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Land use, sowing structures, production of major crops and their implication on food security and sustainable livelihood between Uganda and Hungary for the period 2000–2019

Brian Ssemugenze^{1,2*}, Akasairi Ocwa³, Ronald Kuunya^{1,2}, Noel Kishaija^{4,5}, Kenan Adule⁶, Arpad Illes², Janos Nagy² and Csaba Bojtor²

Abstract

Background The relationship between shifts in agricultural land use, sowing structures, yield of major crops and food security necessitate studies to address today's global challenges such as accelerating economic growthsustaining livelihoods as well as mitigating food insecurity and climate change. Land use changes and utilisation, and sowing structures directly influence both the availability and accessibility of food to the growing global population thus a need for sustainable strategies and policies aimed at addressing the need for adequate food. The contrasting temperate climate of Hungary and the tropical climate of Uganda leads to different land use categories, crop sowing structures, and production of major crops. Therefore, the objective of this study was to analyse the land use, sowing patterns, and crop yield changes for the major industrial and food crops in Hungary and Uganda.

Methods Databases such as Hungarian Central Statistical Office, the World Bank, and the Uganda Bureau of Statistics, covering the period from 2000 to 2019 were the sources of the study data excluding the covid19 period and years later. The data were analysed using XLSTAT, while a trend analysis was performed using the Mann-Kendall test at a 95% confidence level ($\alpha = 0.05$) using EVIEWS software. Land use and land cover (LULC) data from the archives of Uganda National Forest Authority (NFA) and Hungary satellite imagery from NASA EarthData and DIVA GIS was imported to ArcGIS pro for mapping.

Results The trend analysis of the arable land area in both countries using the *Mann-Kendall* Test indicated a significant positive increase ($P = 0.0001$) with the model fit value of 85.59% for Hungary and 83.42% for Uganda. Hungary's agricultural land use slightly declined by 9.3% compared to 19.5% increase of agriculture land use in Uganda. While forest land increased by 15.3% in Hungary, Uganda recorded a 41.9% forest loss to other land use forms. The sowing structures in Hungary remained relatively stable, with minor reductions in maize and wheat areas,

*Correspondence:
Brian Ssemugenze
sbrian@mailbox.unideb.hu

Full list of author information is available at the end of the article



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while Uganda had a substantial increase in maize cultivation by 40%, offset by a 15.4% decrease in banana cultivation. Maize yields increased by 20% (Hungary) and 38.9% (Uganda), wheat yields increased by 10% in Hungary while banana yields declined by 30% in Uganda.

Conclusions Our study has highlighted how sustainability is at risk where increasing agriculture land in Uganda comes at the expense of forest virgin high productive land while strategic sustainability policies of Hungary have converted less productive agricultural fields into forest cover. A need for increased awareness and implementation of available land policies, international and national policy frameworks and guidelines among private agricultural investors, communities, affected land users and financial institutions in Uganda would streamline land use.

Keywords Food security, Sustainable livelihood, Land use, Sowing structures, Hungary, Uganda

Background

According to FAO, food security refers to consistent accessibility (social, physical, and economic) to safe, enough, adequate, and nutritious food that provides all the dietary requirements and preferences of an individual as well promoting a healthy lifestyle [1]. Recent research has focused on establishing the relationship between changes in agricultural land-use and food security amidst the increased economic growth and climate change globally [2]. There is increased demand for land for industries, agriculture, settlement and urbanization due to increased population growth worldwide [3], and this threatens global food security. Changes in land use influence the four main pillars of food security such as food availability, accessibility, utilization, and stability [1]. Such scenarios have been registered in areas where increased need for food, biofuels, and raw materials has led to increased deforestation, loss of biodiversity, and aggravated food insecurity [4]. The global population projection of 9.8 billion by 2050 will increase food demand by almost 50%, a major concern on food supply [5, 10]. Several factors influence food production namely, policies, technological advancement, financial investment, and climate change, however availability of arable land remains the most critical factor [6]. Land use changes prompted by the need for fertile land for agricultural production that favours stable food production and supply [7], have become a norm globally. Such need for land use changes has encouraged national and international policies aimed at reconciliation of agricultural productivity along environmental sustainability [8]. However, all the suggested strategies should adequately consider maintenance of biodiversity and ecosystem services as these are key to long-term food security [9].

As the global population grows exponentially, with projections estimating it will reach 9.8 billion by 2050 [5, 10], global food production faces significant challenges. Both countries differ geographically and economically which shapes the land use, sowing structures and agricultural landscapes. Hungary, located in Central Europe, benefits from a temperate climate, fertile soils, and well-established agricultural practices. The country has a

diverse agricultural sector, characterized by both industrial crops, including maize, barley, rice, and wheat, and food crops such as fruits and vegetables [11]. Hungary's agricultural productivity is enhanced by the application of advanced technologies, extensive mechanization [12], and well-developed infrastructure [13]. Hungary's land use structure features a high proportion of arable land, efficient management practices, and a strong emphasis on sustainable strategies [14]. Hungary's temperate climate [15], together with fertile soils across different agroecological zones which are predominantly flat, and extensive plains [16] supports different land use changes, sowing structures and yield of major crops namely, cereals, oilseeds, and vegetables. This has supported production of food ensuring food security within the country and export to other European countries. Hungary like other European countries face major challenges of labour shortages, aging farmer demographics, extreme weather events thus affecting major crop yields [17]. This necessitates the urgent need for adoption of sustainable farming practices such as agriculture mechanisation.

Uganda, located in East Africa, experiences a tropical climate with considerable variation in rainfall and temperature across the different regions. The country has eight well-defined regions and ten agroecological zones with distinct agroecological conditions, climatic and soil conditions namely; Lake Victoria crescent, northwestern savannah grasslands, Kiyoga plains, north eastern savannah grasslands, lake Albert crescent, highland ranges, northeastern dry lands, western savannah grasslands, and southwestern farmlands [18, 19]), all these have an impact on the crops grown and food produced across seasons. Ugandans mainly practice subsistence agriculture, composed of smallholder farmers. The country's major industrial crops include coffee and tea, which are critical for export earnings, while food crops such as bananas, maize, and cassava are vital for local consumption [20]. The tropical climate characterised with bimodal rainfall patterns in different zones support agriculture and other forms of land use such as mixed cropping, and pastoralism [21]. Approximately 4 million households in Uganda engage in subsistence farming with farm sizes under 2

hectares depending on natural rainfall [22]. The significant portion of subsistence farmers in Uganda are located within the rural areas contributing to significant food production and sustainable livelihood. The major crops cultivated in Uganda include bananas, maize, beans, and cassava as food crops for home consumption while coffee, cotton and tea as income earners for agriculture households [23]. Uganda's agricultural sector is hindered by limited accessibility to modern farming technologies, inadequate infrastructure, and vulnerability to climatic shocks [24]. The land use structure in Uganda is marked by a high reliance on rain-fed agriculture, diverse agro-ecological zones, and a need for improved land tenure systems [25]. The transformation of natural ecosystems into various land use systems [26] presents a significant challenge in Uganda. This transformation is driven by the need to support the livelihoods of smallholders [27]. The high demand for forest products, urban expansion, and infrastructural developments such as highways, hydro-power dams, and industrial parks [28, 29], has increased the pressure on land. Uganda's land use, sowing structures and yield of major crops faces challenges such as soil erosion, deforestation, financial constraints, inadequate infrastructure, land fragmentation, land tenure constraints, inadequate modern farming technologies, and unpredictable weather changes. The agroecological and socio-economic contexts of both countries pose several challenges and opportunities regarding land use, sowing structures and yield of major crops.

Various studies have documented changes in land use, particularly the decline in arable land across Europe, which is crucial for global food production [30]. Across Europe, some countries such as Denmark and Hungary have utilized over 50% of their land for agriculture [31]. However, an increase in forestry and uncultivated land points to a gradual withdrawal from the agricultural production in Europe. This decline has been attributed to the conversion of arable land for settlements and the reforestation of less productive agricultural areas to preserve the environment [32]. They also noted that, while orchards have increased, other forms of arable land use have declined since 1990. High production costs on less fertile land have driven farmers to switch to more viable alternatives such as forestry to avoid losses [33]. The Hungarian government's extensive forest management and conservation plans justify the increase in forestry land [34]. Forests provide multiple community benefits, including wood production and recreational spaces, thus becoming integral to local life [35]. This planned afforestation, along with issues in land ownership, has contributed to the loss of arable land [35]. The competition for land as a major production resource has constrained some land use categories.

Consequently, Uganda has experienced extensive losses of the natural vegetation and increased human activities [29]. These issues are exacerbated by resource overexploitation, unsustainable harvesting and farming practices, and climate change. Notably, threatened ecosystems include Mt. Elgon in Eastern Uganda [36], the Mabira Central Forest Reserve, the Lubigi wetland system [37], and Lake Victoria [38]. These environmental pressures have led to numerous problems, including frequent landslides and floods [39], causing deaths and property loss, biodiversity decline, reduced agricultural productivity, diminished forests [40] and wetland resources [41]. The rising population results in increased demand for arable and settlement land have put immense pressure on fragile ecosystem services [28], evidenced by arable land fragmentation. Therefore, reclassifying the land use systems is crucial for conserving the land cover and effectively managing the land use systems. Agriculture plays a pivotal role in the economic, social, and environmental fabric of both developed and developing nations [13] as a source of food globally.

Uganda and Hungary have different climatic, economic, and social conditions, therefore, comparing agricultural practices, specifically land use and sowing structures, yields valuable insights into sustainable agricultural development. This study compares land use structures, sowing patterns, and the average yields of major industrial and food crops in Hungary and Uganda based on the different agricultural profiles and challenges of both countries. These country specific differences correlate with the prevailing economic activities, government interventions and policies. The study objectives included: (a) Examine land use categories by land area and analyse the agricultural land use trend between 2000 and 2019; (b) Assess sowing structures and average yields of major crops in Hungary and Uganda. The study justification lies in guiding policy interventions aimed at promoting sustainable land use and ecosystems while producing and supplying enough quality food and maintenance of livelihoods amidst the growing population and high investment opportunities in both countries.

Methods

Study area

Uganda, a landlocked country located in East Africa, occupies about 241,550.7 km², of which about 18.2% is water and swamps, and 81.7% is land of the total area. Uganda borders Kenya (East), Tanzania and Rwanda (South), the Democratic Republic of Congo (West), and South Sudan (North) [42]. The country's major source of livelihood is agriculture. Cropland covers the largest land area, followed by bushlands, grasslands, open water, wetlands, forests, and built-up areas [43]. Uganda's climate and rainfall are determined by the presence of water

bodies, relief, and altitude, which influence the land use in Uganda. Uganda experiences both bimodal and unimodal rainfall seasons, with rainfall evenly distributed across its regions, except for the north-eastern part. An average amount of 1,000–1,500 mm of rain is received per year, characterized by wet and dry seasons. Hungary is also a landlocked country, located in the South-Eastern Central region of Europe. It covers a land area of 93,030 km². It shares borders with Slovakia (North), Ukraine (Northeast), Romania (East) Croatia (South), Slovenia (Southwest), Serbia (Southeast), and Austria (West) [44]. The precipitation data for the climatological normal period between 1991 and 2019 shows that Hungary receives 500–800 mm precipitation in a year; however, significant differences vary from one region to another. Spatial rainfall distribution and precipitation are mainly influenced by topography and the Mediterranean climate originating from both the Mediterranean Sea and the Atlantic Ocean [45].

Definition of relationship variables

Land Refers to a composition of several components and ecological resources namely, climate, water, soil, landforms, flora, and fauna interacting with other socio-economic systems like agriculture, forestry, and other land uses [46]. Measured in hectares (ha).

Land use Refers to the different arrangements, and activities in which people engage on a certain piece of land to produce, change, reproduce or maintain it [47].

Land cover Refers to the observed biophysical state of the earth's surface, largely described by the presence or absence of various vegetation types [47].

Land use change Refers to the process by which human activities transform the natural landscape, how land has been used emphasizing the functional role of land for economic activities [48].

Crop yield Crop yield refers to the weight of grain or other economic product, at some agreed standard moisture content, per unit of land area harvested per crop (t/ha) [49].

Data access and processing

This study focused on the pre-pandemic period between 2000 and 2019 to analyse land use, sowing structures and yield trends between Uganda and Hungary. The exclusion of 2020 and following years excluded long-run agricultural and policy trends aimed at containing pandemic shock. The study period provided enough temporal depth to detect structural land use changes. The data was accessed, retrieved and collected from different data

sets; Hungarian land use data was retrieved and collected from the Hungarian Central Statistical Office (land use and sowing structure data) [11], while the Ugandan data was collected from the World Bank database (average crop yield data) [20] and the Uganda Bureau of Statistics (land use and sowing structure data) [50]. The Hungarian data was complete and accessible, while some data for Uganda was incomplete and/or inaccessible. Therefore, the comparisons were based on only available data. The selection of major crops was mainly based on the available data. Crops were ranked based on the land size covered (acreage) and yields, local and global importance; those that scored highly in our selection criteria were considered as major crops for the study.

Data sources

LULC data.

Uganda

To map the land use/land cover for Uganda, premade LULC data was attained from the archives of National Forest Authority (NFA) by means of request for the years 2000, 2010 and 2019, as NFA is the principal custodian for national LULC data in Uganda. The NFA classification scheme majorly produces 13 major classes, which all have constituent LULC classes, namely, Forest (hardwood plantations, softwood plantations, tropical high forest-normally stocked, tropical high forest-depleted/encroached); Woodland (trees and shrubs with average height > 4 m); Bushland (bush, thickets, scrub with average height < 4 m); Pastoral land (grassland, rangelands, pasture land); Cropland (subsistence mixed farmland, commercial farmlands); Wetlands (wetland vegetation, swamp areas); Open water (large rivers, ponds, lakes); Built up area: (urban or rural built up areas); Impediments (bare rocks and soils) [51]. In ArcGIS Pro, the classes of interest in Uganda (Forests, Bushlands, Grassland, Wetlands and Farmlands) were retrieved for visualisation in maps for the purpose of this study. The other LULC classes were subsequently merged into one and named other classes in the maps [52].

Hungary

To determine LULC of Hungary satellite imagery from NASA EarthData and DIVA GIS were utilised. The satellite images were retrieved for the years 2000, 2010 and 2019 [53]. The images retrieved comprised of Red Reflectance, Blue Reflectance, Near Infrared and Normalised Difference Vegetation Index (NDVI). The images were imported into ArcGIS Pro and combined to a single raster file by means of mosaicking to create a seamless image. An unsupervised classification was performed on the mosaicked image using the Iso Cluster Unsupervised classification, where 10 classes were assigned. Ten classes

were assigned to allow model identification of sufficient spectral patterns for easy post classification of the LULC of interest (i.e., Fishponds, Reeds, Forestry, Agriculture and grasslands) [54]. The post classification involved visual interpretation of the ten classes through Open Street Map tool to allow reclassification of the 10 classes into the classes of interest. Other classes such as buildup, bare ground among others were merged and labelled other land uses in the maps. The key identifiers for the five classes of interest were as follows [55].

- Fishponds: Very low reflectance values (appear dark), geometric shapes, and smooth textures located in and near waterbodies like rivers and lakes.
- Reeds: Characterized by moderate NIR AND NDVI reflectance, located adjacent to and surrounding water bodies like fishponds and other waterbodies like rivers and lakes.
- Forestry: Very high NIR and NDVI reflectance (appears bright red in standard colour-infrared composites), found in contiguous, textured patches corresponding to forested areas.
- Agriculture: Exhibits a range of medium reflectance values, often in geometric, rectangular patterns typical of cultivated fields.
- Grasslands: Shows spectral signatures like but often less intense than agriculture, located in non-forested, non-cultivated open areas.

Data analysis

After collecting data from the databases, data was converted into percentages for consistency and analysed using XLSTAT. Trend analysis was done using the Mann-Kendall test at a 95% confidence level ($\alpha = 0.05$) using EVIEWS software. Mann-Kendall test was done specifically on the agricultural land change for both Hungary and Uganda (% of total land area) for 19 years testing for significance. Agricultural land was considered due its importance to land use dynamics, its contribution to national food security, and the availability of consistent annual data from the Hungarian Central Statistical Office, Uganda Bureau of Statistics, and the World Bank. Subsequently, 100 random accuracy points were created using the Create accuracy assessment points tool in ArcGIS tool on all the classified images to allow accuracy inspection in Google Earth Pro. The accuracy points were converted to KML file format and imported in Google Earth Pro for the accuracy inspection. Where the identified classes did not conform to what is on ground, they were edited [56]. The final maps products were reimported in ArcGIS pro for mapping.

Results

Land use (cover) stratification for the period 2000–2019

Figure 1 shows the land use (cover) stratification maps summarising different LULC classes for both Uganda and Hungary for the period 2000 to 2019. Across the study period, both countries have seen agriculture as the dominant land use cover (Fig. 1), this signifies the impact of agriculture to food security and sustainable livelihood of both nations. The land use (cover) stratification has changed over the study period except waterbodies according to the maps. Hungary and Uganda showed some similar land use categories with minor differences. The land use (cover) of Hungary composed of agriculture, forests, grassland, reed, and fishpond while that of Uganda composed of agriculture, forests, bushland, wetland, and grassland.

Major land use categories between Uganda and Hungary for the period 2000–2019

Results showed that agriculture was the dominant land use category for both Uganda (66.46%), and Hungary (58.5%) respectively, forests occupied 16.22% in Uganda while 23.21% in Hungary, grassland occupied 7.6% in Uganda compared to 13.78% for Hungary. Other land use categories (4.51%) included bushland, wetlands, urban areas, water bodies for Uganda while reeds, fishponds, urban areas were among other land use categories (6.1%) for Hungary (Fig. 2). Analysis of land use changes over the study period recorded notable variations whereby agriculture consistently declined by 9.3% from 5853.9 thousand hectares in 2000 to 5309.5 thousand hectares in 2019 in Hungary compared to steady increase of 19.5% (agriculture land use) over the same study period from 90,192 thousand hectares in 2000 to 107,729 thousand hectares in 2019. During the 2000–2010 period, Hungary recorded the peak agriculture land use loss of 8.7% (Fig. 2A). Forests as the second largest land use (cover) in both countries recorded an increasing curve for Hungary while a decreasing curve for Uganda. Large areas of forest land were lost during the study period totalling to 41.9% from 37,866 thousand hectares in 2000 to 21,993 thousand hectares in 2010 however government and individual efforts slightly restored forest cover to 27,292 thousand hectares in 2019, thus a net 27.9%. This compared to Hungary where forest cover has greatly increased 15.3% over the study period from 23.21 thousand hectares in 2000 to 26.76 thousand hectares in 2019 (Fig. 2c). Grassland as an important resource for livestock production increased for Uganda's case but decreased in Hungary. Over the study period, a 20.9% decline was recorded whereby between 2000 and 2010, grassland acreage reduced from 13.79 to 10.51 thousand hectares while Uganda recorded a 98.0% increase from 27,940 thousand hectares in 2000 to 55,315 thousand hectares in

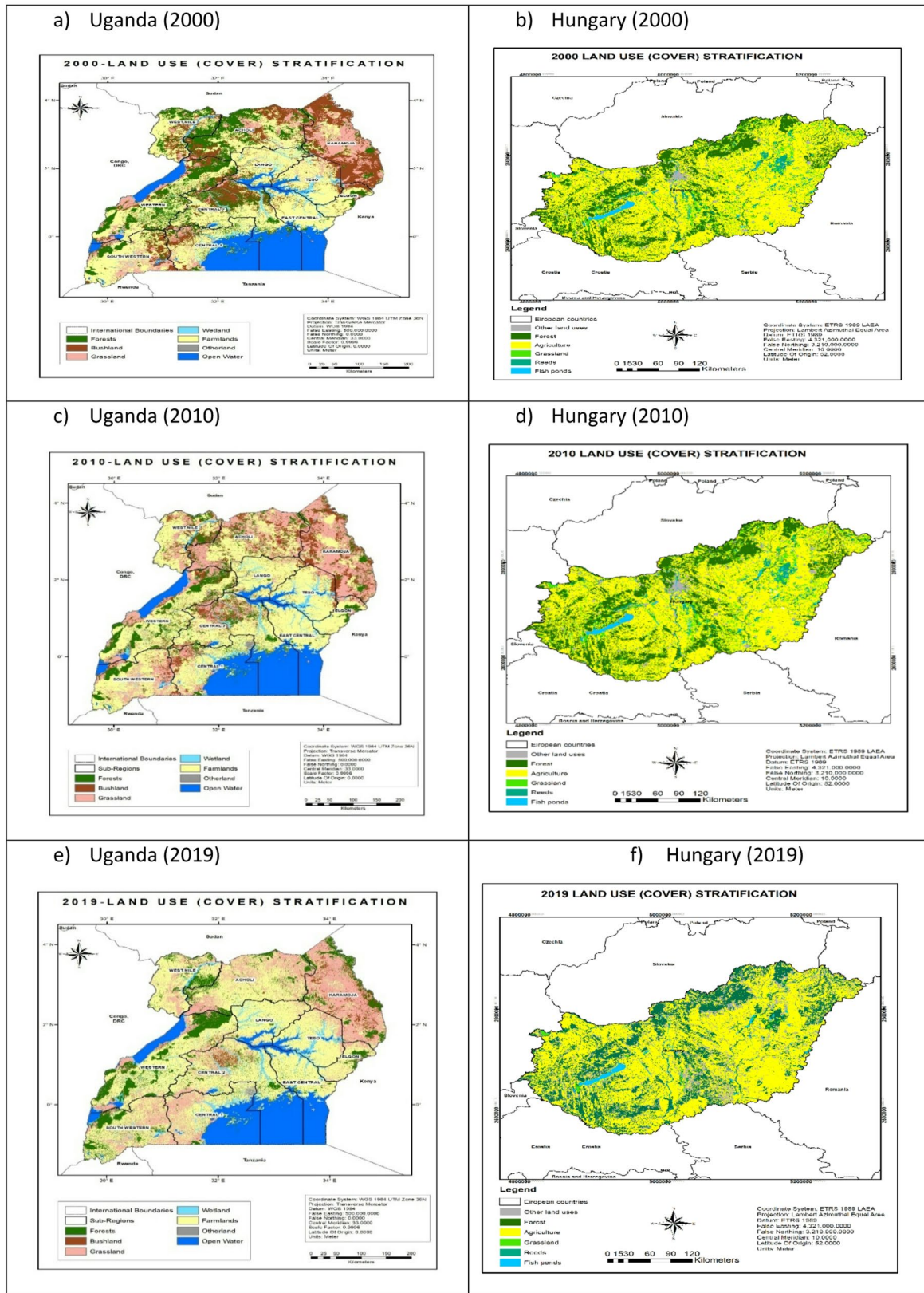


Fig. 1 Land use (Cover) stratification maps for Uganda and Hungary for 2000, 2010 and 2019; NFA data for Uganda; Hungary satellite imagery from NASA EarthData and DIVA GIS

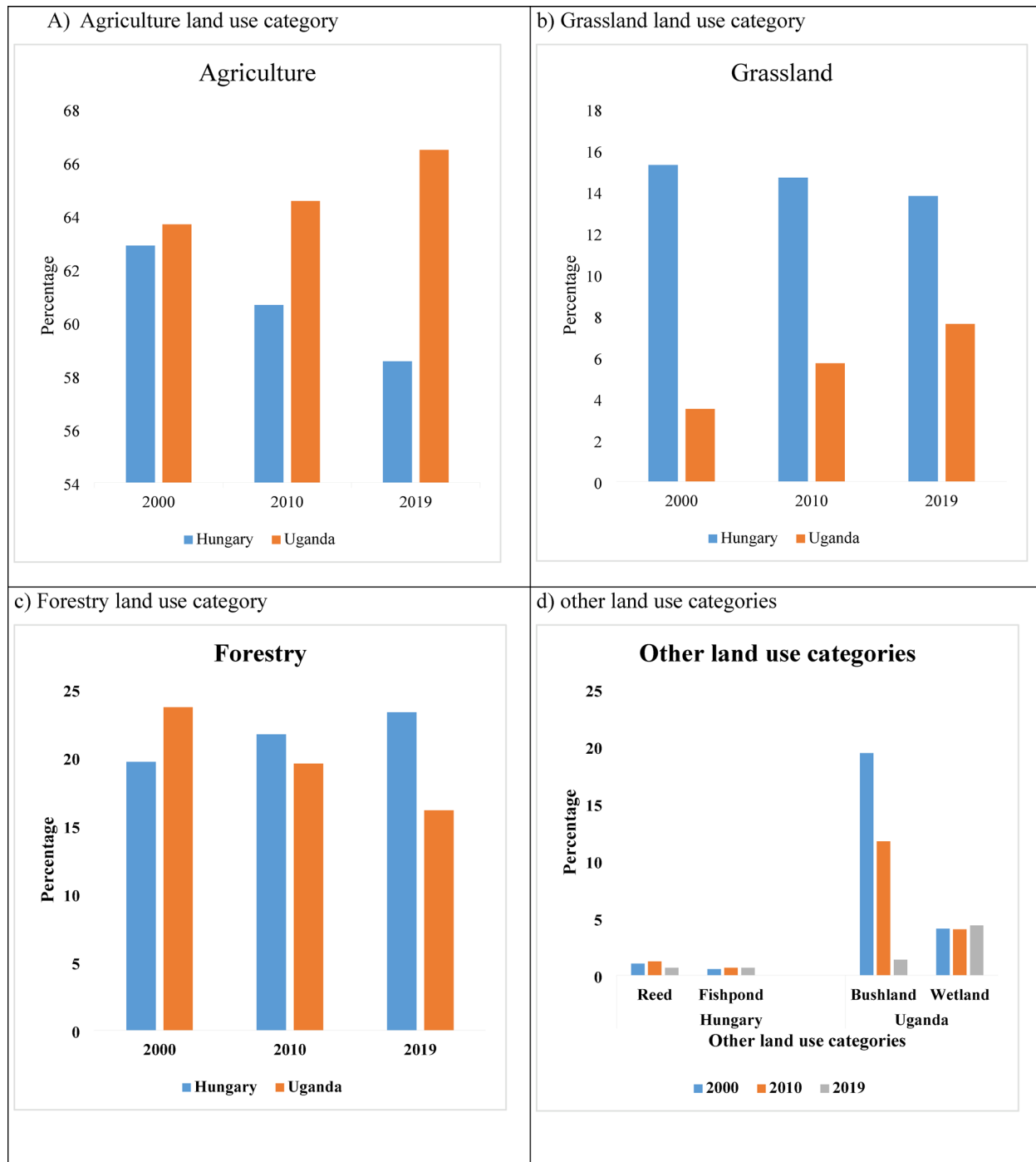


Fig. 2 Comparing major land use categories between Uganda and Hungary; **a)** Agriculture; **b)** Grassland; **c)** Forestry; and **d)** other different land use categories; 2000–2019. Data from UBOS (Uganda) and HCSO (Hungary)

2019, almost doubling over the 19 years (Fig. 2b). Other land use categories varied for both countries whereby reed areas in Hungary severely decreased by 41.8%, fishpond land use consistently increased by 10% from 32 thousand hectares in 2000 to 35.2 thousand hectares in 2019, whereas Uganda had no reed and fishpond land use studied but bushland and wetlands constituted other

land use categories which wasn't the case for Hungary. Bushland drastically decreased by 93.2% from 40,079 thousand hectares in 2000 to 2,734 thousand hectares in 2019. The most significant loss of 88.5% between 2010 and 2019 and 40.8% drop between 2000 and 2010. Wetlands decreased by 4.6% increase from 8,773 in 2000 to

8,385 thousand hectares in 2019 over the study period (Fig. 2d).

Perspective of LULC on smallholder and large-scale farming systems in Uganda and Hungary

Both Uganda and Hungary have presented contrasting agricultural systems during the 2000–2019 study period. These differences have been recorded on farm structure, land use, farm sizes, and productivity thus a reflection of economic development, policy frameworks, and land tenure in both countries. The National Land Act (Act No. CXXII/2013) of Hungary noted that the backbone of Hungary's agricultural sector majorly depends on family farms (3.4 hectares each) which contribute significantly to the country's GDP. Just like Uganda where the agricultural sector is predominantly occupied by smallholder farmers (1–3 acres) [30] as shown in Table 1 below. The Hungarian family farms employ permanent staff as farm labour enhancing yields while Uganda's smallholder farmers face land tenure insecurity, inequality of land accessibility, land fragmentation, land degradation, thus affecting agricultural yields. The Hungarian agriculture large farms make up only 1% occupying above 100 ha; however, these farms utilise the biggest agricultural land (72.2%), small individual farms under 10 ha (25%) however 70% of smallholder (individual) farmers owned less than 1 ha of land. Over the 20-period time, smallholder farms have declined in Hungary however there has been an increase of average farm sizes occupying 70% of total Hungarian agricultural land specialising in arable crop production. There is a bigger difference in average farm sizes between Uganda (1.51 ha) and Hungary (8.6 ha). The percentages of smallholder farms and commercial farms between the two countries didn't differ significantly, Hungary (93.4%, 1%) and Uganda (78–85%, 3–5%) (Table 1). FAO [13, 20], noted a production decline for staple food crops such as bananas, sweet potatoes, and cash crops like coffee and cotton over the past two decades in Uganda. Policy changes aimed at structural consolidation and a shift toward market-oriented crop production should address structural and policy challenges aimed at agricultural sector modernisation through public investment, improved input delivery systems, advisory services, research, and environmental risk

Table 1 Description of farmers and farm sizes between Uganda and Hungary

Description	Uganda	Hungary
Smallholder (individual/family) farm	0.97 ha	3.4 ha
Commercial farm	5.74 ha	486 ha
Average farm size	1.51 ha	8.6 ha
Percentage of smallholder farms	78–85%	93.4%
Percentage of commercial farms	3–5%	1%

(Data source: FAO [13, 20])

management, enabling yield improvement thus addressing food security and sustainable livelihood.

Agricultural land changes in Hungary and Uganda for the period 2000–2019

Trend analysis of agricultural land area using the Mann-Kendall test showed a statistically significant increase in both Hungary ($P=0.0001$; $R^2 = 85.62\%$) and Uganda ($P=0.0001$; $R^2 = 83.6\%$) (Fig. 3). This positive change implies that some land use categories such as forestry and bushlands, have registered a significant decline, which has been converted to agricultural land, reflecting increased deforestation pressures.

The sowing structure and average yield of different crops in Uganda and Hungary sowing structures

Uganda and Hungary recorded diverse agricultural priorities and practices influenced by climatic and weather factors, economic factors, and land use systems. The sowing structure revealed a relatively stable crop structure for Hungary which contrasts Uganda's unstable sowing structure marked by significant changes in food and commercial crops cultivated. Maize production areas increased by 40%, from 0.5 million hectares in 2000 to 0.7 million hectares in 2019 compared to Hungary where maize and wheat production areas slightly decreased by 6.2% and 4.8%, respectively. While Uganda regards maize and banana as major staple food and livestock feed, it's not the case for Hungary thus describing the sowing structural differences. Conversely, Uganda's banana cultivation declined by 15.4%, decreasing from 1.3 million hectares to 1.1 million hectares attributed to disease pressures and land competition (Table 2). Uganda's crop diversification strategy is less formalized and largely market-driven, often influenced by subsistence needs and seasonal climate variability compared to Hungary's technology driven agriculture mainly for commercial purposes and export.

Average crop yields The yield improvements of major crops were noted in both countries categorised into food crops such as maize and wheat for Hungary, maize and banana for Uganda. Hungary and Uganda noted an increased maize yield 20% and 38.9% respectively, wheat yield increased by 10% in Hungary while banana yields saw a strong decline of 30% over the study period. The maize yield trend of Hungary ranges from 6.5 t/ha in 2000 to 7.8 t/ha in 2019 while Uganda's maize significantly increased from 1.8 t/ha in 2000 to 2.5 t/ha in 2019. Wheat a major cereal in Hungary increased from 5.0 t/ha in 2000 to 5.5 t/ha in 2019 while Uganda's banana yield declined from 10.0 t/ha in 2000 to 7.0 t/ha in 2019 (Table 2).

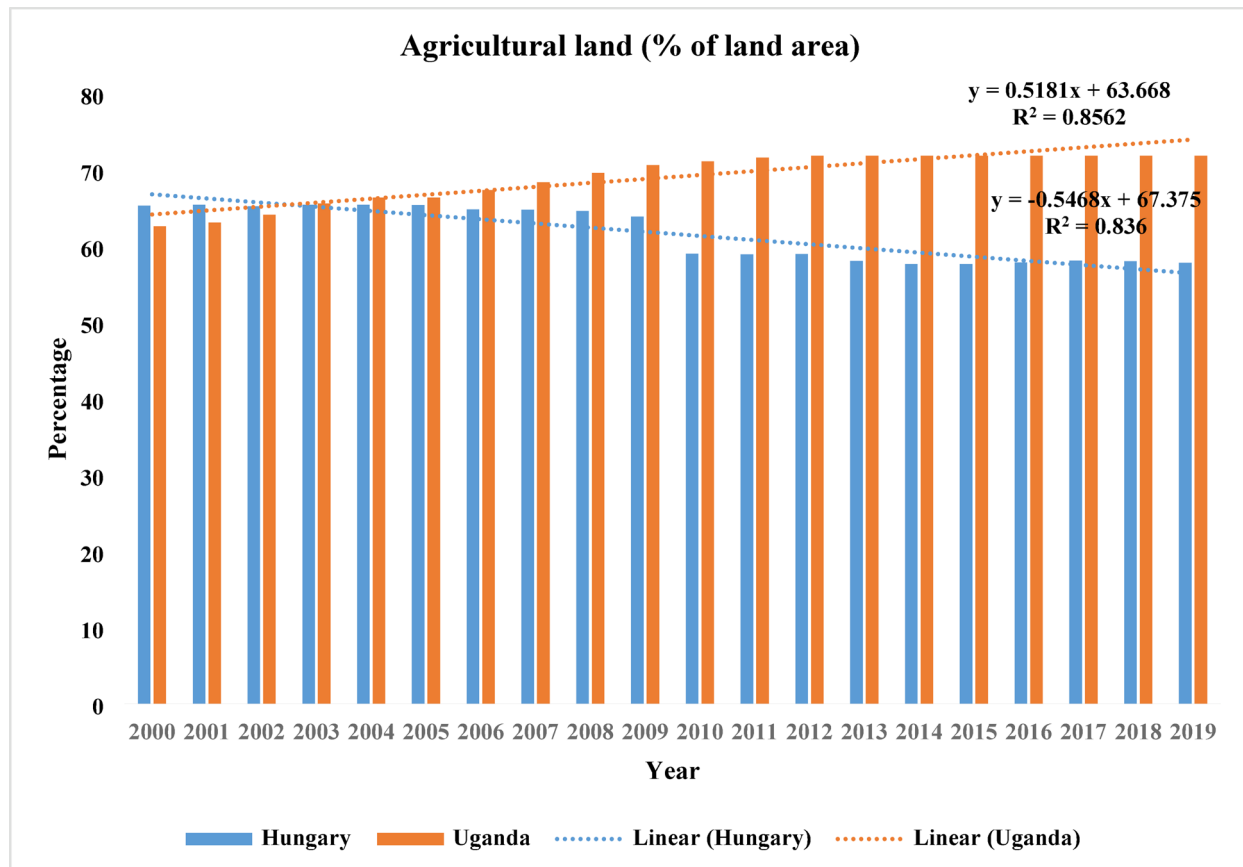


Fig. 3 Percentage agricultural land for Hungary and Uganda; 2000–2019; World Bank, 2020

Table 2 Summary of the major results for land use categories, sowing structures and average yield of major crops in both countries

Land use parameter	Description	Year			
Major Land use categories		2000 (%)	2019 (%)	Change (%)	
	Hungary	Agriculture	89.3	88.4	-5.8
		Forest cover	20	23	15
	Uganda	Agriculture	43	58	19.5
	Forest cover	24	12	-50	
Sowing Structures	Major crops	2000 (million ha)	2019 (million ha)	Change (%)	
	Hungary	Maize	1.2	1.1	-8.3
		Wheat	1.0	0.9	-10
	Uganda	Maize	0.5	0.7	40
	Bananas	1.3	1.1	-15.4	
Average Yields	Major crops	2000 (t/hectare)	2019 (t/hectare)	Change (%)	
	Hungary	Maize	6.5	7.8	20
		Wheat	5.0	5.5	10
	Uganda	Maize	1.8	2.5	38.9
	Bananas	10	7	-30	

Discussion

Land use (cover) stratification for the period 2000–2019

Agriculture, forests and grassland were dominant land use (cover) in both countries, while reed and fishponds were noted for only Hungary. Our study has closed a recent noted research gap in recent studies that excluded open water and other water bodies on land use maps, yet they rank among the largest land use (cover), Luwa et al., [57] noted that most LULC studies conducted in Uganda excluded water bodies among land use categories, a summary of both fishponds for Hungary and open water for Uganda among the land use (cover) stratification, denotes the climate differences and availability of water as an important resource for both agriculture and home use. A study conducted in western Uganda by [52] noted that the dominant LULC were agriculture, forests, waterbodies, grassland, shrubland, wetland, and urban areas. Several factors have been noted to contribute to changing land use (cover) stratification namely, increased demand for human need to survive [57, 58]; exponential population growth amidst the constrained resources causing shortage of essential needs like food, shelter, and other livelihood necessities [52]. Gillespie et al. [58] cited climate change as a key driver of land-use (cover)

changes. In Uganda, deforestation has been noted as a major cause of forest loss as well the rates of urbanization, encroachment on gazetted areas like game parks and reserves, wetlands, have greatly led to loss of different land cover such as wetlands, bushland and grasslands [42, 59]. Important to note that the goal of encroachment is to grow more food, settlement and industrialisation. Therefore, the factors leading to loss and changes of land use (cover) such as high population growth, industrialisation, food insecurity as well as their effects should be checked and handled with utmost care as they threaten the sustainable livelihood and deprive the future generations' survival.

Major land use categories between Uganda and Hungary for the period 2000–2019

Several studies have presented changes in land-use in Uganda majorly focused on areas such as urban settlements, gazetted areas such as national parks, wetlands, game reserves, drylands, rift valleys, as well defining the geographical scope [60–62]. According to the Hungarian Statistical Office [11], agricultural land-use categories Of Hungary showed a decline while forests, reeds and fishponds increased. The study conducted by Bernard et al. [63] showed that agriculture land use consistently increased in Southwestern part of Uganda between 1975 and 1999. This percentage increase of agriculture land use could be attributed to high population growth which translates into increased food demand produced through farming [60]. The Uganda government has rolled out different agriculture programmes and policies aimed at expanding agricultural production. These programmes such as Plan for Modernisation of Agriculture (PMA), National Agricultural Advisory Services (NAADS), have promoted and expanded production of major crops such as tea, sugarcane, palm oil and coffee over the last two decades. These programmes have given out farm support such as seedlings, advisory services, fertilisers, pesticides [64]. The results in both countries are attributed to different factors which have caused a shift from one land use category to another. The significant decrease of agriculture land use in Hungary was attributed to its withdrawal from agricultural production for settlements and the planting of trees [32], thus a positive correlation between decreased agriculture land use and increased forestry land use. Several scholars across Europe have noted a decline of agriculture land use since 1990 [31]. Bozsik and Koncz [32], noted that several economic sectors other than agriculture contribute tremendously to Hungary's GDP and employment opportunities thus taking more land from agriculture. Sectors like real estate and infrastructure developments such as industrial, urbanization, and the development of transport require new areas as they improve the livelihood of the population. Also,

sustainability measures have costed agriculture mainly measures aimed at conserving the soil, nature, landscape, and protection of water protection aspects were also involved. This contrast highlights the different challenges faced by both countries in managing their land resources, with Hungary focusing on sustainability through planned land use changes, while Uganda is struggling with issues of overexploitation, deforestation, and environmental degradation.

Forests as the second largest land use (cover) in both countries recorded an increasing curve for Hungary while a decreasing curve for Uganda. The decrease of forest land cover in Uganda agrees recent studies that indicated decline of forest land area in Uganda [59, 65, 66]. Encroachment to natural resources such as forests by human activities such farming and settlement depletes natural resources [60]. However, a study by Kishaija et al. [52], noted that forest cover in western Uganda increased by 0.1% which contradicts our findings and attributed this to different government forest restoration program by National Forestry Authority. The government has leased out free public land to private individuals who have planted different tree species such eucalyptus [67]. Uganda has been ranked among the countries with the highest forest loss (2.6%) as reported by World bank [68]. The world bank report attributed this forest loss to exploitation by rural households for firewood used for cooking and charcoal burning [69]. Tree planting (forests) has proved as one of the viable options adopted to use less profitable and infertile land which can no longer support agriculture due to high production costs incurred. The government of Hungary has a grand plan regarding forest management and environmental conservation, and this justifies the increase in forestry land. The increased use of trees/treelines has mostly promoted forestry, and such efforts have led to improved climate and environmental adaptation measures [34]. Forests also furnish several uses to the communities, including wood production and recreational purposes, thus making them an integral part of the community, justifying the increase in the forest cover in Hungary. The increased forestry land in Hungary was attributed to planned afforestation, however, disorder in land ownership has led to the loss of arable land [32].

Grassland as an important resource for livestock production increased for Uganda's case but decreased in Hungary. Our findings differ from Kishaija et al. [52] results that grassland declined by 0.22%, however agree that shrubland and wetland have declined, this discrepancy might be because Kishaija et al. [52] limited the study to only western region of Uganda while our study covered Uganda in general and the different databases used for data collection. Recent studies [70, 71] asserted that farmland areas have increased mainly for rural areas

while forest continue decreasing. Scholars have noted that the rate of conversion of natural resources to land use forms is alarming in Uganda as the population tries to meet the livelihood demands, the increased demand for forest products, urban settlements and expansion, and infrastructural developments such as markets, roads, hospitals, schools, power dams, and industrial parks [42]. This has caused massive losses and constrained the natural ecosystems and resources at the cost of survival and livelihood.

Agricultural land changes in Hungary and Uganda for the period 2000–2019

The positive change implies that some land use categories such as forestry and bushlands, have registered a significant decline, which has been converted to agricultural land, reflecting increased deforestation pressures. Different studies have accounted for the changes in land use but mostly focused on the decline in agricultural land in Europe, which is the backbone of food production. A comparison of the size of agricultural land in European countries established that both Denmark and Hungary recorded over 50% of their land being used for agricultural production [31]. It was also reported that only forestry and uncultivated land showed an increase over other land use types, indicating that a significant percentage of the population in Europe is gradually withdrawing from agricultural production. In Uganda, the agricultural land cover has been seen to gradually increase at the expense of other land use forms, such as forest cover and bushland. This change is attributed to the fact that most of the new productive virgin land required for agricultural production is covered by forests. Therefore, people in Uganda tend to cut down trees to open new agricultural fields [72]. Another justification is the promotion of commercial large-scale plantation farming, such as sugarcane growing [73] and palm oil tree production [74]. Such efforts have led the government to give away forest land to investors for agricultural production. Furthermore, to a larger extent, 80% of households in Uganda use wood and charcoal as a source of fuel for cooking [75], therefore, trees are cleared for charcoal production and fuelwood.

The sowing structure and average yield of different crops in Uganda and Hungary sowing structures

Several factors have contributed to changes in sowing structures of both countries such as loss of arable (agriculture) land to other land use forms [76], population pressure [75], global climate change a major threat to crop production, causing food insecurity and poverty [77, 78], shortage of external farm inputs, pests and diseases, slash-and-burn cultivation, nutrient mining, soil fertility issues, deforestation, soil erosion, and

climate-related drivers such as Greenhouse Gas (GHG) emissions, delayed precipitation, and temperature variations [79, 80]. Drought spells across Europe, causing a rise in temperature and decreased precipitation [81, 82], have greatly impacted agricultural productivity among farmers. Land degradation affecting 1.5 billion people has become a global concern as well, leading to land use changes impacting the major crops [83, 84]. An estimate of about 5–8 million hectares of land formerly used for production is lost due to degradation worldwide [85]. Hungary like Uganda face high vulnerability to diverse weather changes, such as frequent droughts, which affect sowing patterns and practices [86], and these drought occurrences are predicted to increase in the future [87, 88]. This implies that sowing structures for different crops will keep changing in both countries. Changes in sowing structures are among the measures adopted to counter strong climate change impacts such as drought disruptions and economic losses [89]. However, despite the changes in the sowing structures due to drought spells in Hungary, there has been a notable increase in cereal yields, mainly maize and wheat [90], attributed to improved farming techniques and research [91], proper cultivation methods, appropriate land use practices, and integrated pest and disease management [92]. The change in sowing structures reflects the need to enhance efforts aimed at adapting to changing climatic and environmental conditions. This justifies the need to tailor agricultural strategies to address each country's unique challenges and opportunities.

Average crop yields Variations in average crop yields revealed significant differences, attributed to country specific agricultural practices, climatic conditions [93], application of advanced agricultural technologies [94, 95], efficient land management practices [96], research and development in agriculture [96]. Hungary's agricultural sector has benefited from appropriate agricultural management practices such as precision irrigation, proper plant density, hybrid selection, and fertilizer application [97], all of which have enhanced maize production. Banana production decline has resulted from climate shock, limited farm external inputs, pests and diseases, poor farm management and cultivation practices, soil fertility management issues, deforestation, soil erosion, and delayed and poorly distributed precipitation [79, 80]. The agricultural sector in Hungary mirrors a well-developed infrastructure, extensive mechanization, and strong government support, all of which have contributed to higher productivity and yield stability, thus improving food security. In contrast, Uganda faces significant challenges, including limited accessibility to modern farming technologies, inadequate infrastructure, and the vulnerability to climatic shocks, all of which impede the agri-

cultural productivity and yield of major crops [80] thus food insecurity. The yield of major crops in both countries has enhanced food security as maize, wheat and banana act as staple food crops and nutritional sources for both human and livestock at local, national, and global arena thus ensuring sustenance and food supply stability.

Policy frameworks and interventions to guide land use, sowing structures and improve major crop yields in Uganda and Hungary

Sustainable land use requires suitable policies tailored towards achieving sustainable development, food security and livelihood improvement. Both Hungary and Uganda have implemented supportive policies, initiatives and programmes thus solving challenges relatable to land use land cover, sowing structures, and yield of major crops. Legal frameworks such as the Uganda Constitution of 1995, Land Act of 1998, and the National Land Policy of 2013, offer major guidance to land use in Uganda however challenges like weak enforcement, outdated laws and policies, and inequitable land distribution hinder effective land use governance. Environmental conservation, sustainable land use management, wetland and forest restoration policies have been the area of focus by Uganda government [98]. Community sensitisation initiatives, adoption of alternative livelihood strategies among communities around wetlands and forests have promoted sustainable land use and economic according to the World Bank [68]. The National Planning Authority, 2020 set the Uganda's vision 2040 aimed at economic transformation through agricultural productivity, sustainable use of natural resources, oil exploration, and industrialization. Enhancing Uganda's sowing structures, land use and yield of major crops requires stronger institutional capacity to all line ministries and programs such as Plan for Modernization of Agriculture (PMA), Ministry of Lands, District Land boards, Ministry of Agriculture, Animal Industry and Fisheries (MAAIF), NAADS [10], thus sustainable agricultural development and food security. Harmonisation of land use and land cover change (LULCC) data with all the above government strategies improves sustainable livelihood, biodiversity balance, and food security through improved agricultural production.

Hungary's rural development budget (38%) supports agricultural and environmental strategies, organic farming expansion (8%), and Natural site protection (5%). Hungary's land use and management policies align closely with the European Union's reformed Common Agricultural Policy (CAP), that fosters a sustainable and modernised land utilisation for agricultural purposes. CAP emphasises funding and support to small and medium-sized farms, young farmers, and other agricultural innovations and practices such as precision,

SMART, and agro-ecological farming. The EU funding of €8.4 billion for 2023–2027 has been dedicated to climate and environmental (€2 billion), and young farmer empowerment (€186 million). The National Forest Strategy (2016–2030) of Hungary promotes sustainable forest management, afforestation, biodiversity protection, and carbon sequestration, ensuring forests contribute to climate resilience and rural livelihoods. Together, these policies reflect Hungary's integrated approach to balancing agricultural productivity, environmental protection, and social equity reinforcing the broader EU goals of the Farm to Fork and Biodiversity strategies for a greener, fairer, and more sustainable rural economy.

Conclusions

Our study has analysed land use, sowing structures, and average yields of major crops drawing a significant comparison and lessons these two countries located in different agroecological regions. Uganda and Hungary have exhibited a diversity of agricultural practices, the common challenges, land use differences, policy differences and measures at balancing productivity with sustainability. Uganda predominantly smallholder-based agricultural systems have proved easily adaptable across all agroecological zones however faced with challenges such as insecure land tenure due to bottlenecks within the land act and outdated laws and policies, limited technology access, and low agricultural mechanization which has seen a total decline in major food crops such as bananas. Compared to Uganda where no regional ties have been evidenced, Hungary has exploited the advantage of being an EU member state through structured land-use planning, policies such Common Agricultural Policy (CAP), that have funded and supported land use, and advanced mechanized farming, this has promoted agricultural production and higher crop yields. Both countries should strengthen strategies and policies that align with the Sustainable Development Goals mainly (SDGs 1, 2, 12, 13, and 15), thus enhancing sustainable agriculture production, climate resilience, promotion of food security, economic growth, and rural livelihoods. The legal frameworks of Uganda such as Vision 2040, Uganda Constitution 1995, National Development Plan III, and National Agricultural Policy, appreciate agriculture as a major socio-economic transformation driver however weak enforcement has derailed implementation in areas of agroforestry integration. Hungary has committed and implemented the EU's Common Agricultural Policy (CAP 2023–2027), National Forest Strategy (2016–2030), National Rural Development Programme, and National Sustainable Development Strategy thus efficient and effective land use, sowing structures, and ecological farming practices, drawing an important lesson

on implementation strategies, regional support which Uganda can adapt.

Despite challenges such as limited modern farming technology, research gaps, poor infrastructure, and climatic shocks, Uganda has improved average yields of some major crops, such as maize. The study highlights the importance of tailored agricultural strategies, suggesting that Hungary's technological investments and Uganda's adaptive methods provide valuable lessons for enhancing land use practices, sowing structures, and crop yields. To strengthen sustainable land use, sowing structures, and food security through increased yield of major crops in both countries, this study recommends the following policies initiatives:

- **Climate-Smart practices and inclusivity:** Uganda should develop, adopt and implement working afforestation and forest conservation programs aimed at the promotion of sustainable agroecological practices that enhance health of the soil and climate shock resilience. This reflects SDG 13 (Climate Action) and SDG 15 (Life on Land), as well as addressing gender and youth inclusion. Crop diversification and post-harvest handling strategies support improved livelihoods and food security (SDG 1 and SDG 2).
- **Mechanization and technology transfer:** Hungary should capitalize on precision technology adoption, agricultural research, and efficient land management policies to strengthen crop production, sowing structures and to optimize crop yields and protect ecological zones. Uganda should invest and fund appropriate mechanization, precision agriculture, and digital tools that have supported Hungary's high yields, while ensuring they are affordable and adapted to smallholder contexts.
- **Research and capacity building:** It is a need of both countries to enact, establish, and strengthen collaborative platforms and programs such as joint academic and research collaboration to aid knowledge exchange on sustainable land use practices, climate resilience, research, agricultural technology and innovations, and climate-smart agriculture, considering their complementary climatic and socio-economic contexts.
- **Policy realignment and enforcement:** Uganda should strengthen institutional coordination under line ministries and agencies such as MAAIF, National Forestry Authority (NFA), and local governments, ensuring policies on land use, gender equity, and sustainability are operationalized in tandem with Uganda's Vision 2040.

The above policy suggestions act as a strong foundation that effectively and efficiently improve collaborative initiatives aimed at achieving sustainability goals and improve diverse agricultural systems of both countries.

Study limitations

This study focused on the period 2000–2019, deliberately excluding the years after 2019 due to the disruptive effects of the COVID-19 pandemic on agricultural systems, data reliability, and market dynamics. Including the pandemic years would have introduced atypical distortions, whereas the selected period provides a stable basis for assessing long-term patterns in land use, sowing structures, and yields. Future studies should extend the analysis beyond 2019 to capture the long-term impacts of COVID-19 and post-pandemic recovery measures on agricultural land use, sowing structures, and crop yields.

Supplementary Information

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Supplementary Material 1

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Author contributions

All authors contributed to the conceptualisation, data analysis, drafting, reviewing, rewriting and editing of this manuscript. Kenan Adule (GIS officer) at NEMA Uganda visualised LULC data from NFA drawing land use maps for the study. All authors, read and approved the final manuscript.

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Data availability

All the datasets generated during and/or analysed during the current study are available at: <https://www.ubos.org/explore-statistics/2/> (Uganda). <https://www.ksh.hu/agriculture> (Hungary).

Declarations

Consent for publication

All authors consent to the publication of this article.

Competing interests

The authors declare that they have no competing interests.

Author details

¹Kerpely Kálmán Doctoral School, University of Debrecen, 138 Böszörményi street, Debrecen 4032, Hungary

²Institute of Land Use, Engineering and Precision Farming Technology, Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, 138 Böszörményi street, Debrecen 4032, Hungary

³Present address: Department of Science Education, Bugema University, P.O. Box 6529, Kampala, Uganda

⁴Roth Gyula Doctoral School of Forestry and Wildlife Management Sciences, H-9400 SOPRON, Bajcsy-Zs, Hungary

⁵Institute of Environmental Protection and Nature Conservation, Faculty of Forestry, University of Sopron, H-9400 SOPRON, Bajcsy-Zs, Hungary

⁶Department of Environmental Planning and Coordination, National Environment Management Authority (NEMA), PO Box 22255, Kampala, Uganda

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