Taylor & Francis
Taylor & Francis Group

Cogent Food & Agriculture

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oafa20

Land degradation unmasked as the key constraint in sunflower (*Helianthus annus*) production: Role of GIS in revitalizing this vital sector

Emmanuely Z. Nungula, Jayne Mugwe, Jamal Nasar, Boniface H. J. Massawe, Anne N. Karuma, Sagar Maitra, Mahmoud F. Seleiman, Turgay Dindaroglu, Naeem Khan & Harun I. Gitari

To cite this article: Emmanuely Z. Nungula, Jayne Mugwe, Jamal Nasar, Boniface H. J. Massawe, Anne N. Karuma, Sagar Maitra, Mahmoud F. Seleiman, Turgay Dindaroglu, Naeem Khan & Harun I. Gitari (2023) Land degradation unmasked as the key constraint in sunflower (*Helianthus annus*) production: Role of GIS in revitalizing this vital sector, Cogent Food & Agriculture, 9:2, 2267863, DOI: 10.1080/23311932.2023.2267863

To link to this article: https://doi.org/10.1080/23311932.2023.2267863

Published online: 13 Oct 2023.

cogent food & agriculture

SOIL & CROP SCIENCES | REVIEW ARTICLE

Land degradation unmasked as the key constraint in sunflower (*Helianthus annus*) production: Role of GIS in revitalizing this vital sector

Emmanuely Z. Nungula[1,2], Jayne Mugwe[1], Jamal Nasar[3], Boniface H. J. Massawe[4], Anne N. Karuma[5], Sagar Maitra[6], Mahmoud F. Seleiman[7], Turgay Dindaroglu[8], Naeem Khan[9] and Harun I. Gitari[1*]

Received: 02 May 2023
Accepted: 03 October 2023

*Corresponding author: Harun I. Gitari, Department of Agricultural Science and Technology, School of Agriculture and Environmental Sciences, Kenyatta University, P.O. Box 43844-00100, Nairobi, Kenya
E-mail: harun.gitari@ku.ac.ke

Reviewing editor:
María Luisa Escudero Gilete, Nutrition and Bromatology, Universidad de Sevilla, Spain

Additional information is available at the end of the article

Abstract: In Tanzania, land degradation has been ranked as the top environmental problem for more than 62 years after independence. Land degradation is a catalyst for poverty increment in rural people's livelihoods by contributing up to a 48% increase in poverty of this population. This paper highlights land degradation as a key constraint to sunflower production while looking at the potential role of Geographic Information System (GIS) in revitalizing the sector. The review focuses on Tanzania, where sunflower production is done mainly by smallholder farmers as a cash crop and a source of vegetable oil. Sunflower production is threatened by land degradation in the form of nutrient mining that decreases the fertility of the soil, hence lowering its potential. Such degradation is mainly contributed to by continuous crop cultivation without replenishment of the soil fertility, crop removal

ABOUT THE AUTHORS

Emmanuely Nungula is an MSc candidate with a research interest in GIS and soil fertility management.

Jayne Mugwe and Harun Gitari are dedicated lecturers at Kenyatta University with expertise in Integrated Soil Fertility Management.

Boniface Massawe and Anne Karuma are GIS and pedologist specialists based at Sokoine University of Agriculture, Tanzania, and the University of Nairobi, Kenya, respectively.

Mahmoud Seleiman and Turgay Dindaroglu are agronomists from King Saud University, Saudi Arabia.

Sagar Maitra and Naeem Khan are Systems agronomists based at the Centurion University of Technology and Management, India, and the University of Florida, USA, respectively.

PUBLIC INTEREST STATEMENT

Agriculture is considered the backbone of the Tanzanian economy with the highest growing rural population. More than 80% of its citizens depend on agriculture as the main production activities and natural resources as a crucial way for their survival, and this large population is located in rural areas. In Tanzania, the demand for edible oil continues to increase annually for both domestic consumption and industrial uses. Among the edible oil crops, sunflower is the main source of edible oil, thus playing a central role in the supply of edible oil. Thus, improving productivity in edible oil production could reduce the large edible oil deficit that resulted from the increasing demand, and thus reduce its importation. Enhancing agricultural productivity could lead to an increase in domestically produced edible oil. Such an intervention would help in meeting both factory and small-scale processors' demand for raw materials for edible oil production. This will be an implication of alleviating the poverty of the people.

after harvesting, and low fertilizer input. This calls for the adoption of modern systems of utilizing GIS, in assessing the suitability potential of the land giving the best decision in managing and adopting the right soil management practices for increasing and sustaining the productivity of the farmland concerning sunflower production in Tanzania.

Subjects: Agriculture & Environmental Sciences; Soil Sciences; Nutrition

Keywords: Tanzania; declining soil fertility; integrated soil fertility management; land suitability assessment; GIS-based land evaluation

1. Introduction

World food production is at a crossroads as the population grows. There is a need therefore to urgently and sustainably increase food production to eradicate hunger for the 800 million people who go hungry every day (FAO- Food and Agriculture Organization, 2017). In most sub-Saharan countries such as Tanzania, the agricultural sector is considered the backbone of the nations' economies with more than 80% of the population relying on agriculture as the main economic activity and a crucial way for their survival. Specifically, in Tanzania, the agriculture sector accounts for approximately 14% of the national income earnings from exportation 30% of the Gross Domestic Product (GDP) (BoT–Bank of Tanzania, 2018). This signifies the importance of the sector and thus the need for current and focused strategies emphasizing the utilization of the agricultural sector to realize the Sustainable Development Goals (SDG) on poverty reduction and zero hunger and thus achieve sustainable livelihoods for the Tanzanians (Msanya et al., 2018). To rally the world behind this important agenda, sustainable development goal number two calls to end hunger, achieve food security, improve nutrition, and promote sustainable agriculture. Additionally, other sustainable development goals cannot be accomplished without a productive and sustainable agricultural sector that considers all important crops.

Sunflower is one of the most important crops in the world, providing multiple products such as edible oil, livestock feeds, fuel, and fertilizer as crop residue and health benefits (Kunduraci et al., 2010). The sunflower production sector offers a lot of potential opportunities to improve livelihood by producing valuable and highly needed edible oils with big domestic (internal) and external markets (Ugulumu & Inanga, 2014). It is approximated that there are about 4 million smallholder farmers cultivating sunflowers in Tanzania (Cleaver et al., 2010). The demand for edible oil continues to increase annually for both domestic consumption and industrial uses (Ceballos et al., 2017; FAO, 2017). Currently, data show that Tanzania's domestic production from both factory and small-scale processors of edible oils does not meet the national demand by producing only 40% of the requirement, with the remainder being from importation (Zhihua, 2017). Despite Tanzania having plenty of land, sunflower production continues to decline due to poor land management like nutrient mining which causes land degradation and also low knowledge on land suitability due to a lack of soil data.

Land use is one of the anthropogenic factors that affect soil reactions and other physicochemical properties (Behera & Shukla, 2015; Ochieng' et al., 2023). The ever-increasing demand for more agricultural land and the degradation of existing ones suggest the need to address the problem through the development of sustainable technologies and the creation of favorable enabling environmental sustainability (Bruinsma, 2009). In Tanzania, sunflower shows high suitability in some regions, which contribute 80% of its production including Singida (25%), Rukwa (16%), Iringa (14%), Dodoma (9%), Manyara (7%), Tabora (6%), and Mbeya (4%), and the remaining 20% is from other region such as Morogoro and Coastal region (FAOSTAT-Food and Agriculture Organization of the United Nations, 2022). However, the current oil crop production in Tanzania does not meet the country's demand. This is mainly due to poor management of the land resulting in decreased land productivity and thus contributing to the demand for more than 500,000 tons of oil that is imported from Russia and Ukraine. Thus, the review was done to address land degradation as the hidden challenge that declines sunflower production. The review outlines the characteristics of the sunflower, and its production trend, first with a global focus, then, on Africa, and finally zeroing down to Tanzania. Here, nutrient mining is identified as the major form of land degradation that causes soil fertility loss, with a subsequent decline in sunflower production, finally suggesting the use of GIS as a modern approach in managing land use to reduce land degradation rate.

Geographic Information System (GIS) has been adopted by different sectors in national development to support decisions for development in agriculture (Otieno et al., 2023). Ultimately, the review highlights the application of GIS in assessing soil suitability as the best way in managing the soil potential that can boost crop production while contributing to soil fertility. The use of GIS in agriculture is crucial as it plays a vital role in enhancing land management and crop production. To farmers, it helps to increase production, reducing production costs and efficiently managing the farms (Otieno et al., 2023; Saglam & Dengiz, 2014). The output maps associated with it help in the monitoring and management of irrigation, soil, and management of agricultural resources (Mueller, 2019). Ashraf (2010) assessed the suitability of growing wheat using multi-criteria evaluation and GIS, he provided information that helped farmers select and know the suitable area for wheat. Another study by Stickler et al. (2007) produced maps that show the production capabilities of sugar cane, oil palm, and soybean by involving cropland quality and ecological requirements to develop a spatial distribution map, which shows the suitable regions where the crops could be grown. Another study in Nigeria by Abah and Mareme (2015) also uses GIS in determining crop suitability and mapping suitability areas for rice, cassava, and yam.

Land degradation is a catalyst for poverty in rural livelihoods in Tanzania by accounting for losses of $1.8 million due to poor practices that led to land degradation on croplands and reduced production potential (Kirui, 2016). Consequently, the government spent about 4.3 US dollars to rehabilitate degraded lands (Kirui, 2016). The use of GIS in land evaluation and management is a modern and innovative approach to achieving high productivity potential while managing the land (Otieno et al., 2023). This review will inform and help the government in making policies and strategies by integrating GIS as a management tool that will facilitate access to sustainable land management information to manage the land and reduce the land degradation index in Tanzania. In addition, using GIS, which will ensure the accessibility of the information anywhere, different stakeholders and institutions including those providing agriculture input services such as fertilizers and extension services use the information in recommending and advising farmers on areas best suited for production and how to overcome those limitations and guiding strategic planning for sustainable agriculture development.

2. Methodology

This review article was based on a comprehensive literature review which involved searching for relevant articles to gather information relevant to the study including reputable sources like academic journals, academic databases such as pub media Google Scholar science, direct government publications, and recognized research institutions with statistical data from the government institutions like Ministry of Agriculture (MoA), Bank of Tanzania (BoT), and other institutions including FAO. During this search, we focused on several elements including agricultural challenges in Tanzania narrowed to sunflower crops. Other elements included land use and management systems, fertilizer use (including both organic and inorganic), poverty, and food security in Tanzania. Globally and African content information on sunflower production, Tanzania's sunflower production trend, land degradation in the form of fertility decline constraint for sunflower production, and proposed different alternatives that can be utilized in restoring the fertility potential and increase production of sunflower crop. The modern and innovative technologies of using GIS in Identifying the suitable location for the specific crop to achieve sustainable land management were also discussed, all intended for improving soil productivity and boosting sunflower productivity as a key to attaining a green agricultural economy. The study was also faced with some limitations including difficulties in accessing the soil properties-based data for

Tanzania and the current sunflower production trend from 2021 to 2023 by country and by region. The data on land degradation extent in Tanzania is still a problem they still use generalized data, not spatiotemporal data. This hinders the scope of the review.

3. Characteristics of sunflower

Sunflower (*Helianthus annus*) is an annual crop with a rough hairy stem, a height of between 1 and 5 m, and coarsely toothed rough leaves (7–30 cm in length), which are arranged in spirals (Agy et al., 2012). The plant has attractive head flowers with an average width of 7.5–15 cm, and very attractive chrome petals that face the sun's direction during the 12 hours of light time (Ali & Ullah, 2012). The characteristic of sunflowers to face the sun's direction helps in enhancing rapid growth and hence hastens maturity (Andrew et al., 2013). Sunflower produces oil after harvesting and refining. The plant ought to be planted at a spacing of 60 cm between rows with an inter-plant spacing of about 20 cm with the seeds being sown at a depth of between 3 and 4 cm.

Sunflower is described as a short-day plant with direct-acting to daylight length. It survives in different climate conditions including arid areas (though under irrigation) to semi-arid or temperate conditions. Nonetheless, the crop does not withstand frost conditions, and therefore it thrives well at mean temperatures ranging between 18 and 25°C (Andrew et al., 2013; Chappa et al., 2022). Sunflower becomes mature and ready for harvesting within 70 days in areas with a short season and 200 days in higher altitude areas. In the areas where the crop is irrigated, particularly in the subtropics, the growing period takes about 130 days. Early planting during the season is essential to attain maximum yield. Late planting of the seed shortens the vegetative stage making the plant mature early, thus resulting in a decrease in head size and seed weight (Fullen & Catt, 2004).

Sunflower grows and performs well in well-drained soil with a high ability to hold water and a nearly neutral soil pH ranging from 6 to 7.5 (Andrew et al., 2013). According to Saglam and Dengiz (2014), loamy, sandy loam, loam sand, sand clay loam, silty loamy, and silty clay loamy soils support sunflower production by allowing root movement, aeration, water infiltration, and better drainage. Based on climate and length of the growing season, sunflower water requirement varies from 600 to 1000 mm per year. The water use for the crop is dependent on the growth stage, with 20% of water being utilized during the vegetative period, 55% in the flowering stage, and 25% in the yield formation and ripening periods. For the smooth continuation and completion of its reproduction cycle, sunflower, just like any other plant, needs all 17 essential nutrients. The key essential nutrients include carbon, oxygen, and hydrogen, which are used in the largest amounts in the formation of the plant's basic structure (Fullen & Catt, 2004). The remaining 14 essential nutrients are usually absorbed by the plants' roots in ionic forms from the soil solution and can be supplied through the soil or plant leaves as fertilizers once their deficiency is detected. Sunflower requires a supply of large amounts of nitrogen (N) of approximately 75 kg N ha^{-1}, phosphorus (P) (40 to 60 kg P_2O_5 ha^{-1}), and potassium (K) (40 to 60 kg K_2O ha^{-1}) (Njira & Nabwami, 2015). In addition, the plant needs micronutrients such as calcium (Ca), magnesium (Mg), and sulfur (S) in small quantities for growth (Alberio et al., 2005).

Deficiency in any of the essential nutrients results in diminished plant development (Brady & Weil, 2008). Therefore, plant nutrition is a very important aspect of crop production due to the functional role played by various nutrient elements in the enhancement of biochemical processes taking place within the plants. Such processes include photosynthesis, reproduction, starch formation, enzyme activity, root and shoot growth, and protein synthesis, which together impact greatly the overall production in terms of quality and quantity (Njira & Nabwami, 2015).

4. Sunflower production trend

4.1 Global and continental sunflower production

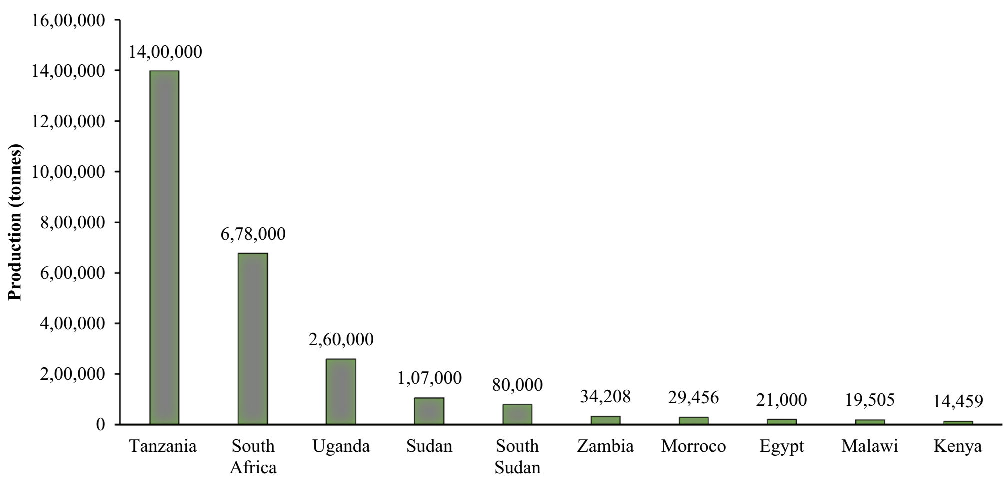
Sunflower production accounts for a big contribution to the edible oils in the world with the global crop's annual production being estimated to be 56 million tons (mt) (Atlas Big, 2022). According to

Table 1. Sunflower seed production in the 15 top-producing countries

No	Country	Production (tons)	Production per person (kg)	Production area (hectare)	Yield (kg ha-1)
1	Russian	15,379,287	104.71	8,414,731	1,827.70
2	Ukraine	15,254,120	360.93	5,958,900	2,559.90
3	Argentina	3,825,750	85.98	1,875,938	2,039.40
4	Romania	3,569,150	182.81	1,282,700	2,782.50
5	China	2,420,000	1.74	850,000	2,847.10
6	Turkey	2,100,000	25.99	751,693	2,793.70
7	Bulgaria	1,937,210	274.78	815,560	2,375.30
8	Hungary	1,706,850	174.69	564,110	3,025.70
9	France	1,298,140	19.29	603,920	2,149.50
10	Tanzania	1,040,000	19.19	1,000,000	1,040
12	Kazakhstan	838,710	45.91	815,288	1,028.70
13	Moldova	811,442	228.52	357,082	2,272.40
14	Spain	782,290	16.77	701,770	1,114.70
15	Serbia	729,079	104.13	219,404	332

Data source: FAOSTAT (2022).

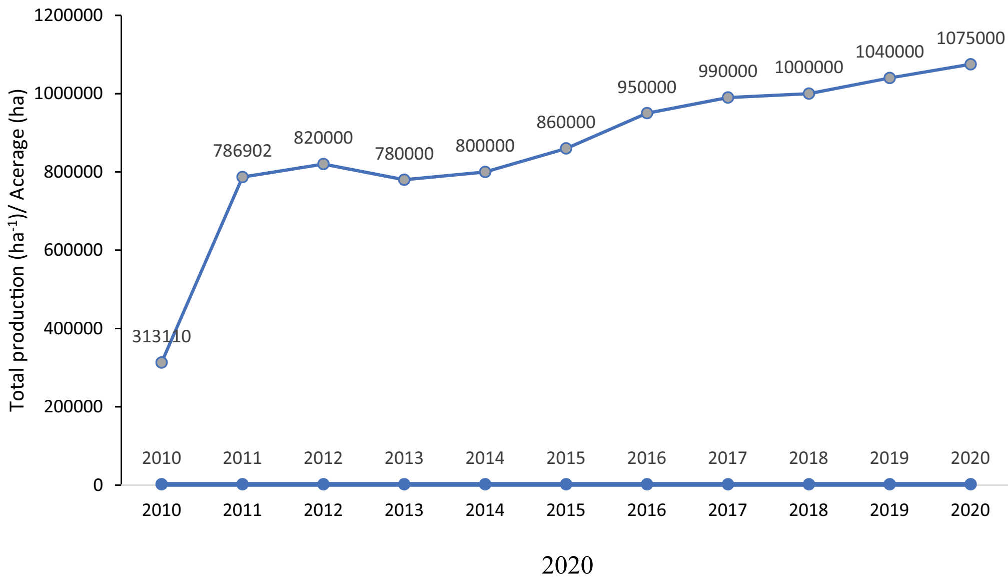
Figure 1. Sunflower seed production, top 10 producers in Africa. Source: FAOSTAT (2022).



FAOSTAT (2022), the sunflower production trend varies with the region where the European region produces 36.7 mt (73% of the global share), Asia 6.1 mt (12%), Africa 2.7 (4.8%), and oceanic region is the last producing 11,000 t (0.0002%). Russia is the largest sunflower producer (15.3 mt year^{-1}), whereas Ukraine takes the second position with an output of 15.2 mt year^{-1} (Table 1). These two nations account for more than 54% of the global sunflower production. Tanzania is at position 10 with a sunflower production of 1 mt annually. The country has dedicated an area of one million hectares, which gives an average yield of 1,040 kg ha^{-1}.

In Africa, whereby the sunflower production is 2.4 mt (equivalent to 4.8% of the world's production), Tanzania ranks first in the crop's production contributing 38.8% of the continent's production (Figure 1). This is followed by South Africa, Uganda, Sudan, South Sudan, Zambia, Morocco, Egypt, Malawi, and Kenya with an annual output of 678 000, 260 000, 107 000, 80 000, 34 208, 29 456, 21 000, 19 505, and 14 459 tons, respectively. The least sunflower-producing nation in Africa is Botswana with an annual record of 58 tones (STASTICA, 2022).

Figure 2. Status of sunflower production in Tanzania from 2010 to 2020.



4.2 Sunflower production status in Tanzania

Agricultural production continues to dominate Tanzania's economy every day thereby contributing to more than 30% of the national GDP. In this circumstance, the enhancement of agricultural productivity is the way forward for the national development strategy to achieve the goals of poverty suppression, reducing hunger and improving farmers' livelihood in the country (Michael et al., 2014). The sunflower industry in Tanzania has shown some improvement despite a lot of challenges in this sector (Leyaro & Morrissey, 2013; Ugulumu & Inanga, 2014). According to FAOSTAT (2022), African countries contribute only 4.8% of the world's sunflower oil production which is equal to 5,022,9567 tons. Tanzania is the second producer of sunflower oil contributing to 43.5% of African sunflower oil production by producing 1,075,000 tons after South Africa, which is the first among African countries. For the last decade, the country's sunflower production has been increasing annually from less than 400,000 tons in 2010 to over a million tons in 2020 (Figure 2). The increase in production is a result of an increase in the area rather than production per unit area. Productivity has remained low at 1,075,000 tons.

The production trend in Tanzania shows that Singida is the leading region by producing 25% of the Tanzania sunflower, which is 350,000 t followed by Rukwa (224000 t), Iringa (196000 t), Dodoma (126000 t), Manyara (98000 t), Tabora (84000 t), Mbeya (56000 t), and 280,000 t from the other 29 remaining regions (Figure 3) (FAOSTAT, 2022). Despite the truth that Tanzania is a major sunflower-producing country in Africa, the crop's production is still practiced mainly by smallholder farmers who are faced with a lot of challenges including limited access to quality agricultural inputs, and unfavorable financial services. Other challenges are poor infrastructure, and undefined land ownership structures leading to not only low yields but also poor-quality production (Zhihua, 2017). All of these challenges trigger the low production potential of Sunflower as a major oil crop in Tanzania leading to the increase in oil demand every year due to the population growth

5. Soil Fertility constraint to sunflower production in Tanzania

Soil productivity decline and increased food insecurity are major challenges in Tanzania, especially for smallholder farmers (Kiriba et al., 2019; Mohammadi & Sohrabi, 2012). Other soil factor constraints include soil acidity, rainfall variability, droughts, and limited resources (Gudu et al., 2009). Soil fertility decline is the scenario whereby the production ability of the soil is reduced due to the poor nutrient status of the soil. The decline in soil fertility status is the biggest problem in dryland areas of sub-Saharan Africa whereby it affects the production of crops including oilseed

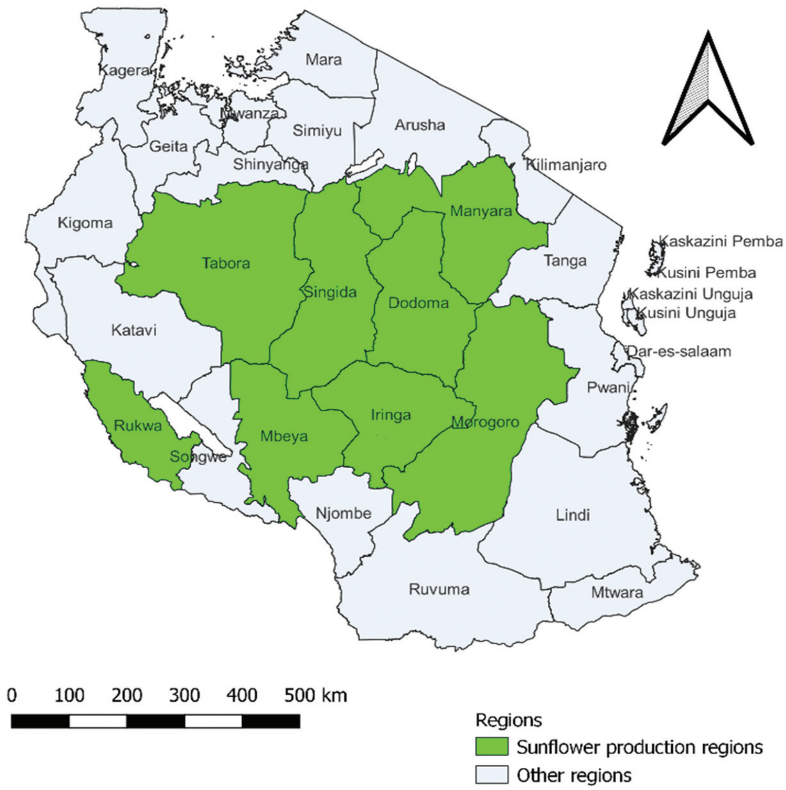


Figure 3. Map showing sunflower growing regions in Tanzania. Source: Majule (2017).

crops like the sunflower (Ochieng' et al., 2021). Agricultural production in Tanzania continues to decline due to the long-term effect of land degradation compelled by unsuitable land use due to poverty (Barbier et al., 2016). However, despite land degradation being the main cause of production decline, there are other challenges, which include poor soil fertility, lack of quality seeds, unsustainable agricultural practices, and poor technology (Msanya et al., 2016). Fertility decline continues to be a big challenge in crop production and it is mainly caused by poor cropping practices and long-term cultivation without any nutrient replenishment which alters the biological, chemical, and physical properties of the soil (Mugo et al., 2021; Shao et al., 2023).

Most of the crops grown in dryland areas are produced under the low amount of nutrients like nitrogen and phosphorus leading to low yields (Chappa et al., 2022; Raza et al., 2022; Seleiman et al., 2021). Although there is constant upgrading of genetically improved varieties, currently the sunflower-producing countries have continued to experience low yields of between 1.1 and 2.4 t ha^{-1}. Sunflower is one of the crops with a high ability to withstand drought stress because of its deep and far-reaching taproot system which can extend deeper than the normal rooting depth of the common annual crops to extract nutrients and water (Andrew et al., 2013). Such a characteristic is the main reason that makes sunflower be cultivated under arid and semiarid climatic conditions (García-Vila et al., 2012). In Tanzania, the sunflower is cultivated in semi-arid areas including Singida, Dodoma, Manyara, and Tabora. Consequently, the Ministry of Agriculture declared the sunflower to be a strategic crop in these semi-arid areas. Nonetheless, its production in such areas is faced with a lot of challenges such as soil fertility decline.

Dodoma, Singida, and Manyara regions are dominated by shallow soils originating from granite rocks and are referred to as Lithosol. This kind of soil is usually poor in nutrient status and has a low amount of organic matter content, due to the granitic parent materials and low vegetation cover (Msanya et al., 2018). Most of the smallholder farmers in Dodoma, Singida, and Manyara do not apply inorganic fertilizers or any other technology to replenish the nutrients (Chappa et al., 2022), for that case, the nutrient status of the soil where sunflower is grown is generally poor. Other causes of soil fertility decline include land degradation due to soil erosion, crop residue removal for animal feed, poor tillage, and management practices, and nutrient mining caused by crop removal after harvesting (Kimbi et al., 2011; Msanya et al., 2018; Nyawade et al., 2019). Therefore, the poor nutrient status in dryland regions of Tanzania, which is mainly caused by human influence has direct effects on agricultural production.

5.1 Land degradation as a cause of soil fertility constraints in Tanzania

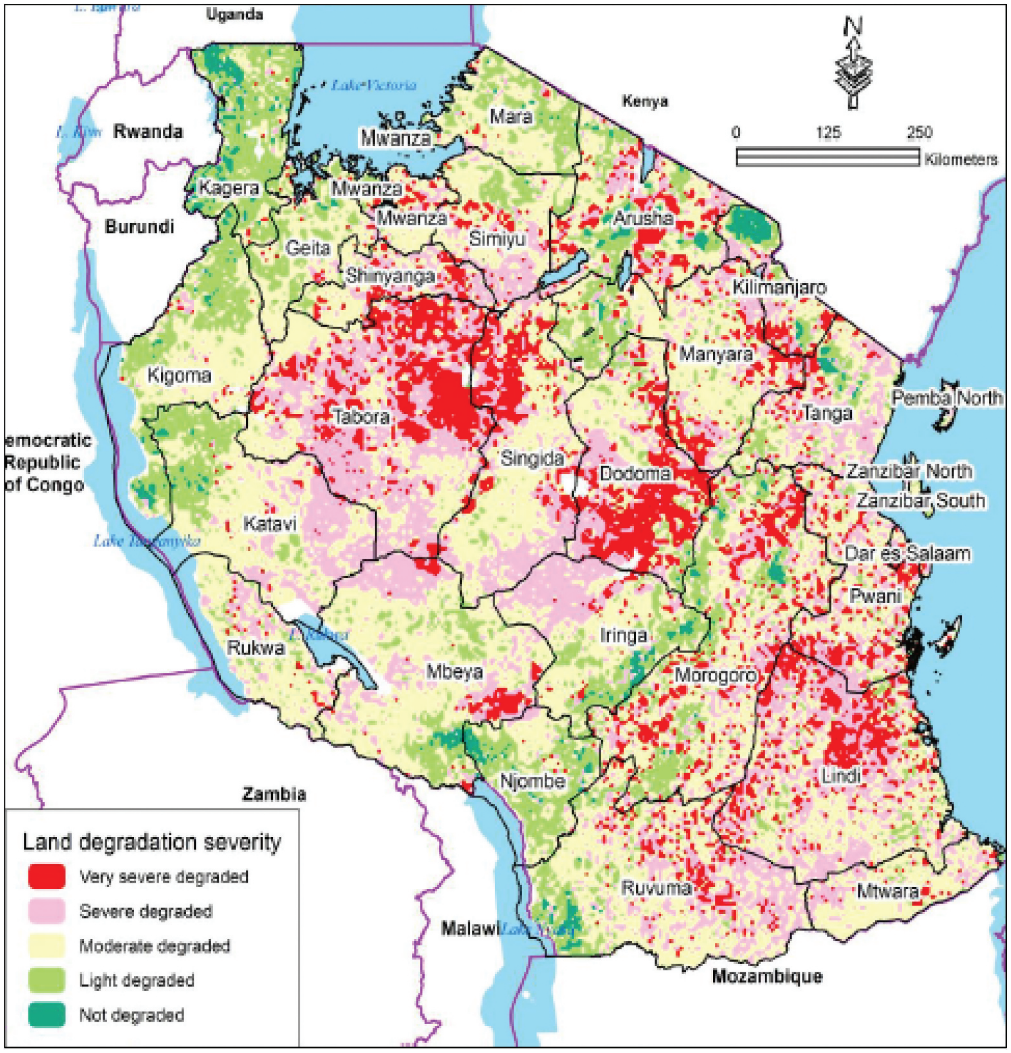
Land degradation is the change in the physicochemical characteristics of the soil that declines the soil production potential (Goher et al., 2023; Hossain, 2006). Land degradation can physically include soil structure degradation, soil compaction, and soil crusting or can be chemical degradation including soil acidity, soil salinity, and waterlogging finally reduces soil fertility (Heckman et al., 2003; Rascio et al., 2008). Soil manipulation by tillage can often result in structure deterioration through regular practice, also soil compaction reduces the number of large pores that are responsible in facilitating water infiltration and allow roots to penetrate and grow easily in the soil, compaction also led to adverse effect through water-logging that occurs and cause nitrogen loss through denitrification process, which finally lowers the nitrogen content in the soil (Hossain, 2006; Sims et al., 1998).

Land degradation is the leading environmental problem often mentioned in much literature in Tanzania (Mongi, 2012). For instance, surveys conducted in the semi-arid region of mid-western Tanzania indicated that low soil fertility was the most important constraint to improved production among crop cultivators (Mongi, 2012). Kirua (2016) and Oldeman et al. (1991) showed that land degradation is the major cause of soil fertility decline in sub-Saharan Africa with overgrazing contributing 49%, with over-exploitation and deforestation contributing 27%, whereas poor agricultural practices account for 24%. The fertility decline in Tanzania is attributed to poor grazing practices that have contributed to the reduction in the vegetation cover, destruction of soil microorganisms, soil crusting, and compaction which are highly derived by poverty level (Kirui, 2016). This impact allows the occurrence of soil erosion and makes this form the leading factor of land degradation occupying 16% of all degradation index. This highly contributes to the fertility decline by wearing away a topsoil layer, which normally contains large amounts of organic matter and soil nutrients (Nyawade et al., 2019).

Land degradation associated with poor soil fertility management practices is a major factor underlying poor agricultural productivity in sub-Saharan Africa. About 65% of agricultural land is degraded, mainly due to low nutrient application, soil erosion, and soil acidification (Zingore et al., 2015). The output of land degradation includes a decline in organic matter content and soil microorganism activities due to soil fertility decline (Heckman et al., 2003). The decline in organic matter results in the alteration of physical, biological, and chemical soil properties and a strong reduction in soil fertility as it plays several roles in the soil despite being a storage house of nutrients (Heckman et al., 2003). Also, microbial activities decrease due to a low level of organic matter in the soil because, the soil microbial need organic matter for producing the food through decomposition process. Through this process, the microorganisms play a significant role in releasing the nutrients in the soil and hence become available for the plant (Hossain, 2006; Sims et al., 1998). In addition, the decline in organic matter is caused by various factors including crop residue removal and insufficient application of organic fertilizers such as animal manure, green manure, compost manure, and inorganic fertilizer (Heydarzadeh et al., 2021).

In Tanzania, the land degraded index increased from 42% in 1980 to more than 51% in 2017. The data showed that nearly two-thirds of the dryland areas in the country are seriously degraded (Majule, 2017). The extent and magnitude vary across regions, depending on the type and intensity of the economic activities that drive the degradation. However, there is a serious relationship between the decline and sunflower production in the country due to land degradation, particularly

Figure 4. Map indicating the inter-relationship between land degradation and sunflower production in Tanzania. Source: Majule (2017).



through soil erosion. Some of the sunflower-producing areas have very severe, severe, and moderate land degradation statuses that imply the interrelationship between land degradation and decline in sunflower production (Figure 4).

5.2 Nutrient mining

Nutrient mining or depletion is the major form of land degradation practices in Tanzania. Nutrient replenishment done mainly through manures or fertilizer application is inadequate to replace nutrients removed by the crops, resulting in nutrient mining due to imbalanced fertilization (Heckman et al., 2003; Hossain, 2006; Mwadalu et al., 2022). High depletion rates of those nutrients required in moderate to higher amounts, e.g. nitrogen, phosphorus, potassium, and sulfur, are severe in most places depending on soil nutrient availability and the amounts used (Heckman et al., 2003; Sims, 1999). Nutrient mining is a key peril to sustainable agricultural production, both in small and medium-input agriculture (Msanya et al., 2018).

According to Zingore et al. (2015), Tanzania is among the sub-Saharan African countries that contain some of the oldest and most inherently infertile soils, with most of the areas characterized by low nutrient contents, especially for nitrogen, phosphorus, and nitrogen, and thereby highly susceptible to erosion (Table 2). The fragility of soils to degradation is due to the limited use of both fertilizer and organic nutrient inputs. Tanzania reveals high negative values, and losses of

Table 2. Soil-based nutrient parameter status in Tanzania		
Soil parameter	**Concentration**	**Rating***
TN (g kg^{-1})	1.33	Low
Av.P (mg kg^{-1})	9	Low
K (cmol kg^{-1})	1.19	Low
Ca (cmol kg^{-1})	7.13	Medium
Mg (cmol kg^{-1})	1.5	Medium

*Marx et al. (1999).

Source: Funakawa et al. (2012).

macronutrients at the country level are estimated at 20 to 40 kg N ha^{-1}, 4 to 7 kg P ha^{-1}, and 17 to 33 kg K ha^{-1} annually. These high levels of negative balances are due to over-exploitation of soil nutrient stocks as farmers use low levels of nutrients in both organic and inorganic form, coupled with the removal of nutrients in harvested produce and losses mainly through erosion. This is in line with Msanya et al. (2018) who reveal nutrient mining is a very serious problem all over the world including Tanzania.

The low rate of organic and inorganic fertilizer application to mostly farmers in agricultural production is because they practice low input and rain-fed subsistence agriculture which finally contributes to poor crop quality and yields (Hossain, 2006). According to FAOSTAT (2022), the consumption rate of fertilizer does not show a good trend, because the amount of fertilizer by nutrient applied in the soil is very small compared to the size of the cropland in Tanzania. Here, the cultivated land is approximately 15,521,200 ha, and the use of fertilizer per year is 171,355 tonnes, 32,934 tonnes, and 17,737 tonnes for nitrogen, phosphorus, and potassium, respectively.

6. Approaches to overcome current fertility constraints in sunflower production

6.1 Fertilizer application

A fertilizer is any substance added to soil or directly to the plant to supply essential nutrients to improve plants' growth and yield (Rascio et al., 2008). Plants need food like animals, but this food is usually supplied through fertilizer application that contains various mineral elements, and plants uptake those mineral nutrients available in the soil by roots to provide the basic chemicals for their metabolic reactions (Sessitsch et al., 2002). The nutrient supply from soils to plants is in most cases limited and therefore needs to be supplied by fertilizer application to improve the quality and quantity (Mwadalu et al., 2022). Fertilizer application replaces the mineral element that is taken up from the soil by a plant and improves the nutrient potential of soils by creating a favorable growing environment than natural soil (Saikia & Jain, 2007).

The use of organic fertilizers such as animal manure, crop residue, green manure, and compost manure can be used as a fertilizer supplement in the soil to enhance crop production (Risse et al., 2006). Application of organic fertilizer to replenish the soil nutrients is a better practice for agricultural purposes, because the material added to the soil is the source of plant nutrients, and the content added stabilizes the soil structure (Sessitsch et al., 2002), enhancing the water-holding capacity of the soil, increase infiltration rate, increase CEC, and provide a better environment for the microbial activity (Kimbi et al., 2011). Also, it helps to mitigate soil acidity and soil erosion by facilitating soil aggregation (Abou El-Magd et al., 2006; Rascio et al., 2008). Soil rich in organic matter needs low application of inorganic fertilizer and responds positively by providing higher crop yields than soils that have a deficiency in organic matter. Some research shows that one ton of cattle manure can supply about 2.95 kg N, 1.59 kg P_2O_5, and 2.95 kg of K_2O, while sheep and goat manure can supply 3% N, 1% P2O5, and 2% K_2O while poultry manure contains 7–8% N, 11–14% P_2O_5 and 2–3% K_2O (Kimbi et al., 2011). The farm composts contain 0.80–1.25% N, 0.4–0.6% P_2O_5, and 2.0–3.3% K_2O while the town composts contain around 1% P2O5, 1.4% N, and 4%

K_2O and the regular application of compost over the years can greatly improve the chemical and physical fertility and productivity of soils. Also, using green manure is said to release 60–80 kg N ha^{-1} on average (Rascio et al., 2008).

Inorganic fertilizers or synthetic fertilizers are fertilizers mined from mineral deposits or manufactured from synthetic compounds (Kimbi et al., 2011). The common inorganic fertilizers are those which contain nitrogen, phosphorus, and potassium like NPK, DAP, TSP, MOP, CAN, and SA (Bayu et al., 2006). The benefit of applying inorganic fertilizers as fertilizer supplements is that they work more quickly than organic fertilizers in providing available nutrients of higher percentages than organic fertilizers, which means that the nutrient is usually in available form compared with organic fertilizers that need to undergo the decomposition process first (Kimbi et al., 2011; Senjobi et al., 2010). Also, inorganic fertilizer is less expensive and contributes little to the soil health and sustainability of soil structure. However, inorganic fertilizers show some negative effects if used carelessly, since they can pollute the environment, especially groundwater, e.g. nitrates, and can even burn plant roots if applied close to the roots in high concentrations, e.g. urea and ammonium nitrate (Rascio et al., 2008; Sessitsch et al., 2002). So inorganic fertilizer is not supposed to be continuously used alone without even having the habit of leaving crop residue on the farm because it kills off the natural microorganism by producing toxic effects (Makinde & Ayoola, 2008).

6.2 Sunflower-legume intercropping approach

The intercropping technique is the process of growing different crop species in a single field (Maitra et al., 2021; Soratto et al., 2022). This is one of the best approaches to replenishing the nutrients in the soil (Gitari et al., 2018b). The technique increases biodiversity in the field and emphasizes the interactions between biotic and abiotic components (Maitra et al., 2021; Nyawade et al., 2020). Also, there are great benefits of intercropping including increasing yield per area, reducing the number of weedings, reducing the use of pesticides, and better utilization of available resources (Nasar et al., 2023; Shao et al., 2023). Gitari et al, (2018a, 2020) reported that intercropping crops with different legumes is a climate-smart cropping practice useful to farmers with high climatic risk situations by reducing soil and nutrient loss while allowing the ground cover establishment and increasing yields.

Despite the main objective of intercropping is the achievement of maximum yield than a single cropping pattern of the same land area in a given period, it also ends up with an improvement of the soil fertility status (Gitari et al., 2019; Maitra et al., 2001). Altieri (1995) considered the intercropping system as an economic method in areas with short growing seasons and in rainfed areas for achieving higher yield production with small cost invested for farm inputs and increasing use efficiency, specifically for smallholder farmers (Manasa et al., 2018; Nyawade et al., 2019). Higher production in intercropping can be accompanied by a high growth rate, high biomass production, and efficient use of resources and pieces of land available (Maitra et al., 2001; Raza et al., 2021). Moreover, the intercropping system reveals some complementary effects among the intercropping crops that influence the increase in production due to less competition among crops (Maitra et al., 2000).

Sunflower-legume intercropping offers an advantage in conserving the soil by the provision of coverage to the soil surface by the canopy of the legume crop. This offers an advantage to dry areas because more transpiration takes place in the foliage creating a cooler condition, thus the improved ability of the system to minimize the soil temperature effect (Mao et al., 2012). Also, during the water stress, crops use available water in the soil at the canopy level, thereby they get the soothing effect of the microclimate (Eskandari et al., 2019; Goher et al., 2023; Seleiman et al., 2021). Generally, in the sunflower-legume intercropping system competition for nutrients among the species can be minimized by choosing a plant with dissimilar morphological characteristics to that of a sunflower (Lithourgidis et al., 2011). Hence, in this manner, there is an efficient use of available resources which are then converted into dry-matter production. Babec et al. (2021)

Table 3. Sunflower nitrogen uptake, yield, and stover yield under intercropping approaches

Treatment	Nitrogen uptake (g/kg)	Yield (t ha^{-1})	Stover yield (t ha^{-1})
Sunflower without fertilizer	0.8	2.8	17.4
1:1 Sunn hemp +sunflower	1.4	3.4	25.4
2:1 Sunn hemp + Sunflower	1.5	4.1	26.1
Sunflower with fertilizer	1.2	5.0	49.4

Source: Chappa et al. (2023).

reported that sunflower-legume intercropping brings better results not only in yield but also in plant growth parameters while minimizing the cost of input (pesticides and nitrogenous fertilizer application), hence more profit is obtained.

The intercropping system replenishes the soil fertility due to the ability of legumes to do biological fixation of nitrogen of about 80 to 350 kg ha^{-1} (Jena et al., 2022). This affects the micro-organism dynamics and increases the mineralization of nutrients in the rhizosphere (Li et al., 2009). In this system, nitrogen from the atmosphere is fixed by microorganisms and used up by legumes and the associated plant, where legume plants contribute up to 15% of nitrogen to the associated plant (Zhang et al., 2004). Yield biomass in intercropping is higher than in a pure standing crop due to the higher crop uptake of the nutrient not only nitrogen but also phosphorus and potassium at the rate of 43 and 35% as compared to the pure standing crop, respectively (Morris & Garrity, 1993). Chappa et al. (2022) reveal the importance of sunflower-sunn hemp intercropping in increasing sunflower yields since sunn hemp fixes a huge amount of nitrogen up to 67 kg which can decrease nitrogenous fertilizer requirements of nitrogen per acre and thereby minimize the cost for fertilizer. In addition, Chappa et al. (2023) reported an increase in nitrogen uptake by intercropping sunflower with sunn hemp from 0.8 g kg^{-1} (Sunflower without fertilizer) to 1.4 and 1.5 g kg^{-1} using 1:1 Sunn hemp + sunflower and 2:1 Sunn hemp + Sunflower intercropping approaches that increased the grain and stover yield from 2.8 and 17.4 t ha^{-1} to 3.4 up to 4.1 t ha $^{-1}$ for yield and 25.4 up to 26.1 t ha^{-1} for stover yield using 1:1 Sunn hemp + sunflower and 2:1 Sunn hemp + Sunflower intercropping approaches, respectively (Table 3).

Different studies indicate changes in physical and chemical properties in the rhizosphere through practicing a legume-based intercropping system by adding organic matter and a change in soil microbial population which increases the availability of nutrients such as soil organic carbon, nitrogen, and phosphorus (Mobasser et al., 2014). Also, through the use of various legume-based intercropping systems, phosphorous uptake can be improved (Haile et al., 2023; Jena et al., 2022). Maitra et al. (2021) reveal the improvement in phosphorus uptake through the use of the inter-cropping system in acidic soils. Phosphorus is a limiting nutrient in acidic soils, practicing legume-based intercropping systems, the roots of legume plants such as groundnuts, beans, and cowpeas release phosphatases and organic acids into the rhizosphere environment and enhance Phosphorus availability and uptake by the plant so practicing intercrops in combination with these crops more Phosphorus can be available (Ryan et al., 2011). Also, the organic acid released by legume roots reduces the harmful effect of Al toxicity on the associated plant root (Mobasser et al., 2014; Ryan et al., 2011).

Kumar et al. (2019) revealed better performance in yield attributes by showing significantly increased yield attributes including the number of pods/capitulum per plant, seed weight per plant (g), number of seeds per plant, number of seeds per pod/capitulum, seed yield (kg ha^{-1}), 1000 seed weight (g), and biological yield (kg ha^{-1}) through application sunflower and groundnut intercropping and black gram in different cropping patterns, the output of this research evidently that the intercropping approach of sunflower with legumes influence yield attributes and productivity and is the way forward to attain higher yield of sunflower crop.

6.3 Integrated soil fertility management (ISFM) approach

Another approach is integrated soil fertility management (ISFM), which involves integrating those available practices including the use of organic fertilizer (farm yard manure, compost manure, green manure), synthetic fertilizer, crop residue, cover crop, and improved germplasm to improve the soil fertility and increase crop productivity (Babec et al., 2020). Integrated soil fertility management holds benefits by reducing nutrient depletion, conserving the environment, enhancing food security, and reducing the number of greenhouse gases emitted from the soils and fertilizers thereby promoting climate-smart agriculture (Kisaka et al., 2023; Mwakidoshi et al., 2023; Vanlauwe et al., 2010).

Research done on assessing the benefits of using ISFM for climate-smart agriculture in southwestern Nigeria for 20 years reveals the increment in maize grain yield by 2.6 tonnes per hectare from 2 tonnes per hectare for normal maize. This was achieved through the application of an integrated approach by combining maize-soybean rotations with the NPK fertilizers and inoculation of legumes with N-fixing bacteria; this was the highest recorded yield compared to the same inputs when applied separately (Vanlauwe et al., 2010).

Zohry and Ouda (2022) researched the application of the integrated fertilizer approach in sandy soil to attain high yield by using biofertilizers, compost, and manure in sunflower, soybean, and canola in Egypt. The findings showed that the use of chemical fertilizer only gives the average yield, whereas the application of integrated fertilizer practice with 50% biofertilizer and 50% compost resulted in the highest yield. Thus, the application of an integrated approach in managing the soil improves the soil fertility status and sustains the highest yield potential by producing much oil.

A study on the profitability of using ISFM in Kenya shows that the approach is profitable because the local, regional, and international markets influence the benefits of ISFM-produced products (Mucheru-Muna et al., 2010). ISFM is an approach that provides alternatives that increase yield and economics by sustaining productivity for farmers. Mugwe et al. (2019), observe the increase in crop yields and economic benefits by involving various ways of managing fertility like intercropping sunflowers and legumes with an application of nitrogen-rich fertilizers among the ISFM practices. Evidence proves that Integrating approach like legume-maize rotation lowers the cost of nitrogen application, thus increasing the yield of one crop without any side effect on the performance of the other crop, thus the farmers can increase their profitability by reducing the cost of production (Ojiem et al., 2014).

A study on the use of ISFM on sunflower production conducted in Dodoma, Tanzania, by Chappa et al. (2023) shows increases in different plant growth parameters and yield relative to control. The study reveals an increase in plant height from 124.83 cm with Sole sunflower without fertilizer to 141.08 up to 168.58 cm from different ISFM approaches, while other parameters include Leaf area from 366.89 cm^2 to 402.37 up to 606.89 cm^2, head diameter from 18.88 cm to 21.17 cm and 26.33 cm. On the side of yield, parameters showed an increase in number of seeds per plant from with sole sunflower without fertilizer 1027 to 1252 and 1879 with different ISFM approaches, increase in weight of seeds per plant from 63.3 g to 77.5 and 116.3 g, increase in yield from 2.81 t ha^{-1} with sole sunflower without fertilizer to 3.45 up to 5.04 t ha^{-1} using different ISFM approaches (Table 4).

7. Land suitability evaluation

Land evaluation involves assessing the level of suitability for particular land use by considering permanent factors of suitability including climate, soil conditions, and topography except for the economic status (Baniya et al., 2009). This process is essential because it comes with answers to

Table 4. Sunflower growth and yield parameters from different ISFM approach

Treatment	Plant height (cm)	Leave area (cm^{-2})	Head diameter (cm)	No. of seeds $plant^{-1}$	Weight of seeds (g plant-^{1})	Yield (t ha^{-1})
Sole sunflower without fertilizer	124.83	366.89	18.58	1026.75	63.33	2.81
(1:1 Sunn hemp +sunflower) no fertilizer	141.08	402.37	21.17	1252.08	77.54	3.45
(1:1, Sunn hemp + sunflower) with fertilizers	167.25	617.25	25.50	1879.25	116.33	5.17
(2:1 Sunn hemp + Sunflower) no fertilizer	132.42	427.52	20.50	1479.33	91.17	4.05
(2:1 Sunn hemp + sunflower) with fertilizer	150.67	450.30	23.25	1726.92	106.33	4.73
Sunflower with fertilizer	168.58	606.59	26.33	1827.17	113.42	5.04

Source: Chappa et al. (2023).

very important questions such as which areas are well suited for specific land use, and what kind of land use is best suited (Kimaro et al., 2001). The findings of this kind of evaluation give details concerning the doubt and potential opportunities for the specified use of the land unit by providing guidance and alternatives during the decision-making on sustainable use of the resources. Such a finding is essential for land use planning and development strategies (Otieno et al., 2023). This kind of evaluation provides room for the identification of the limiting factors that may hinder a sustained use of the land and allows decision makers and policymakers like land users, planners, and agricultural scientists to develop sustained land management strategies that would remove those limiting factors and improve productivity ability of the areas (Baniya et al., 2009; Otieno et al., 2023).

Land use matching is an important step that is performed after the land survey procedure in the land evaluation process. The process nullifies relationships that exist between the land qualities or characteristics and the requirements of land use. In a few words, matching is the collision between the land requirements of specific crops with the land characteristics to give a prediction of crop performance (FAO- Food and Agriculture Organization, 1976). Matching land use with the crop requirement process involves the adaptation and adjustment of the land use types (Ritung et al., 2007). There is a set of procedures to follow during the matching process which involves the comparison of the requirements of land use with the identified land qualities for each unit. This stage involves the grouping of the measured values of the land qualities against the range classes followed by the allocation of the land unit to the fitted land suitability class.

During the allocation, the limiting factors are usually considered for the cases where at least one limitation is enough for the land to be allocated in the “not suitable class”. A method of considering the most severe limitation needs to be applied. For instance, sunflower production is not suitable in areas with leveled land and sufficient rainfall with highly saline soil, according to the most severe limitation, but in areas with less severe limitations combining of rating for individual qualities approach is used (Kimaro & Hieronimo, 2014). Land can be categorized in a spatially distributed way according to the agricultural potential of the land based on the selected soil properties and topographic and climate characteristics (Abdelrahman et al., 2016; Achoki & Gichaba, 2015; Kimaro & Hieronimo, 2014).

7.1 Importance of land suitability assessment

Land evaluations are one of the important processes towards reduction of the human influence on natural resource degradation and identifying the sustainable appropriate land use option. Such kind of analysis allows decision-makers to implement the best land management and increase land productivity by identifying the main limiting factors for the specified agricultural production (Achoki & Gichaba, 2015). It is the information obtained through the land evaluation process that guides decisions on the best utilization of land resources by giving out the constraints and opportunities for specific land use, therefore this process is a necessary prerequisite in the development of land use planning (Ritung et al., 2007). Additionally, such a kind of analysis is vital in agriculture production due to the reasons that it identifies the main limiting factors that may hinder production and hence allows those land users and planners together with farmers to make a sustainable decision before implementation on how to remove or reduce such constraints to increase production (Verheye et al., 2020).

The land suitability assessment approach is a method for analyzing land's potential to determine the best location for growing various crops (Achoki & Gichaba, 2015). In planning and managing land resources, one of the most advantageous uses of the Geographic Information System (GIS) is the study of site suitability and preparation of land use maps. Land/soil suitability evaluation is required to decide which crop is most suited to a place with limited resources (Jamil et al., 2018). Potential Land Suitability Assessment determines the land's suitability for a specified use (Bandyopadhyay et al., 2009). The basic purpose of "is to achieve people's satisfaction with a particular land use form (Malczewski & Boroushaki, 2008), and it can assist policymakers in developing strategies to increase agricultural productivity by identifying potentially suitable land for cultivation (FAO, 1976; Malczewski & Boroushaki, 2008).

Land suitability evaluation maximizes the use of existing lands in a particular location and provides the necessary information and knowledge about the potentiality and possible circumstances (Kimaro & Hieronimo, 2014; Malczewski & Boroushaki, 2008). Land suitability assessments serve as a reference for prescribing suitable crops for a specific soil to optimize agricultural yield per unit of land, labor, and inputs (Meng et al., 2013). To determine a parcel of land's suitability for agricultural output, proper parameters must be used. This is due to the existence of several factors that affect land-use suitability assessment such as environmental, topographic, climatic, and soil characteristics and social costs (Jamil et al., 2018; Pramanik, 2016). For land suitability analysis, the use of the multi-criteria evaluation (MCE) approach by integrating several factors such as topographic characteristics, climatic conditions, and soil properties and giving weights based on expert judgment to discover possible solutions for various land-related issues with alternative land use options is discussed. The overlay operations using MCE are based on GIS to produce information related to crop yields that are more capable of assisting in management and decision-making (Otieno et al., 2023; Senanayake et al., 2020).

7.2 Use of Geographic Information System (GIS) in land evaluation

GIS application currently draws high tension to the majority of researchers in different fields due to results that have been shown while utilizing it by being an efficient and effective method for extracting, storing, analyzing data, evaluating, and studying the spatial variation of soil properties (Meng et al., 2013). The integration of GIS and the Multi-Criteria Decision Analysis (MCDM) technique will always decide for identifying well-suitable places for production (Halder et al., 2020). Mokarram and Aminzadeh (2010) suggest that the use of a Geographic Information System (GIS) is an innovative approach for acquiring, investigating, and evaluating data and outcomes because a researcher can fix small mistakes more quickly and get more accurate results. Nowadays there are a significant number of study on-site suitability studies utilizing GIS, and Multi-Criteria Decision Analysis (MCDM) integration, including Site Suitability Assessment for Cultivation and suitability analysis for various crops (Jamil et al., 2018; Kihoro et al., 2013; Zaredar & Jafari, 2010), land management purposes, and land-use suitability (Romeijn et al., 2016). GIS and Multi-Criteria Decision Analysis (MCDA) integration can be used well enough for planning and managing how agricultural land is used to make good judgments in complex and dynamic agricultural systems (Sanchez-Lozano et al., 2013; Shearer & Xiang, 2009).

In addition, as revealed by various researches (El Baroudy, 2016; Mokarram & Aminzadeh, 2010; Mustafa et al., 2011; Sanchez-Lozano et al., 2013), geographic information systems (GIS) offer vital potential for enhancing land suitability assessments and offering critical information for agricultural planners and managers, to identify the best suitable area for long-term agricultural planning (Pramanik, 2016). Some approaches usually employ the Frequency Ratio (FR) and Weight of Evidence (WoE) to solve a wide variety of problems involving suitability assessment. The approaches are usually employed in mapping landslide potentiality (Mustafa et al., 2011; Pramanik, 2016), flood susceptibility (El Baroudy, 2016), soil erosion susceptibility (Arabameri et al., 2019; Pournader et al., 2018; Senanayake et al., 2020) since it takes into account ground-based information to map locations with similar conditions in a given region.

Sunil and Prolay (2022) conducted a study aimed at identifying potentially viable agricultural land in the Gangarampur subdivision (West Bengal) using Multiple Criteria Decision-Making (MCDM) and machine learning procedures to evaluate the efficacy of the employed methodologies. Fuzzy Complex Proportional Assessment (FCOPRAS) model and Random Forest (RF) model were involved. RF findings showed that 14.7% of the land was excellent, 22.3 was highly suitable, with 23.6% was moderately suitable for cultivation. FCOPRAS showed 15.4, 22.5, and 19.8% of the land being excellent, highly suitable, and moderately suitable for cultivation, respectively. The study contributed to the evaluation of soil fertility and site suitability and, hence, helped the local government officials, academicians, and farmers in utilizing the land. Another study by Sarkar et al. (2023) aimed to evaluate agricultural land suitability for vegetable crop farming in the Uttar Dinajpur district. The bivariate statistical techniques' frequency ratio, entropy index, and weights of evidence models were taken into consideration. Influencing parameters such as elevation, slope, geology, geomorphology, stream density, rainfall, geohazard, and soil properties were taken into account. The findings showed that 16.9, 26.6, 20.4, and 9.3% of the land was highly, moderately, marginally, and less suitable for vegetable farming, respectively.

According to Wyland (2009), GIS was used in Corn Belt and Mississippi River Delta areas in the USA to generate maps, which were produced by integrating survey data and satellite images, which provided the lay of the land suitability for corn, soybean, cotton, and rice crops grown in the area. The data produced was helpful to crop growers' associations, crop insurance companies, fertilizer companies, and land planners in forecasting and planning for crop production. Achoki and Gichaba (2015) conducted a study involving the use of GIS and remote sensing for food security in Kenya. GIS software was used to map arable lands, monitor crops, and design market structures. They used ArcGIS software in the selection of planting sites, data collection, managing irrigation, and as a guide in harvest analysis. The GIS platform integrated remote sensing imagery, which helped in monitoring plant growth, health, and yield. It did help them to know the potential of each farmland, allowing for maximum exploitation. Also, Otieno et al. (2023) conducted research in Nairobi Peri-urban counties on soil fertility management for capsicum cultivation, whereby using GIS to come up with a soil fertility map from the selected areas in those counties which were to be used for fertilizer management option to increase capsicum production.

Also, a study by Mugo et al. (2016) in Kitui, Kenya, involved the application of GIS in identifying suitable locations for green gram production. The study revealed that the land assessed is suitable for the production of green gram with variation in degrees of suitability of 44, 24, and 37%

implying marginally suitable, moderately suitable, and highly suitable, respectively. The findings of the study were used by the County government of Kitui to advise farmers on the best location for green gram production where they could achieve maximum yields. Kamau et al. (2015) did a study on crop-suitability analysis by involving GIS and remote sensing, and the data on soil texture, pH, drainage, slope, soil depth, temperature, and rainfall were selected as the main suitability criteria. The results show that 38% of the land used for agricultural production was highly suitable for cultivating potatoes, 51% was moderately suitable, and 11% was marginally suitable. The results were used to advise the local smallholder farmers on the suitability of the areas for potato cultivation. Saha et al. (2021) conducted a study to identify suitable sites for agricultural practices in an anabranching site of the sooin river. A total of 16 parameters were taken into consideration for identifying land suitability. The final suitability map of the study was generated using the “Weighted Overlay” method on the GIS environment and classified as very high suitable (4.1%), high suitable (28.7%), moderately suitable (49.7%), low suitable (14.3%), and unsuitable (3.2%). The study noticed that the northern and eastern parts of the region were partially not suitable for agriculture. Further, the study advised governments and other organizations to take initiatives to improve soil management, and flood control, so then the area would be highly suitable for agricultural productivity.

Forkuo and Nketia (2011) researched digital soil mapping using GIS software for cropland suitability. By use of GIS, they produced a crop map that was used to determine land suitability for the production of the crops selected in the study area. Nduwumuremyi et al. (2013) used GIS to map sites for limestone mining and determine the quality of local limestone in Rwanda whereby they involve the use of the Global Positioning System for recording geographical coordinates of limestone deposits. The data collected from the field were processed using Arc GIS software and produced a map showing different areas with limestone deposition which could be used for agricultural purposes. A study conducted by Isdory et al. (2021) at the Magozi irrigation scheme, in Iringa, Tanzania, involved the use of Arc GIS software to predict the soil salinity spatial distribution and then the prediction map used to recommend the management options for rice production in the irrigation scheme.

Mbayaki and Karuku (2022) conducted a study at Katumani, Kenya, on the soil hydraulic properties of a chromic Luvisol aiming at considering the percentage of silt, sand, and clay and soil bulk density. The authors utilized the ArcGIS software to map the study areas. Through the use of GIS, they were able to map the ward in Machakos County. Also, another research conducted on evaluating physicochemical soil properties and P sorption features from soils in different land use of Kiambu County in Kenya used GIS software to locate the interesting areas with different land use (maize plantation, forest) and soil sampling points for the study (Rop et al., 2022). Reith et al. (2021) utilized the GIS and high-resolution imagery dataset to monitor the extent of land degradation in the semiarid Kiteto and Kongwa districts of Tanzania from 2000 to 2019. The researchers utilized the freely available datasets in the Landsat time series, open-source software, and cloud-computing. Further, the authors compared their results of the land degradation assessment based on the adopted high-resolution data and methodology (AM) with the default medium-resolution data and methodology (DM) that is suggested by the United Nations Convention to combat desertification. According to AM, 16% of the area was degraded, whereas DM revealed total land degradation as 70% of the area. The results help in spatial planning that should focus on degraded areas by implementing sustainable land management practices based on the results.

Mwendwa et al. (2019), conducted a study at Upper Kabete in Kenya on land evaluation for crop production, aiming at assessing the suitability of different sites for crop production and then recommending possible soil improvements in the current management practices to increase crop production. In the study, the researchers utilized the GIS specifically ArcGIS Software using the Ordinary Kriging interpolation method to map the sampling units that were used to produce the suitability map for crop production. The output showed the study area to be suitable for coffee, maize, beans, pigeon peas, potatoes, onion, and spinach. Nonetheless, it was noted some units required improvement in the management practices to be suitable for the aforementioned crop production. Another study was carried out by Otieno et al. (2023) to determine areas best suited for capsicum production in the peri-urban counties of Nairobi, Kenya, for growing capsicum (*Capsicum annuum* L.). The study applied the Analytic Hierarchy Process (AHP) with GIS integration using Quantum Geographic Information Software (QGIS). A suitability map was produced and results showed that 50% of land in Kiambu County, 8% in Kajiado County, and 12% in Machakos County is suitable for capsicum production. The remaining areas were reported to be unsuitable for the production of the crop due to the presence of some limitations such as texture, soil pH, drainage, and climate.

8. Conclusion and recommendation

Land degradation is a key challenge limiting the production of sunflowers in Tanzania, which occurs due to nutrient mining triggered by continuous cultivation of the crop in the same field without replenishment of the soil, crop, or residue removal after harvesting and low fertilizer input which finally decreased soil fertility and production potential of sunflower. The implementation of significant short- and long-term measures to combat the poor land use practices on land resources should be imposed by the government by adaption of measures that will ensure proper land management. This can be achieved by applying specific practices at the right time, location, and amount to reduce land degradation which is mainly contributed by poor agricultural practices. The government ought to create policies and strategies based on the current situation to ensure that emerging challenges are addressed as part of the overall efforts to combat the impacts of global climate change like the adoption of conservation agriculture that will benefit food security, soil health, and overall nutrition of the citizens. In addition, the government must ensure the accessibility of spatial information on land suitability of a particular location and their limitation that will guide sustainable land management to achieve land degradation neutrality. This will involve the use of GIS in agriculture given that it plays a vital role in enhancing land management and crop production for farmers, helps in increasing production, reducing costs associated with it and efficiently managing the farms. More importantly, the output maps associated with it help in the monitoring and management of soil and other agricultural resources.

Funding
This work was supported by the Researchers Supporting Project King Saud University, Riyadh, Saudi Arabia [RSPD2023R751].

Author details
Emmanuely Z. Nungula[1,2]
Jayne Mugwe[1]
ORCID ID: http://orcid.org/0000-0003-1405-7166
Jamal Nasar[3]
ORCID ID: http://orcid.org/0000-0003-4559-0676
Boniface H. J. Massawe[4]
ORCID ID: http://orcid.org/0000-0002-8233-7058
Anne N. Karuma[5]
ORCID ID: http://orcid.org/0000-0002-4497-2173
Sagar Maitra[6]
ORCID ID: http://orcid.org/0000-0001-8210-1531
Mahmoud F. Seleiman[7]
Turgay Dindaroglu[8]
ORCID ID: http://orcid.org/0000-0003-2165-8138
Naeem Khan[9]
Harun I. Gitari[1]
E-mail: harun.gitari@ku.ac.ke
[1] Department of Agricultural Science and Technology, School of Agriculture and Environmental Sciences, Kenyatta University, Nairobi, Kenya.
[2] Centre of Environment and Sustainable Development, Mzumbe University, Morogoro, Tanzania.
[3] Institute of Rice Industry Technology Research, Key Laboratory of Functional Agriculture, College of Agricultural Sciences, Guizhou University, Guiyang, China.
[4] Department of Soil and Geological Science, Sokoine University of Agriculture, Morogoro, Tanzania.
[5] Department of Land Resource Management and Agricultural Technology, College of Agriculture and Veterinary Sciences, University of Nairobi, Nairobi, Kenya.
[6] Department of Agronomy and Agroforestry, Centurion University of Technology and Management, Khurda, India.
[7] Plant Production, College of Food and Agriculture Sciences, King Saud University, Riyadh, Saudi Arabia.
[8] Department of Forest Engineering, Faculty of Forestry, Karadeniz Technical University Trabzon, Turkey.
[9] Department of Agronomy, Institute of Food and Agricultural Sciences, University of Florida, Gainesville, USA.

Disclosure statement
No potential conflict of interest was reported by the author(s).

Citation information
Cite this article as: Land degradation unmasked as the key constraint in sunflower (*Helianthus annus*) production: Role of GIS in revitalizing this vital sector, Emmanuely Z.

Nungula, Jayne Mugwe, Jamal Nasar, Boniface H. J. Massawe, Anne N. Karuma, Sagar Maitra, Mahmoud F. Seleiman, Turgay Dindaroglu, Naeem Khan & Harun I. Gitari, *Cogent Food & Agriculture* (2023), 9: 2267863.

References

Abah, R. C., & Mareme, B. J. (2015). Crop suitability mapping for cassava, yam, and rice. *Journal of Agriculture Science*, *9*(1), 1916–9752. https://doi.org/10.5539/jas.v9n1p96

Abdelrahman, M. A. E., Natarajan, A., & Hegde, R. (2016). Assessment of land suitability and capability by integrating remote sensing and GIS for agriculture in Chamarajanagar district, Karnataka, India. *The Egyptian Journal of Remote Sensing & Space Science*, *19*(1), 125–141. https://doi.org/10.1016/j.ejrs.2016.02.001

Abou El-Magd, M. C. M., El-Bassiony, A. M., & Fawzy, Z. F. (2006). Effect of organic manure without chemical fertilizers on growth, yield, and quality of some varieties of broccoli plants. *Journal of Applied Science Research*, *2*(10), 791–798.

Achoki, D. O., & Gichaba, C. M. (2015). *Geographic information systems and remote sensing for food security in*. Department of Geology; University of Nairobi.

Agy, M. S. F. A., Oliveira, R. L., Carvalho, G. G. P., Leao, A. G., & Ribeiro, O. L. (2012). Ingestive behavior and physiological responses of goats fed with diets containing sunflower cake from biodiesel production. *Arqueol Brasilliensia Medical Vertenary and Zootec*, *64*(5), 1292–1301. https://doi.org/10.1590/S0102-09352012000500029

Alberio, C., Izquierdo, N. G., & Aguirrezábal, L. A. N. (2005). Sunflower Crop Physiology and Agronomy. In E. Martínez-Force, N. T. Dunford, & J. J. Salas, (Eds.), *Sunflower* (pp. 53–91). AOCS Press. https://doi.org/10.1016/B978-1-893997-94-3.50009-X

Ali, A., & Ullah, S. (2012). Effect of nitrogen on achene protein, oil, fatty acid profile, and yield of sunflower hybrids. *Chilean Journal of Agriculture Resources*, *72*(4), 564–567. https://doi.org/10.4067/S0718-58392012000400016

Altieri, M. A. (1995). *Agroecology: The science of sustainable agriculture* (2nd ed.). Westview Press.

Andrew, R. L., Kane, N. C., Baute, G. J., Grassa, C. J., & Rieseberg, L. H. (2013). Recent nonhybrid origin of sunflower ecotypes in a novel habitat. *Molecular Ecology*, *22*(3), 799–813. https://doi.org/10.1111/mec.12038

Arabameri, A., Cerda, A., & Tiefenbacher, J. P. (2019). Spatial pattern analysis and prediction of gully erosion using a novel hybrid model of entropy-weight of evidence. *Water*, *11*(6), 1129. https://doi.org/10.3390/w11061129

Ashraf, S. (2010). Land suitability analysis for wheat using multi-criteria evaluation and GIS method. *Research Journal of Biological Science*, *5*(9), 601–605. https://doi.org/10.3923/rjbsci.2010.601.605

Atlas Big. (2022). *World sunflower production by country. Accessed at world sunflower production by country*. Retrieved September 21, 2022, from https://www.atlasbig.com

Babec, B., Šeremešić, S., Hladni, N., Cuk, N., Stanisavljevi ́c, D., & Rajkovi ́c, M. (2021). Potential of sunflower-legume intercropping: A way forward in sustainable production of sunflower in temperate climatic conditions. *Agronomy*, *11*(12), 2381. https://doi.org/10.3390/agronomy11122381

Babec, B., Šeremešić, S., Hladni, N., Terzić, S., Vojnov, B., Ćuk, N., & Gvozdenac, S. (2020). Effect of intercropping sunflower with legumes on some sunflower morphological traits. *Ratarstvo i Povrtarstvo*, *57*(2), 61–67. https://doi.org/10.5937/ratpov57-23813

Bandyopadhyay, S., Jaiswal, R. K., Hegde, V. S., & Jayaraman, V. (2009). Assessment of land suitability potentials for agriculture using a remote sensing and GIS-based approach. *International Journal of Remote Sensing*, *30*(4), 879–895. https://doi.org/10.1080/01431160802395235

Baniya, N., Böehme, M., & Baniya, S. (2009). Physical land suitability assessment for the large cardamom Amomum subulatum Roxb. cultivation in hills of Kathmandu Valley. *Chinese Journal of Population Resources and Environment*, *7*(4), 59–63. https://doi.org/10.1080/10042857.2009.10684954

Barbier, E. B., Hochard, J. P., & Vadrevu, K. P. (2016). Does land degradation increase poverty in developing countries? *PLoS One*, *11*(5), e0152973. https://doi.org/10.1371/journal.pone.0152973

Bayu, W., Rethman, N. F. G., Hammers, P. S., & Alemu, G. (2006). Effects of farmyard manure and inorganic fertilizers on sorghum growth, yield, and nitrogen use in a semi-arid area of Ethiopia. *Journal of Plant Nutrition*, *29*(2), 391–407. https://doi.org/10.1080/01904160500320962

Behera, S. K., & Shukla, A. K. (2015). Spatial distribution of surface soil acidity, electrical conductivity, soil organic carbon content, and exchangeable potassium, calcium, and magnesium in some cropped acid soils of India. *Land Degradation and Development*, *26*(1), 71–79. https://doi.org/10.1002/ldr.2306

BoT–Bank of Tanzania. (2018). *Annual report 2016/17. 254*. Retrieved August 10, 2022, from https://www.bot.og.tz

Brady, N. C., & Weil, R. R. (2008). *The nature and properties of soils* (14th ed.). Pearson Prentice Hall.

Bruinsma, J. (2009). The resource outlook to 2050: How much do land, water, and crop yields need to increase by 2050? *Conference: How to feed the world in 2050. Proceeding of a technical meeting of experts*, Rome, Italy, June 24–26(pp. 1–33).

Ceballos, F., Hernandez, M. A., Minot, N., & Robles, M. (2017). Grain price and volatility transmission from International to domestic markets in developing countries. *World Development*, *94*, 305–320. https://doi.org/10.1016/j.worlddev.2017.01.015

Chappa, L. R., Mugwe, J., Gitari, H. H., & Maitra, S. (2023). Upholding sunflower (Helianthus annuus) yield and profitability while maintaining soil fertility under intercropping with Sunn Hemp and mineral fertilizer application. *International Journal of Bioresource Science*, *10*(1), 31–49. https://doi.org/10.30954/2347-9655.01.2023.4

Chappa, L. R., Mugwe, J., Maitra, S., & Gitari, H. I. (2022). Current status and prospects of improving sunflower production in Tanzania through intercropping with Sunn Hemp. *International Journal of Bioresource Science*, *9*(1), 1–8. https://doi.org/10.30954/2347-9655.01.2022.1

Cleaver, J., Schram, R., & Wanga, G.(2010). Bioenergy in Tanzania: The country context. In *Chapter 3. Bioenergy and Food Security—The BEFS Analysis for Tanzania 2071-0992* FAO; Food and Agriculture Organization of the United Nations. Rome, Italy.

El Baroudy, A. A. (2016). Mapping and evaluating land suitability using a GIS-based model. *Catena*, *140*, 96–104. https://doi.org/10.1016/j.catena.2015.12.010

Eskandari, H., Alizadeh-Amraie, A., & Kazemi, K. (2019). Effect of drought stress caused by partial root zone irrigation on water use efficiency and grain yield of maize (*zea mays* L.) and mung bean (*Vigna radiata* L.)

in different intercropping planting patterns. *Environmental Stresses in Crop Sciences*, *12*(1), 29–40.

FAO- Food and Agriculture Organization. (1976). *A framework for land evaluation: Soils bulletin 32*. Food and Agriculture Organization of the United Nations,

FAO- Food and Agriculture Organization. (2017). *Regional overview of food insecurity and nutrition: The Food security and nutrition-Conflict Nexus: Building resilience for food security, nutrition and peace*. Food and Agriculture Organization of the United Nations.

FAOSTAT-Food and Agriculture Organization of the United Nations. (2022). *Statistics database*. Retrieved September 10, 2022, from http://faostat3.fao.org

Forkuo, E. K., & Nketia, A. K. (2011). Digital soil mapping in GIS Environment for crop-land suitability analysis. *International Journal of Geomatics & Geosciences*, *2* (1), 133–146.

Fullen, M. A., & Catt, J. A. (2004). Soil management: Problems and solutions. *European Journal of Soil Science*, *56*(5), 681–687. https://doi.org/10.1111/j.1365-2389.2005.00756.x

Funakawa, S., Yoshida, H., Watanabe, T., Sugihara, S., & Kosaki, T. (2012). Soil fertility status and its determining factors in Tanzania. In *Soil health and land use management*. IntechOpen. https://doi.org/10.5772/29199.

García-Vila, M., Fereres, E., Prieto, M. H., Ruz, C., & Soriano, M. A. (2012). Sunflower. In P. Steduto, T. C. Hsiao, E. Fereres, & D. Raes (Eds.), *Crop yield response to water* (pp. 164–173). FAO.

Gitari, H. I., Gachene, C. K. K., Karanja, N. N., Kamau, S., Nyawade, S., & Schulte-Geldermann, E. (2019). Potato-legume intercropping on sloping terrain and its effects on soil physico-chemical properties. *Plant and Soil*, *438*(1–2), 447–460. https://doi.org/10.1007/s11104-019-04036-7

Gitari, H. I., Gachene, C. K. K., Karanja, N. N., Kamau, S., Nyawade, S., Sharma, K., & Schulte-Geldermann, E. (2018a). Nitrogen and phosphorous uptake by potato (*Solanum tuberosum* L.) and their use efficiency under potato-legume intercropping systems. *Field Crops Research*, *222*, 78–84. https://doi.org/10.1016/j.fcr.2018.03.019

Gitari, H. I., Gachene, C. K. K., Karanja, N. N., Kamau, S., Nyawade, S., Sharma, K., & Schulte-Geldermann, E. (2018b). Optimizing yield and economic returns of rain-fed potato (*Solanum tuberosum* L.) through water conservation under potato-legume intercropping systems. *Agriculture and Water Management*, *208*, 59–66. https://doi.org/10.1016/j.agwat.2018.06.005

Gitari, H. I., Nyawade, S. O., Kamau, S., Karanja, N. N., Gachene, C. K. K., Raza, M. A., Maitra, S., & Schulte-Geldermann, E. (2020). Revisiting intercropping indices with respect to potato-legume intercropping systems. *Field Crops Research*, *258*, 107957. https://doi.org/10.1016/j.fcr.2020.107957

Goher, R., Alkharabsheh, H. M., Seleiman, M. F., Diatta, A. A., Gitari, H., Wasonga, D. O., Khan, G. R., & Akmal, M. (2023). Impacts of heat shock on productivity and quality of *Triticum aestivum* L. at different growth stages. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *51*(1), 13090. https://doi.org/10.15835/nbha51113090

Gudu, S., Kisinyo, P., Makatiani, E., Odee, D., Esegu, J., Shamchama, S., Othieno, C., Okalebo, J., Osiyo, J., & Owuoche, J. (2009). Screening of Sesbania for tolerance to aluminium toxicity and symbiotic effectiveness with acid tolerant rhizobia strains in acid soil in Western Kenya. *Experimental Agriculture*, *45*(4), 417–427. https://doi.org/10.1017/S0014479709990044

Haile, M. A., Karanja, N. N., Nyawade, S. O., Gitari, H., Cheruto, G., Nyawira, L., Raza, M. A., & Kamau, S. (2023). Lupin and Lima beans diminish potatoes' N and P uptake, uptake efficiency, and use efficiency. *Potato Research*, 1–7. https://doi.org/10.1007/s11540-023-09625-9

Halder, B., Bandyopadhyay, J., & Banik, P. (2020). Assessment of hospital sites' suitability by spatial information technologies using AHP and GIS-based multi-criteria approach of rajpur–sonarpur municipality. *Modeling Earth Systems and Environment*, *6*(4), 2581–2596. https://doi.org/10.1007/s40808-020-00852-4

Heckman, J. R., Sims, J. T., Beegle, D. B., Coale, F. J., Herbert, S. J., Bruulsema, T. W., & Bamka, W. J. (2003). Nutrient removal by corn grain harvest. *Agronomy Journal*, *95*(3), 587–591. https://doi.org/10.2134/agronj2003.5870

Heydarzadeh, S., Gitari, H., Rahimi, A., Khiavi, H. K., Maitra, S., & Hosseinpour, A. (2021). Yield and quality traits of field-grown sugar beet (*beta vulgaris* L.) in response to foliar application of micronutrients and different levels of manure. *International Journal of Bioresource Science*, *8*(2), 103–112. https://doi.org/10.30954/2347-9655.02.2021.7

Hossain, M. F. (2006). Nutrients removed in harvested portion of crop by continuous corn receiving organic and inorganic fertilizers. *Journal of Plant Sciences*, *1*(3), 264–272. https://doi.org/10.3923/jps.2006.264.272

Isdory, D. P., Massawe, B. H. J., & Msanya, B. M. (2021). Predicting soil ECe based on values of EC1: 2.5 as an indicator of soil salinity at Magozi irrigation scheme, Iringa, Tanzania. *Tanzania Journal of Agricultural Sciences*, *20*(1), 63–71.

Jamil, M., Sahana, M., & Sajjad, H. (2018). Crop suitability analysis in the Bijnor district, UP, using geospatial tools and fuzzy analytical hierarchy process. *Agribiological Research*, *7*(8), 506–522. https://doi.org/10.1007/s40003-018-0335-5

Jena, J., Maitra, S., Hossain, A., Pramanick, B., Gitari, H. I., Praharaj, S., Shankar, T., Palai, J. B., Rathore, A., Mandal, T. K., & Jatav, H. S. (2022). Role of legumes in cropping system for soil ecosystem improvement. In H. Jatav & V. Rajput(Eds.), *Ecosystem services: Types, management, and benefits*. Nova Science Publishers, Inc. 415 Oser Avenue, Suite N Hauppauge, NY, 11788 USA. https://doi.org/10.52305/PFZA6988

Kamau, S. K., Kuria, D., & Gachari, M. K. (2015). Crop-land suitability analysis using GIS and remote sensing in Nyandarua County, Kenya. *Journal of Environment and Earth Science*, *5*(6), 121–131.

Kihoro, J., Bosco, N., & Murage, H. (2013). Suitability analysis for rice growing sites using a multi-criteria evaluation and GIS approach in great Mwea region, Kenya. *International Journal of Science & Emerging Technologies*, *2*(1), 12–20. https://doi.org/10.1186/2193-1801-2-265

Kimaro, D., & Hieronimo, P. (2014). Land for agriculture in Tanzania: Challenges and opportunities. *Journal of Land and Society*, *1*(1), 91–102.

Kimaro, D. N., Msanya, B. M., Mwango, S. B., Kimbi, G. G., & Kileo, E. P. (2001). Land suitability evaluation for the production of the major crops in the Southwestern part of the Uluguru Mountains, Morogoro rural district, Tanzania. *Soils and Land Resources of Morogoro Rural and Urban Districts*, *2*.

Kimbi, G. G., Rutachokizibwa, V., Mollel, N. M., Simalenga, T. E., Ngetti, M. S., & Biswalo, P. L. (2011). Identification of SUA-TU linkage Project needs

assessment: A preliminary survey. *Report submitted to SUA-TU Linkage Project Institute of Continuing Education*. Sokoine University of Agriculture.
Kiriba, D., Thuita, M., Semu, E., Ikerra, S., Msanya, B., & Masso, C. (2019). Maize response to chemical and microbial products on two Tanzanian soils. *Journal of Agricultural Science*, *11*(2), 1–11. https://doi.org/10.5539/jas.v11n2p71
Kirui, O. K. (2016) *Economics of land degradation, sustainable land management and poverty in Eastern Africa – The extent, drivers, Costs and impacts*. [PhD Thesis, University of Bonn].
Kisaka, M. O., Shisanya, C., Cournac, L., Manlay, J. R., Gitari, H., & Muriuki, J. (2023). Integrating no-tillage with agroforestry augments soil quality indicators in Kenya's dry-land agroecosystems. *Soil and Tillage Research*, *227*, 105586. https://doi.org/10.1016/j.still.2022.105586
Kumar, E. S., Mandal, T. K., Mishra, G. C., Barman, S., & Maitra, S. (2019). Effect of intercropping summer sunflower *(Helianthus annuus* L.) with legumes on yield attributes and productivity of crops. *International Journal of Agriculture, Environment and Biotechnology*, *12*(3), 281–285.
Kunduraci, B. S., Bayrak, A., & Kiralan, M. (2010). Effect of essential oil extracts from oregano (*Origanum onites* L.) leaves on the oxidative stability of refined sunflower oil. *Asian Journal of Chemistry*, *22*(2), 1377–138.
Leyaro, V., & Morrissey, O. (2013). Expanding agricultural production in Tanzania. *Scoping study for IGC Tanzania on the National Panel Surveys*.
Li, Y., Ran, W., Zhang, R., Sun, S., & Xu, G. (2009). Facilitated legume nodulation, phosphate uptake, and nitrogen transfer by arbuscular inoculation in an upland rice and mung bean intercropping system. *Plant and Soil*, *315*(1–2), 285–296. https://doi.org/10.1007/s11104-008-9751-9
Lithourgidis, A. S., Vlachostergios, D. N., Dordas, C. A., & Damalas, C. A. (2011). Dry matter yield, nitrogen content, and competition in pea–cereal intercropping systems. *The European Journal of Agronomy*, *34*(4), 287–294. https://doi.org/10.1016/j.eja.2011.02.007
Maitra, S., Ghosh, D. C., Sounda, S., & Jana, P. K. (2001). Performance of intercropping legumes in finger millet (*Eleusine coracana*) at varying fertility levels. *Indian Journal of Agronomy*, *46*(1), 38–44.
Maitra, S., Ghosh, D. C., Sounda, G., Jana, P. K., & Roy, D. K. (2000). Productivity, competition and economics of intercropping legumes in finger millet (*Eleusine coracana*) at different fertility levels. *Indian Journal of Agricultural Sciences*, *70*(12), 824–828.
Maitra, S., Hossain, A., Brestic, M., Skalicky, M., Ondrisik, P., Gitari, H., Brahmachari, K., Shankar, T., Bhadra, P., Palai, J. B., Jena, J., Bhattacharya, U., Duvvada, S. K., Lalichetti, S., & Sairam, M. (2021). Intercropping: A low input agricultural strategy for food and environmental security. *Agronomy*, *11*(2), 343. https://doi.org/10.3390/agronomy11020343
Maitra, S., Samui, R. C., Roy, D. K., & Mondal, A. K. (2001). Effect of a cotton-based intercropping system under rainfed conditions in the Sundarban region of West Bengal. *Indian Agriculturist*, *45*(3–4), 157–162.
Majule, A. E. (2017). *Land degradation neutrality target setting process (LDN TSP): Report on LDN target setting, submitted to UNCCD National focal point, Vice President's office*. Vice President's Office.
Makinde, E. A., & Ayoola, A. A. (2008). Residual influence of early season crop fertilization and cropping system on growth and yield of cassava. *American Journal of Agriculture and Biological Science*, *3*(4), 712–715. https://doi.org/10.3844/ajabssp.2008.712.715
Malczewski, J., & Boroushaki, S. (2008). Implementing an extension of the analytical hierarchy process using ordered weighted averaging operators with fuzzy quantifiers in ArcGIS. *Computational Geoscience*, *34*(4), 399–410. https://doi.org/10.1016/j.cageo.2007.04.003
Manasa, P., Maitra, S., & Reddy, M. D. (2018). Effect of Summer maize-legume intercropping system on growth, productivity and competitive ability of crops. *International Journal of Management, Technology, and Engineering*, *8*(12), 2871–2875.
Mao, L., Zhang, L., Li, W., van der Werf, W., Sun, J., Spiertz, H., & Li, L. (2012). Yield advantage and water saving in maize/pea intercrop. *Field Crop Research*, *138*, 11–20. https://doi.org/10.1016/j.fcr.2012.09.019
Marx, E., Hart, J., & Stevens, R. (1999). *Soil test interpretation guide*. Oregon State University Extension Service.
Mbayaki, C. W., & Karuku, G. N. (2022). Soil hydraulic properties of a chromic luvisol in Katumani, Kenya. *Tropical and Subtropical Agroecosystems*, *25*(9), 1–13. https://doi.org/10.56369/tsaes.4200
Meng, Q., Liu, Z., & Borders, B. E. (2013). Assessment of regression kriging for spatial interpolation–comparisons of seven GIS interpolation methods. *Cartography and Geographic Information Science*, *40*(1), 28–39. https://doi.org/10.1080/15230406.2013.762138
Michael, A., Kuznetsov, D., & Mirau, S. (2014). Estimation of irrigation water demand in rice production Tanzania. *Mathematical Theory Model*, *4*(7), 24–39. https://doi.org/10.11648/j.acm.20140304.19
Mobasser, H. R., Vazirimehr, M. R., & Khashayar, R. K. (2014). Effect of intercropping on resource use, weed management, and forage quality. *International Journal of Plant Animal Environment and Science*, *4*(5), 706–713.
Mohammadi, K., & Sohrabi, Y. (2012). Bacterial biofertilizers for sustainable crop production: A review. *Journal of Agricultural and Biological Science*, *7*, 307–316.
Mokarram, M., & Aminzadeh, F. (2010). GIS-based multi-criteria land suitability evaluation using ordered weight averaging with fuzzy quantifier: A case study in shavur plain. *Remote Sensing Spatial Information Science*, *38*(2), 508–512.
Mongi, H. J. (2012). *Addressing land degradation in Tanzania: Contemporary issues related to policies and strategies*. Available at SSRN 2150752.
Morris, R., & Garrity, D. (1993). Resource capture and utilization in intercropping; non-nitrogen nutrients. *Field Crops Research*, *34*(3–4), 319–334. https://doi.org/10.1016/0378-4290(93)90120-c
Msanya, B. M., Munishi, J., Amuri, N., Semu, E., Mhoro, L., & Malley, Z. (2016). Morphology, genesis, physico-chemical properties, classification and potential of soils derived from volcanic parent materials in selected districts of Mbeya region. *International Journal of Plant & Soil Science*, *10*(4), 1–19. https://doi.org/10.9734/IJPSS/2016/24855
Msanya, B. M., Mwasyika, T. A., Amuri, N., Semu, E., & Mhoro, L. (2018). Pedological characterization of typical soils of Dodoma capital city district, Tanzania: Soil morphology, physico-chemical properties, classification, and soil fertility trends. *Annals of Advanced Agricultural Sciences*, *2*(4). https://doi.org/10.22606/as.2018.24002
Mucheru-Muna, M., Pypers, P., Mugendi, D., Kung'u, J., Mugwe, J., Merckx, R., & Vanlauwe, B. (2010). A staggered maize–legume intercrop arrangement robustly increases crop yields and economic returns in the highlands of Central Kenya. *Field Crops*

Research, *115*(2), 132–139. https://doi.org/10.1016/j.fcr.2009.10.013

Mueller, R. (2019). *GIS for agriculture; GIS best practices*. Retrieved August 5, 2022, from www.esri.com

Mugo, N. J., Karanja, N. N., Gachene, C. K., Dittert, K., Gitari, H. I., & Schulte-Geldermann, E. (2021). Response of potato crop to selected nutrients in central and Eastern highlands of Kenya. *Cogent Food & Agriculture*, *7*, 1898762. https://doi.org/10.1080/23311932.2021.1898762

Mugo, J. W., Kariuki, P. C., & Musembi, D. K. (2016). Identification of suitable land for green gram production using GIS-Based analytical hierarchy process in Kitui County, Kenya. *Journal of Remote Sensing & GIS*, *5*(3). https://doi.org/10.4172/2469-4134.1000170

Mugwe, J., Ngetich, F., & Otieno, E. O. (2019). Integrated soil fertility management in sub-Saharan Africa: Evolving paradigms toward integration. In F. Leal, A. Azul, L. Brandli, P. Özuyar, & T. Wall (Eds.), *Zero hunger. Encyclopedia of the UN sustainable development goals*. Springer. https://doi.org/10.1007/978-3-319-69626-3_71-1

Mustafa, A. A., Singh, M., Sahoo, R. N., Ahmed, N., Khanna, M., Sarangi, A., & Mishra, A. K. (2011). Land suitability analysis for different crops: A multi-criteria decision making approach using remote sensing and GIS. *The Researcher*, *3*(12), 61–84.

Mwadalu, R., Mochoge, B., Mwangi, M., & Gitari, H. (2022). Heightening sorghum nitrogen uptake while maintaining optimal soil nutrient levels through mineral fertilizer application. *Journal of Applied Life Sciences and Environment*, *54*(4), 458–472. https://doi.org/10.46909/journalalse-2021-040

Mwadalu, R., Mochoge, B., Mwangi, M., Maitra, S., & Gitari, H. (2022). Response of Gadam sorghum (*Sorghum bicolor*) to farmyard manure and inorganic fertilizer application. *International Journal of Agriculture, Environment and Biotechnology*, *15*(**1**5 (1), 51–60. https://doi.org/10.30954/0974-1712.01.2022.6

Mwakidoshi, E. R., Gitari, H. I., Muindi, E. M., Wamukota, A. W., Seleiman, M. F., & Maitra, S. (2023). Smallholder farmers' knowledge of the use of bioslurry as a soil fertility amendment for potato production in Kenya. *Land Degradation & Development*, *34*(8), 2214–2227. https://doi.org/10.1002/ldr.4601

Mwendwa, S. M., Mbuvi, J. P., & Kironchi, G. (2019). Land evaluation for crop production in Upper Kabete Campus field, University of Nairobi, Kenya. *Chemical and Biological Technologies in Agriculture*, *6*(16), 1–10. https://doi.org/10.1186/s40538-019-0156-1

Nasar, J., Zhao, C. J., Khan, R., Gul, H., Gitari, H., Shao, Z., Abbas, G., Haider, I., Iqbal, Z., Ahmed, W., Rehman, R., Liang, Q. P., Zhou, X. B., & Yang, J. (2023). Maize-soybean intercropping at optimal N fertilization increases the N uptake, N yield and N use efficiency of maize crop by regulating the N assimilatory enzymes. *Frontiers in Plant Science*, *13*, 1077948. https://doi.org/10.3389/fpls.2022.1077948

Nduwumuremyi, A., Mugwe, N. J., Rusanganwa, C. A., & Mupenzi, J. (2013). Mapping of limestone deposits and determination of the quality of locally available limestone in Rwanda. *Journal of Soil Science and Environmental Management*, 4(5), 87–92. https://doi.org/10.5897/JSSEM2013.0386

Njira, K. O. W., & Nabwami, J. (2015). A review of effects of nutrient elements on crop quality. *African Journal of Food Agriculture Nutrition & Development*, *15*(1), 9777–9793. https://doi.org/10.18697/ajfand.68.13750

Nyawade, S. O., Gachene, C. K. K., Karanja, N. N., Gitari, H. I., Schulte-Geldermann, E., & Parker, M. (2019). Controlling soil erosion in smallholder potato farming systems using legume intercrops. *Geoderma Regional*, *17*, e00225. https://doi.org/10.1016/j.geodrs.2019.e00225

Nyawade, S., Gitari, H. I., Karanja, N. N., & Gachene, C. K. K. (2020). Enhancing climate resilience of rain-fed potato through legume intercropping and silicon application. *Frontier in Sustainable Food Systems*, *4*, 566345. https://doi.org/10.3389/fsufs.2020.566345

Ochieng', I. O., Gitari, H. I., Mochoge, B., Rezaei, C., & Gweyi-Onyango, J. P. (2021). Optimizing maize yield, nitrogen efficacy, and grain protein content under different N forms and rates. *Journal of Soil Science and Plant Nutrition*, *21*(3), 1867–1880. https://doi.org/10.1007/s42729-021-00486-0

Ochieng', I. O., Ranjani, S., Seleiman, M. F., Padhan, S. R., Psiwa, R., Sow, S., Wasonga, D. O., & Gitari, H. I. (2023). Increasing rainwater use efficiency, gross return, and grain protein of rain-fed maize under nitrate and urea nitrogen forms. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, *51*(3), 13293. https://doi.org/10.15835/nbha51313293

Ojiem, J. O., Franke, A. C., Vanlauwe, B., De Ridder, N., & Giller, K. E. (2014). Benefits of legume–maize rotations: Assessing the impact of diversity on the productivity of smallholders in Western Kenya. *Field Crops Research*, *168*, 75–85. https://doi.org/10.1016/j.fcr.2014.08.004

Oldeman, L. R., Hakkeling, R. T. A., & Sombroek, W. G. (1991). *World map of the status of human-induced soil degradation (GLASOD)* Retrieved May 23, 2023, from https://www.isric.org

Otieno, M. A., Gitari, H. I., Maitra, S., & Nungula, E. Z. (2023). GIS-AHP technique land suitability assessment for capsicum (capsicum annum L.) production. *International Journal of Bioresource Science*, *10*(1), 19–30. https://doi.org/10.30954/2347-9655.01.2023.3

Pournader, M., Ahmadi, H., Feiznia, S., Karimi, S., & Peirovan, H. R. (2018). Spatial prediction of soil erosion susceptibility: An evaluation of the maximum entropy model. *Earth Science Information*, *11* (3), 389–401. https://doi.org/10.1007/s12145-018-0338-6

Pramanik, M. K. (2016). Site suitability analysis for agricultural land use of Darjeeling district using AHP and GIS techniques. *Modeling Earth Systems and Environment*, *2*(2), 1–22. https://doi.org/10.1007/s40808-016-0116

Rascio, N., Dalla, V. F., La Rocca, N., Barbato, R., Pagliano, C., Raviolo, M., Gonnelli, C., & Gabbrielli, R. (2008). Metal accumulation and damage in rice (cv. Vialone nano) seedlings exposed to cadmium. *Environmental and Experimental Botany*, *62*(3), 267–278. https://doi.org/10.1016/j.envexpbot.2007.09.002

Raza, M. A., Gul, H., Wang, J., Yasin, H. S., Qin, R., Khalid, M. H. B., Naeem, M., Feng, L. Y., Iqbal, N., Gitari, H., Ahmad, S., Battaglia, M., Ansar, M., Yang, F., & Yang, W. (2021). Land productivity and water use efficiency of maize-soybean strip intercropping systems in semi-arid areas: A case study in Punjab Province, Pakistan. *Journal of Cleaner Production*, *308*, 127282. https://doi.org/10.1016/j.jclepro.2021.127282

Raza, M. A., Yasin, H. S., Gul, H., Qin, R., Din, A. M. U., Khalid, M. H. B., Hussain, S., Gitari, H., Saeed, A., Wang, J., Rezaei-Chiyaneh, E., Sabagh, A. E., Manzoor, A., Fatima, A., Ahmad, S., Yang, F., Sikalicky, M., & Yang, W. (2022). Maize/Soybean strip intercropping produces higher crop yields and saves water under semi-arid conditions. *Frontiers in Plant Science*, *13*, 1006720. https://doi.org/10.3389/fpls.2022.1006720

Reith, J., Ghazaryan, G., Muthoni, F., & Dubovyk, O. (2021). Assessment of land degradation in semiarid Tanzania—using multiscale remote sensing datasets to support sustainable development goal 15.3. *Remote Sensing*, *13*, 1754. https://doi.org/10.3390/rs13091754

Risse, L. M., Cabrera, M. L., Franzluebbers, A. J., Gaskin, J. W., Gilley, J. E., Killorn, R., & Zhang, H. (2006). *Land application of manure for beneficial reuse*.

Ritung, S., Wahyunto, A. F., & Hidayat, H. (2007). *Land suitability evaluation with a case map of Aceh Barat district*. Indonesian Soil Research Institute and World Agroforestry Centre.

Romeijn, H., Faggian, R., Diogo, V., & Sposito, V. (2016). Evaluation of deterministic and complex analytical hierarchy process methods for agricultural land suitability analysis in a changing climate. *International Journal of Geographical Information*, *5*(6), 99. https://doi.org/10.3390/ijgi5060099

Rop, K., Karuku, G. N., & Nduhiu, C. K. (2022). Evaluation of physico-chemical properties and P sorption characteristics of soil with different land use in Tigoni, Kiambu County, Central Kenya. *Tropical and Subtropical Agroecosystems*, *25*(2). https://doi.org/10.56369/tsaes.4062

Ryan, P. R., Tyerman, S. D., Sasaki, T., Furuichi, T., Yamamoto, Y., Zhang, W. H., & Delhaize, E. (2011). The identification of aluminium resistance genes provides opportunities for enhancing crop production on acid soils. *Journal of Experimental Botany*, *62*(1), 9–20. https://doi.org/10.1093/jxb/erq272

Saglam, M., & Dengiz, O. (2014). Distribution and evaluation of soil fertility based on a geostatistical approach in Bafra Deltaic Plain. *Turkish Journal of Agricultural Research*, *1*(2), 186–195. https://doi.org/10.19159/tutad.27089

Saha, S., Sarkar, D., Mondal, P., & Goswami, S. (2021). GIS and multi-criteria decision-making assessment of sites suitability for agriculture in an anabranching site of sooin river, India. *Modeling Earth System and Environment*, *7*(1), 571–588. https://doi.org/10.1007/s40808-020-00936-1

Saikia, S. P., & Jain, V. (2007). Biological nitrogen fixation with non-legumes: An achievable target or a dogma. *Current Science*, *92*(3), 317–322.

Sanchez-Lozano, J. M., Teruel-Solano, J., Soto-Elvira, P. L., & García-Cascales, M. S. (2013). Geographical Information Systems (GIS) and Multi-Criteria Decision Making (MCDM) methods for the evaluation of solar farms locations: A case study in south-eastern Spain. *Renewable and Sustainable Energy Reviews*, *24*, 544–555. https://doi.org/10.1016/j.rser.2013.03.019

Sarkar, D., Saha, S., & Mondal, P. (2023). Modeling agricultural land suitability for vegetable crops farming using RS and GIS in conjunction with bivariate techniques in the Uttar Dinajpur district of Eastern India. *Green Technologies and Sustainability*, *1*(2), 100022. https://doi.org/10.1016/j.grets.2023.100022

Seleiman, M. F., Aslam, M. T., Alhammad, B. A., Hassan, M. U., Maqbool, R., Chattha, M. U., Khan, I., Gitari, H. I., Uslu, O. S., Roy, R., & Battaglia, M. L. (2021). Salinity stress in wheat: Effects, mechanisms and management strategies. *Phyton-International Journal of Experimental Botany*, *91*(4), 667–694. https://doi.org/10.32604/phyton.2022.017365

Senanayake, S., Pradhan, B., Huete, A., & Brennan, J. (2020). Assessing soil erosion hazards using land-use change and landslide frequency ratio method: A case study of Sabaragamuwa province, Sri Lanka. *Remote Sensing*, *12*(9), 1483. https://doi.org/10.3390/rs12091483

Senjobi, B. A., Peluola, C. O., Senjobi, C. T., Lawal, I. O., Ande, O. T., & Salami, B. T. (2010). Performance of *Corchorus olitorius* as influenced by soil type and organic manure amendments in yewa north local government area, Ogun state. *African Journal of Biotechnology*, *9*(33), 5309–5312.

Sessitsch, A., Howieson, J. G., Perret, X., Antoun, H., & Martinez-Romero, E. (2002). Advances in rhizobium research. *Critical Reviews in Plant Science*, *21*(4), 323–378. https://doi.org/10.1080/0735-260291044278

Shao, Z., Mwakidoshi, E. R., Muindi, E. M., Soratto, R. P., Ranjan, S., Padhan, S. R., Wamukota, A. W., Sow, S., Wasonga, D. O., Nasar, J., Seleiman, M. F., & Gitari, H. I. (2023). Synthetic fertilizer application coupled with bioslurry optimizes potato (*Solanum tuberosum*) growth and yield. *Agronomy*, *13*(8), 2162. https://doi.org/10.3390/agronomy13082162

Shearer, K. S., & Xiang, W. N. (2009). Representing multiple voices in landscape planning: A land suitability assessment study for a park land-banking program in Concord, North Carolina, USA. Landsc. *Urban Planning*, *93*(2), 111–122. https://doi.org/10.1016/j.landurbplan.2009.06.010

Sims, J. T. (1999). Phosphorus soil testing: Innovations of water quality protection. *Soil Science and Plant Analysis*, *29*(11–14), 1471–1489. https://doi.org/10.1080/00103629809370044

Sims, J. T., Simard, R. R., & Joern, B. C. (1998). Phosphorus loss in agricultural drainage: Historical perspective and current research. *Journal of Environmental Quality*, *27*(2), 277–293. https://doi.org/10.2134/jeq1998.00472425002700020006x

Soratto, R. P., Perdoná, M. J., Parecido, R. J., Pinotti, R. N., & Gitari, H. I. (2022). Turning biennial into biannual harvest: Long-term assessment of arabica coffee–macadamia intercropping and irrigation synergism by biological and economic indices. *Food and Energy Security*, *11*(2), 365. https://doi.org/10.1002/fes3.365

STASTICA. (2022). *Production volume of sunflower seed oil worldwide*. Retrieved March 15, 2023. from https://www.statista.com/statistics/613490/sunflowerseed-oil-production-volume-worldwide

Stickler, C., Coe, M., Nepstad, D., Fiske, G., & Lefebvre, P. (2007). Readiness for REDD: A preliminary global assessment of tropical forested land suitability for agriculture. *United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP), Thirteenth session*, Bali, Indonesia. December 3-14, 2007.

Sunil, S., & Prolay, M. (2022). Estimation of the effectiveness of multi-criteria decision analysis and machine learning approaches for agricultural land capability in Gangarampur Subdivision, Eastern India. *Artificial Intelligence in Geosciences*, *3*, 179–191. https://doi.org/10.1016/j.aiig.2022.12.003

Ugulumu, E. S., & Inanga, E. L. (2014). Information accessibility for sunflower Growers in Tanzania. *Journal of Information & Knowledge Management*, *4*(3), 35–44.

Vanlauwe, B., Bationo, A., Chianu, J., Giller, K., Merckx, R., Mokwunye, U., Ohiokpehai, O., Pypers, P., Tabo, R., Shepherd, K. D., Smaling, E. M. A., Woomer, P. L., &

Sanginga, N. (2010). Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. *Outlook on Agriculture*, *39*(1), 17–24. https://doi.org/10.5367/000000010791169998

Verheye, W., Koohafkan, P., & Nachtergaele, F. (2020). *Land use, land cover and soil Sciences - vol. II - The FAO guidelines for land evaluation*. http://www.eolss.net/Eolss-sampleAllChapter.aspx.

Wyland, J. (2009). *GIS for Agriculture-agribusiness grows with crop specific maps; GIS for Agriculture; GIS best practices*. Retrieved July 30, 2022, from www.esri.com/

Zaredar, N., & Jafari, S. (2010). Land suitability analysis using a multi-attribute decision-making approach. *International Journal of Environmental Sustainable Development*, *1*(5), 2010–2064.

Zhang, F., Shen, J., Li, L., & Liu, X. (2004). An overview of rhizosphere processes related to plant nutrition in major cropping systems in China. *Plant & Soil*, *260*(1/2), 89–99. https://doi.org/10.1023/B:PLSO.0000030192.15621.20

Zhihua, Z. D. (2017). *The sunflower sector in Tanzania. Great potential for industrial competitiveness (English)*. World Bank Group.

Zingore, S., Mutegi, J., Agesa, B., Tamene, L., & Kihara, J. (2015). Soil degradation in sub-Saharan Africa and crop production options for soil rehabilitation. *Better Crops with Plant Food*, *99*(1), 24–26.

Zohry, A. E. H., & Ouda, S. (2022). Soil-smart practices: Integrated soil fertility management. *Climate-Smart Agriculture*, *Springer*, 27–43. https://doi.org/10.1007/978-3-030-93111-7-2