve as carriers of materials such as nutrients in the case of nano-fertilizers (Raja et al., 2012). According to (Singh et al., 2017), nano-fertilizers can be a synthesized or modified form of traditional fertilizers, fertilizer bulk materials, or extracts from different vegetative or reproductive parts of the plant. These are processed through different chemical, physical, mechanical, or biological methods with the help of nanotechnology to improve soil fertility, productivity, and quality of agricultural produce. A number of nano-fertilizers have been developed using different forms of nano-particles as fertilizer delivery systems. These include nano-particles of gold, titanium, silver, and others. Some of these nano-particles are non-biodegradable, which poses future hazardous situations to the environment as they accumulate (Jampílek & KráL'Ová, 2015). Similarly, nano-biofertilizers involving the use of particular microbial inoculants, for instance, rhizobium bacteria and actinomycetes incorporated into a nanomaterial such as modified clay or exfoliated vermiculite were studied and generated positive outcomes (Subhashini 2020).

7. Advantages of nano-fertilizers over traditional fertilizers

The utilization of nano fertilizers enhances soil health by improving microbial diversity, thereby boosting soil fertility and hence improving nutritional quality and yields (Mupambwa & Mnkeni, 2001). Nano-fertilizers are less bulky and this prevents unnecessary leakage to non-target areas, a characteristic that makes these fertilizers environmentally friendly thus minimizing the effects of climate change (Singh et al., 2017; Raliya et al., 2017; Wijesinghe & Weerasinghe, 2015).

Furthermore, nano-fertilizers tend to increase resistance to pests and diseases, minimize lodging of plants and also enhance deeper rooting (Qureshi et al., 2018).

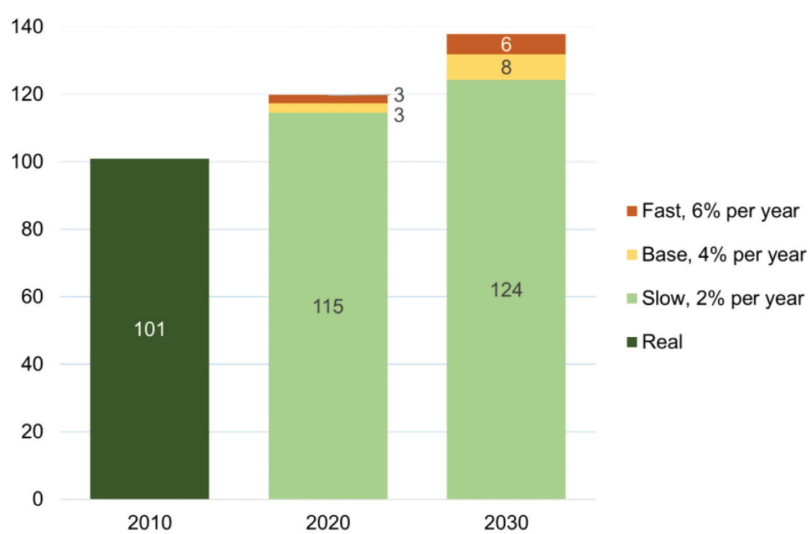
8. Inorganic fertilizers

Inorganic fertilizers have been used globally for quite a long period of time. In 2015, the global nutrient capacity for NPK was estimated at 285 million tonnes, out of which 245 million tonnes were supplied. This amount is anticipated to have reached 317 million tonnes in 2020 in response to the global campaign for fertilizer use (FAO, 2017). These amounts highlight an increasing trend of fertilizer use anticipated over years (figure 1).

Projections to 2030 for global nitrogen fertilizer consumption (Tg N) under three different economic growth scenarios (Integer and LMC, 2013)
Source: (Heffer & Prud'homme, 2016)

Considering the increasing global food demands, it is automatic that fertilizer use will definitely increase more so the inorganic fertilizers as per the projections above. There is no doubt that the global use of inorganic fertilizers has generated a significant increase in food production. However, this increase has been accompanied by negative consequences of environmental contamination arising from the consistent use of agrochemicals (Liu et al., 2014). Excessive fertilizer application has severely affected water quality, coupled with nutrient use efficiency of crops (Drechsel et al., 2015). Consistent and unskillful use of inorganic fertilizers increases the chemical portions leaking into non-target parts of the environment through water runoff. This causes reduced agricultural outputs, long-term soil degradation, and environmental health hazards (Raimi et al., 2017). In many cases, chemical fertilizer-based agriculture is coupled with pesticide application. When agrochemicals are used, they penetrate the plant system such that any consuming organism directly takes up these chemicals. With consistent uptake of these chemicals, bioaccumulation takes effect in the tissues of the consumer organisms later on spreading throughout the food chain. The end results are the rising chronic health hazards in humans (Sharma & Singhvi, 2017). Statistics show that less than 50% of the applied nitrogen, less than 10% of the phosphates, and less than 40% of the potassium from applied NPK fertilizers is retrieved by the plant and utilized (Baligar & Fageria, 2015). The bulky nature of these fertilizers results in 18–20% leakage into water masses causing algal blooms that reduce water quality and may potentially harm aquatic organisms from the production of toxins (Raimi et al., 2017; Reddy et al., 2017). Furthermore, poor fertilizer management causes volatilization of ammonium fertilizers which accumulate particulate matter ($PM_{2.5}$) into the atmosphere. These particles tend to cause respiratory damage once inhaled (Kathryn Clark, 2014). In cases of insufficient oxygen in the soil, anaerobic microorganisms utilize nitrates through denitrification. This process together with nitrous acid emissions adds nitrogen into the

Figure 1. The graph highlighting projections of fertilizer use by 2030.



atmosphere, thereby escalating global warming effects (Zhang et al., 2016). The fertilizer industry is also a potential source of heavy metals such as cadmium and chromium in addition to radionuclides (Savci, 2022). Therefore, long-term effects of these chemical fertilizers cause soil degradation emerging from changes in soil properties such as pH, salinity, and water-holding capacity. These changes in turn affect soil faunal and floral diversity (Aktar et al., 2009).

9. Potential for a bio-economy in the agricultural sector

Bio-based economy refers to knowledge-based production and the use of biological resources to provide products, processes, and services in all economic sectors within the frame of a sustainable economic system. The agricultural sector bio-based economy means an economic system that relies on renewable organic resources from plants, animals, and microorganisms (McCormick & Kautto, 2015). Several kinds of research are underway to ensure that this is put in effect if we are to achieve some of the sustainable development goals (SDGs) as planned. The agricultural bio-based economy can address SDG No. 2 of improving food and nutritional security by increasing the production of healthy food. A bio-based economy has the potential to boost a country's economic sector through increasing employment in both formal and informal sectors. The utilization of *Azolla* and other high biomass plants as organic fertilizers will enable smallholder farmers to compete in the global market for the burgeoning demand for organic products. This will in turn improve the agricultural sector by ensuring sustainable food production and reducing the effects of soil degradation.

10. Conclusion and recommendation

The gradually declining soil fertility is the greatest constraint to agricultural production in Uganda. This has been steered by poor and inefficient agricultural practices majorly by smallholder farmers constituting over 70% of the entire agricultural sector. Monocropping and continuous tillage are regarded as the major inefficient agricultural practices which promote effects of climate change coupled with pest and disease infestation. Reliance on rain-fed agriculture has also affected production owing to the realities of climate change. There is an urgent need to adopt measures that restore fertility to the damaged soils as a way of improving food production and hence food security. Utilization of organic manures is highly recommended. However, there is a need to clean and process them in order to reduce their bulk thus promoting nutrient use efficiency which in turn enhances yields.

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