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EDITED BY
Claire Helen Quinn,
University of Leeds, United Kingdom

REVIEWED BY
Michael Lattorff,
University of KwaZulu-Natal, South Africa
Jonas Cromwell,
University of Leeds, United Kingdom

*CORRESPONDENCE
Pieterjan De Bauw
pieterjan.debauw@colead.link;
network@colead.link

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Characterizing avocado production systems for Ugandan exports: the need for consolidation and support for sustainable development

Peter Sseruwagi[1,2], Edouard Lehmann[1], Paul Sigombe[3], Gabriel Ddamulira[4], Jan Willem Van Casteren[5] and Pieterjan De Bauw[1]*

[1]Department of Research and Innovation Brokerage, COmmittee Linking Entrepreneurship – Agriculture – Development (COLEAD), Brussels, Belgium, [2]Gittands Agro Ltd., Kampala, Uganda, [3]Avocado Association Uganda (AAU), Kampala, Uganda, [4]National Crops Resources Research Institute - National Agricultural Research Organisation (NaCRRI-NARO), Kampala, Uganda, [5]eProd Solutions Ltd., Nairobi, Kenya

Hass avocado production and trade are rapidly expanding globally, with increasing consumer demands on quality, safety and sustainability. Last decade, the contribution of East Africa has increased tremendously following several comparative advantages. However, despite substantial recent public and private investments, Uganda's Hass production and export lags behind neighboring countries. This is mainly due to the sector's limited organization, resulting in a fragmented market with varying socio-economic, environmental, and agronomic conditions. Consequently, the limited data and insights on these variable production systems negatively impact the effectiveness of interventions and investments in the sector. In this study, Hass avocado producers were randomly selected across Uganda. Field visits included farm and field surveys, GPS mapping of production areas, and soil sampling for wet-chemistry analysis. Descriptive statistics, multivariate logistic regression, and ANOVA were used to assess the impact of farm and field characteristics on production practices and access to advisory services and certification. Farming systems and dynamics were characterized by assessing demographics, economic data, marketing, farmer organization, and farming practices including soil and nutrient management, irrigation, pest and disease control, and post-harvest management. Results show a fragmented and immature but expanding Hass sector in Uganda. Production mostly occurs in small- to medium-sized fields with no or limited inputs (i.e., fertilisers, pesticides, irrigation), using manual labor (family or hired) under mixed cropping systems, but lacking critical infrastructure, agronomic knowledge, extension services, and access to markets. In contrast to farmer's belief that soils are suitable and fertile for Hass avocado, soil analyses indicate the urgent need for site specific soil management interventions. Implementation of good agronomic practices and access to inputs and advisory services seem mostly related to farm and field size, and to a lesser extent influenced by farmer age, orchard age, and agroecology, while membership of farmer organizations/associations currently seem to bring limited benefits. This study highlights several comparative advantages and opportunities for the Hass sector in Uganda and identifies the priority challenges to be tackled in future investments and interventions targeting a sustainable avocado industry.

KEYWORDS

avocado, Hass, export, small and medium sized producers, sustainable production, farming system analysis, sector organization, markets

1 Introduction

Avocado (*Persea americana* Mill.) production and trade are rapidly expanding globally with the most important attraction being the nutritional benefits of the fruit (Kagumba et al., 2023). Avocado originated from Mexico and Central America (Storey et al., 1986) and is currently grown in many tropical and sub-tropical areas around the world (40°N and 40°S) (Shumeta, 2010; Kagumba et al., 2023). Global demand for avocado rapidly raises as fruits are widely used in many popular fresh recipes like guacamole, ice creams, and juices, but they have also several industrial applications like in natural cosmetics and body care oil products (Swisher, 1988; Bergh, 1992; Palma et al., 2016; Saavedra et al., 2017; Colombo and Papetti, 2019).

According to the latest production and market statistics, avocado production increased at a compound annual growth rate (CAGR) of 7% up to ca, 8.5 million metric tons between 2012 and 2022 (Shahbandeh, 2024a; van Rijswick et al., 2024), and the global avocado market is estimated to further increase from 9 billion USD in 2021 to 19.9 billion USD by 2026 (Shahbandeh, 2024b). The top producers and exporters of avocado are currently Mexico, Colombia, Peru and Kenya responsible for ca, 30, 12, 9 and 6% of total global production, respectively (van Rijswick et al., 2024). The United States of America (USA) and Canada account for 27% of the global avocado market value estimated on 4.86 bn USD, followed by Europe (22%, USD 3.96 bn), Asia, Oceania (11%, USD 1.98 bn), Africa (4%, USD 0.72 bn), and the Middle East (4%, USD 0.72 bn), while the rest (32%) is sold to various smaller markets. The African avocado market is forecasted to have a CAGR of 5.78%, mostly contributed to by Egypt, which is responsible for 41% of total imports in Africa, followed by Morocco (21%) and South Africa (14%) (van Rijswick et al., 2024).

Globally, consumers demand high quality (taste, consistency, dry matter, ripeness, wholeness – devoid of defects), affordable, and safe avocado fruits that are produced in a sustainable manner (Gamble et al., 2010; Giuggioli et al., 2023). For example, many consumers in the European Union (EU) and United Kingdom (UK) have a perception that long-distance sourced produce like avocados from south America are rather unsustainable due to concerns about food miles, greenhouse gas emissions, and irrational irrigation water usage in dry areas. Additionally, consumer preferences are changing in favor of (often organic) food grown using sustainable agronomic practices that are aligned with so-called agroecological principles, including improved biodiversity and diversification, low irrigation and limited use of chemical inputs (i.e., pesticides and fertilisers) (Migliore et al., 2017). The latter demand calls for a critical review of production practices in specific high potential areas.

Optimal avocado growth requires balanced nutrition (Araújo et al., 2018), homogeneous distribution of water supply (ca, 1,000–1,750 mm annually), moderate relative humidity, an average temperature of 25–30°C, and deep, permeable and free draining soils with pH ranging from 6 to 7, which are conditions that are easily found in East Africa. The avocado industry in East Africa has grown tremendously over the past few years due to the favorable climatic conditions and deliberate government initiatives to promote avocado as a source of household nutrition, income generation, and poverty alleviation for social and economic rural development. In addition, the growing global demand for Hass avocado has motivated many small- and medium-sized farmers to invest in avocado farming for income generation (Mujidu, 2024; Ntirenganya, 2024; Kassam, 2024; FAO, 2023). For years, Kenya has led commercial avocado production and export in Africa with a well-established commercial sector that has recognized brands on the international export market and producing ca, 518,500 metric tons in 2023 (Mujidu, 2024), following successful seedling import and subsidy programs. Tanzania and Rwanda also transitioned recently from subsistence avocado farming to significant global avocado exporters in 2023 (Kassam, 2024; Ntirenganya, 2024; FAO, 2023).

In contrast, while having similar potential, Uganda's avocado sector mostly relies on smallholder growers trading smaller volumes of local 'jumbo' (big) varieties that have medium to large-sized (300–400 g) fruits (Freshela, 2024) on local and regional markets. Jumbo fruits lack uniformity and are therefore rather unfit for export. Interestingly, Hass and Fuerte varieties were already introduced in Uganda in the early 1990s by the Food and Agriculture Organisation (FAO) to support horticulture development. These varieties were not readily adopted by farmers because the small size (<300 g) of the fruits was unattractive on the local market. The latter primarily contributed to the general reluctance of smaller-scale, resource-poor farmers to adopt the Hass variety. Therefore, several Hass and Fuerte promotion campaigns were organized since 2008 by the Horticulture Research and Development Programme in the National Crops Resources Research Institute of the National Agricultural Research Organisation (NaCRRI-NARO) and production guides were developed and distributed together with quality (grafted) Hass avocado seedlings throughout the country. Past programmes deliberately targeted middle- and high- income farmers with financial and land resources to adopt Hass avocado as a viable enterprise (Sseruwagi, 2011). Until now, Hass avocado is still poorly accepted on local markets in Uganda, which contrasts to the situation in Kenya and to a lesser extent in Tanzania where Hass is more successfully integrated in both domestic and export markets. However, despite lacking details, avocado production in Uganda has expanded rapidly and it ranked among the top ten largest avocado exporting countries in Africa in 2023 (Freshela, 2024), engaging over at least 100,000 farmers. The country registered a steady rise in avocado exports from 4 tons in 2013 to 469 tons in 2020. In 2021, the country exported 3,148 tons of avocado with ca, 67% going to Qatar and 11% to the EU. Currently, it is estimated that exported volumes exceed 15,000 metric tons annually, with a significant portion sent to Europe and the Middle East. In addition to these exported volumes, non-export grade and excess Hass avocado fruits are sold to local processors in Uganda for oil extraction [National Agricultural Advisory Services (NAADS) in 2024].

Despite this rapid growth following several private and public investments in (Hass) avocado farming for export, the avocado industry in Uganda currently remains very immature and not well-structured, and it faces several challenges for sustainable growth. Challenges include stiff regional and international competition, stringent sanitary and phytosanitary standards (SPS), mounting buyer and consumer demands, traceability requirements, inadequate safe handling infrastructure, and weak small- and medium-sized producer and marketing organizations, i.e., Business Membership Organizations (BMOs). Currently, the lack of data on Uganda's small- and medium-sized Hass avocado growers hampers understanding of the farming systems, and the great socio-economic diversity and variability in production environments. This impedes targeted investments in the sector and complicates support aiming to build organized and well-structured avocado BMOs and supply chains.

Therefore, this study aims to (i) better understand and characterize the Hass avocado production systems (i.e., farm environment including economic, social, and environmental aspects with a major focus on production practices and soil health), (ii) analyze which farm characteristics influence adoption of good agronomic practices and access to advisory and inputs, (iii) assess the key challenges and opportunities for the sector, and (iv) guide future investments and interventions targeting a sustainable commercial avocado industry in Uganda.

2 Data and methods

2.1 Study area and research design

Avocado producers were sampled from current major avocado producing areas in Uganda, covering seven of the fourteen agro-ecological zones (Wortmann and Eledu, 1999) (Supplementary Table S1), being *(1) Western Mid-Altitude Farmlands & the Semliki Flats (WMAFSF); (2) Lake Victoria Crescent and Mbale Farmlands (LVCMF); (3) Western Medium-High Farmlands (WMHF); (4) Southwestern Grass-Farmlands (SWGF); (5) Southern and Eastern Lake Kyoga Basin (SELKB); (6) Northeastern Semi-arid Short Grass Plains (NESaSGP) and (7) Northern Moist Farmland (NMF)*. The areas are characterized by diverse vegetation ranging from rainforest to savanna grassland, and they covered medium to high altitudes (680–1,220 m asl) with moderate mean temperatures (≥20°C) and bimodal and unimodal rainfall patterns (ca, 1,000–1,200 mm/year). A cross-sectional descriptive research design involving measurement of both quantitative and qualitative data on avocado production and marketing in Uganda was then conducted from November 2023 to February 2024.

2.2 Data type, source and variables measured

Primary data was collected from small- and medium-sized avocado farmers using a questionnaire survey for farm and field inspection in key avocado growing regions of Uganda (2.1). Primary data covered 12 thematic areas, including: *land ownership & size, farm labour, technical advice & extension, input sourcing & use, farming system, enterprise information, soil & nutrient management, water management, pest & disease management, post-harvest management, safety standards & traceability, marketing,* and *farmer organisation*. To augment and support findings from the primary data, consultations were made with key stakeholders of the sector in Uganda. Consulted stakeholders represented government institutions responsible for development of the avocado sub-sector like the National Agricultural Research Organisation (NARO) and BMOs like the Avocado Association of Uganda (AAU), Hortifresh, and Masindi Avocoop.

2.3 Data collection

2.3.1 Sample selection and sampling design

As a first step, the target population for this study was defined to all small- and medium- sized Hass avocado farmers in Uganda. To select a representative sample of producers throughout the country, we sourced from the large network of AAU. The association has vast experience in the avocado sector and has been mapping avocado growers extensively throughout the country for the last 10 years based on consultations, networking, and field visits. Within this country-wide network database of AAU, 112 avocado farms were randomly selected. As such, it was expected that retained farms would have a rather homogenous distribution, well covering the geographic areas of production. The latter can effectively be observed in Figure 1, representing the retained and sampled producers across Uganda, with a higher density in the traditionally major crop production zones.

2.3.2 Farm and field data collection

After selecting randomly distributed farms throughout the country, a team of researchers was sent out to the selected Hass producing farms for sampling and data collection. Two different surveys were conducted and used to collect information at farm and field level from each site. Both surveys were developed, refined, and concluded combining relevant information currently used and needed for proper farm, producer, value chain, and market characterization.

Preconstructed surveys were then integrated in the innovative supply chain management software developed by eProd Solutions Ltd. (https://www.eprod-solutions.com/). The latter software enabled the collection and management of different types of questions and responses (e.g., open, multiple choice, limited choice, e.g., Yes or No, etc.), with inclusion of conditions (e.g., being compulsory to fill in and skipping options depending on the previous question, etc.). The software captures basic information and metadata during interviews (including GPS locations) allowing to check validity and correctness of the entered data.

Surveys were conducted in two steps. Preliminary information was collected at farm level by the first survey to capture several social, economic, and environmental aspects. When a farm had more than one field, it was asked to select the largest and most representative plot. Subsequently, more specific information was captured from the single or most representative field of the farm utilizing a second field survey. The selected fields were then visited, and polygons (Figure 2) were captured using GPS systems to map field boundaries and extract surface.

2.3.3 Soil sampling and analyses

To improve insights into the actual soil status of avocado fields besides current soil management practices (Table 1), a composite soil sample was collected from the topsoil (0–30 cm depth) of each of the 112 selected fields, and subsequently air-dried, sieved, and sent to Crop Nutrition Laboratory Services Ltd. (CROPNUTS) in Limuru (Kenya) for standard soil analyses (ISO/IEC 17025 accredited). Soil pH (H_2O) was determined (potentiometric) in a soil: water suspension

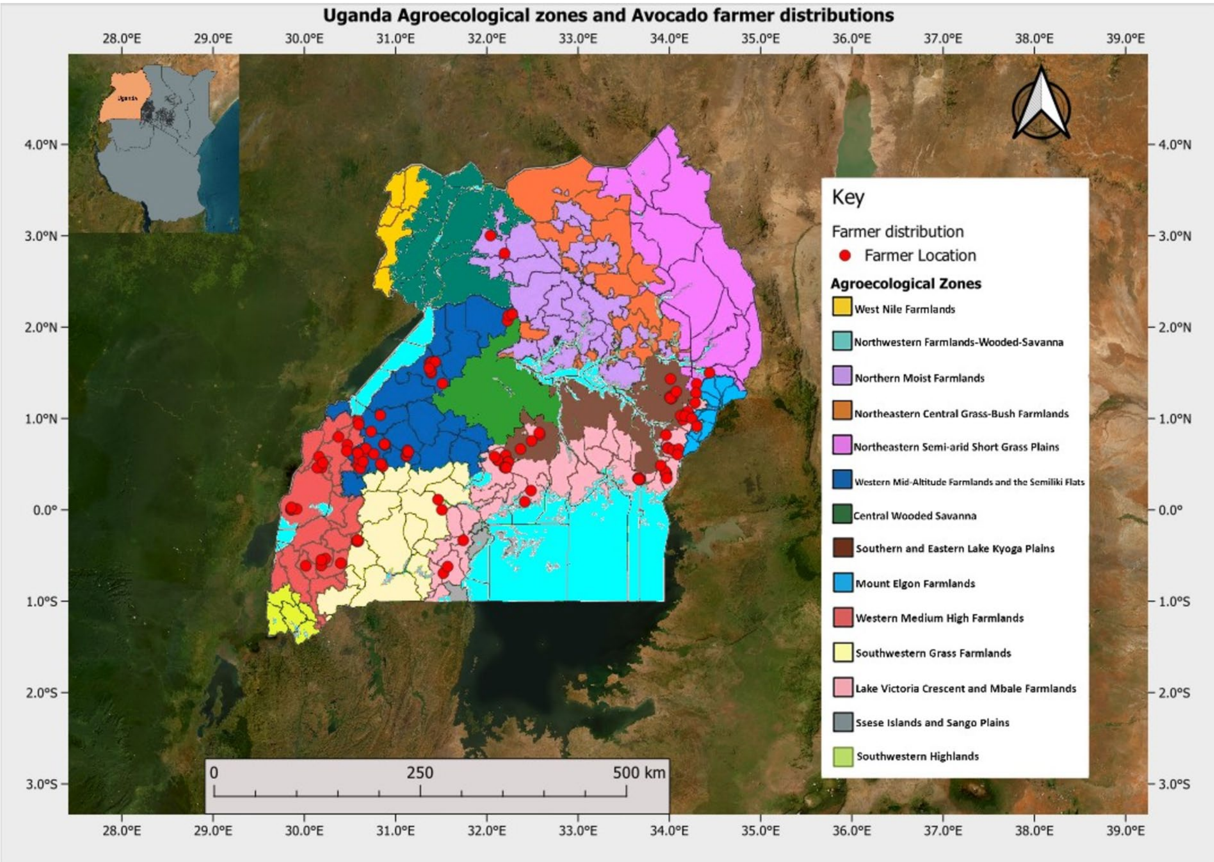

FIGURE 1
Map of Uganda indicating the sampled field locations of the study where data was collected, projected on the 14 agroecological zones of Uganda (From top to bottom - 1: West Nile Farmlands; 2: Northwestern Farmlands-Wooded-Savanna; 3: Northern Moist Farmlands; 4: Northeastern Central Grass-Bush Farmlands; 5: Northeastern Semi-arid Short Grass Plains; 6: Western Mid-Altitude Farmlands and the Semiliki Flats; 7:Central Wooded Savanna; 8: Southern and Eastern Lake Kyoga Plains; 9: Mount Elgon Farmlands; 10: Western Medium High Farmlands; 11: Southwestern Grass Farmlands; 12: Lake Victoria Crescent and Mbale Farmlands; 13: Ssese Islands and Sango Plains; 14: Southwestern Highlands).

of 1:2, availability of phosphorus, potassium, calcium, magnesium, sulphur, manganese, boron, copper, zinc, and aluminum were quantified after Mehlich 3 extraction [composed of 0.2 M glacial acetic acid, 0.25 M ammonium nitrate, 0.015 M ammonium fluoride, 0.013 M nitric acid, and 0.001 M ethylene diamine tetra acetic acid (EDTA)] using Inductively coupled Plasma Optical Emission Spectroscopy (ICP-OES). Cation Exchange Capacity (CEC) was then calculated. Total nitrogen and organic matter were determined by a CN analyser (elemental analysis) after combustion.

The results were used to identify soil problems, and to derive a potential site-specific soil fertility and correction program. Optimal ranges were set for each soil parameter according to Chandrasekaran et al. (2010), with values below or above being considered as 'too low' or 'too high'. The optimal ranges are here set at 6–6.8 for pH (H_2O), 50–100 mg/kg for phosphorus, 192–513 mg/kg for potassium, 1970–2,300 mg/kg for calcium, 197–355 mg/kg for magnesium, 20–200 mg/kg for sulphur, 30–250 mg/kg for manganese, 1–2 mg/kg for boron, 2–10 mg/kg for copper, 2–20 mg/kg for zinc, 15–30 meq/100 g for CEC, 0.2–0.5% for total nitrogen, and 3–4% for organic matter.

2.3.4 Data analysis, description and interpretation

Farm, field, and soil data were verified for any inconsistencies before statistical analysis. Standard statistical analyses were conducted with the Statistical Package for Social Sciences (SPSS) software package (IBM SPSS Statistics, 2013). Frequencies, distribution patterns, percentages and observed probabilities, means, medians, and standard errors were calculated and visualized. To evaluate the impact of explanatory predictor farm characteristics on the adoption of specific management practices, logistic regression was then conducted in R version 4.4.1 (R Development Core Team, 2012) using the glm() function and using stepwise regression on both forward and reverse directions and using the Akaike Information Criterion (AIC) for best model selection (Table 2). Logistic regression is considered well-suited for analysis of the collected data, given its ability to model binary outcome variables, such as whether specific management practices were implemented (yes/no). The fixed characteristic variables (i.e., field size, farmer age, gender, orchard age, membership of farmer group/organisation, and agroecology) were treated as independent predictors. The logistic regression model estimated the probability of adopting a particular management practice or access to advisory based on the values of these predictors. By examining the significance of the regression coefficients (β) and their associated odds ratios, the models provide insights into which fixed variables have an influence on the likelihood of adopting specific management practices. To validate the findings of the logistic regression, ANOVA

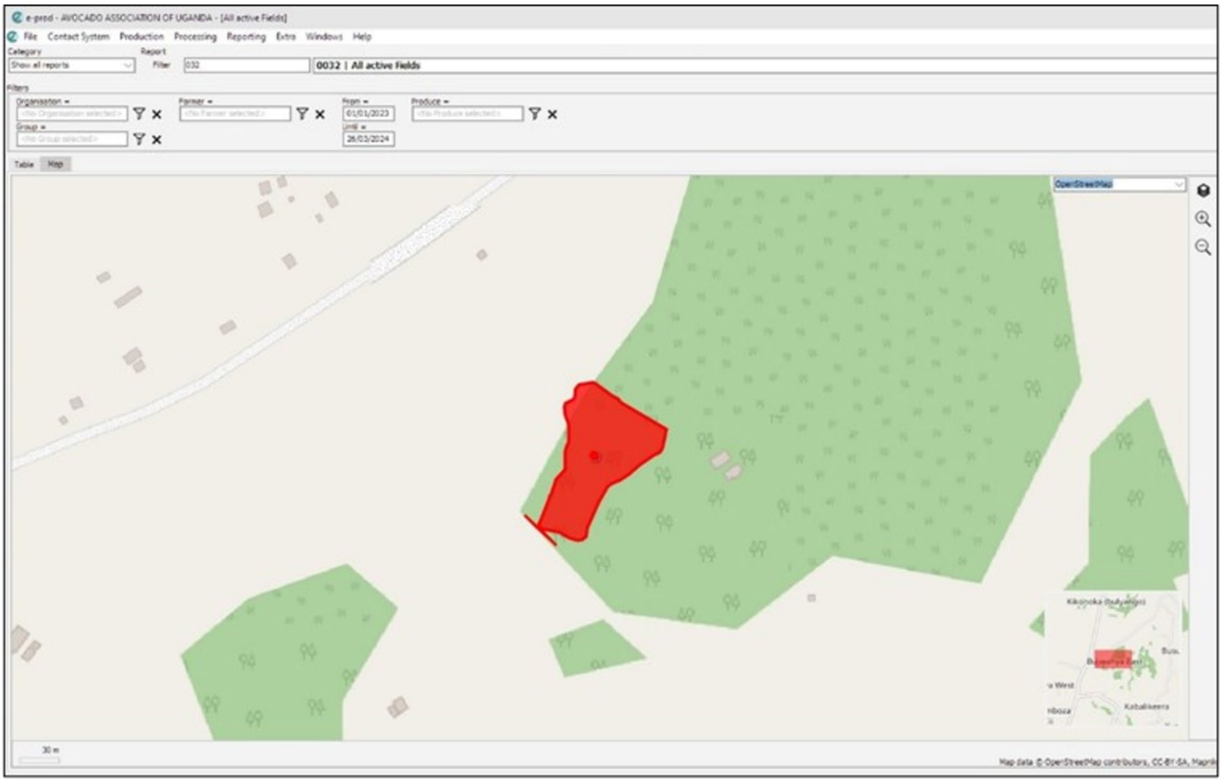

FIGURE 2
Example of a captured field polygon for area extraction using GPS systems in the eprod solutions tool.

was additionally performed (Park, 2009). This approach facilitates a nuanced understanding of the factors driving decision-making within the avocado farm management context.

3 Results

3.1 Avocado production system characteristics

3.1.1 Demographic information and economic activities

Results demonstrate that most of the avocado farmers are male (82%), and that gender had no significant influence on any of the dependent farm management variables (Table 2). Most of the avocado growers (63%) are middle-aged (41–60 years), while 22 and 14% belong to the younger (21–40) and older (61–80) groups, respectively. The growers own small- to medium-sized farms of ca, 52 acres on average (with a median size of 6 acres) with avocado plot sizes of 9 acres on average but ranging from 1 to 150 acres and with a median size of 4 acres. More than half of the farms (57%) have more than one avocado field, while the rest have only one single field (Supplementary Table S2).

Only a minor fraction of the growers (22%) does not hire labor or do not use additional family workers (26%). Family and hired labor are used in equal proportions with an average of six workers per farm (Supplementary Table S2). Older orchards rely more on hired labor, while family labor is more common on smaller fields (and less in the agroecological zone SWGF) (Table 2). There is a strong positive and high statistically significant relationship between tree age and hired labour and interestingly, field size did not significantly influence the amount of hired or family labour (Table 2). Only 15 percent of the avocado farmers carry out mechanized operations on the farm, and this is positively influenced by field size and farmer age (Table 2). Crop production is considered the main economic activity for 95% of the farmers, followed by mixed – (i.e., crop and livestock production) and fish farming. Most of the farmers could not determine one single most time- and resource-demanding farm activity and annual total investment. A few farmers consider purchasing agricultural inputs, planting, crop management and irrigation as the most engaging farm activities, and annual farm investments of between 25.8 and 2,580 EUR [i.e., 100 K and > 10,000 K Ugandan shillings (USh)] were reported (Supplementary Table S3).

3.1.2 Avocado farming system

Supplementary Table S4 presents the Hass avocado farming system characteristics (varieties grown, access and source of good/certified avocado planting material and age of avocado crops) while data on intercropping are not presented. Results showed mixed cropping to be the dominant farming system in each of the seven sampled agro-ecological zones. In each zone, Hass avocado is grown together with diverse crop species like bananas, beans, cabbage, carrots, cassava, coffee, green peas, groundnuts, jackfruit, mangoes, sweet pepper, pineapple, potato, sorghum, soya beans, sugarcane, sunflower, sweet potato, tea and watermelon that were grown together in different combinations. The history of the

TABLE 1 Avocado producer perceptions and practices related to soil health and nutrient management.

Category	Responses (%)
Producer considers the soil of their plot as fertile and suitable for avocado	
Yes	97.3
No	2.7
Frequency farmer conducts soil analyses	
Never	92.0
Every 3 years	7.1
Every 10 years	0.9
If never, what is the reason?	
Lack of knowledge	56.3
Too costly	33.9
Not a farm priority	8.0
No access to a laboratory	1.8
Decision on type and rate of fertilizers and/or manure to apply	
Do not know	47.3
Always same type and amount of fertiliser	42.0
Based on general crop nutrient guidelines	8.9
Based on soil analysis with tailored recommendations	1.8
Soil management practices	
Organic and compost manure	72.4
Crop residues	10.8
Drainage	9.4
Erosion bands	7.2
Cover crops	4.3
Mulching	3.5
Minimum tillage	2.9
None	25.9

assessed plots shows great diversity in the crop species grown prior to planting avocado in the different locations. Most of the targeted farmers (94%) only grow the popular commercial avocado variety Hass, while few also grow Fuerte (3.6%) and Jumbo (2.68%) together with Hass. In addition, only 57% of the farmers planted certified avocado seedlings, which were sourced from private commercial nurseries, while the rest raised their own seedlings (Figure 3). Access to certified planting material seems only to depend on the location (agroecology) and not on size, farmer age, or farmer group membership (Table 2). The age of the Hass avocado trees on the examined fields ranged from 1 to 9 years with 95% being less than five years old, demonstrating the young character of the Hass sector and the recent investments and transformations made (Supplementary Table S4).

3.1.3 Soil health and nutrient management

Table 1 and Supplementary Table S5 presents information on soil health and nutrient management, and it includes the farmers' perceptions on their plot's fertility and suitability for growing avocado, the frequency and reason for conducting soil analysis, and the rationale behind the farmer's decision on what and how much fertilizer and/or manure to apply. Results demonstrate that almost all farmers interviewed (97%) consider the soil of their plots to be very fertile and suitable for Hass avocado production. However, the majority (92%) have never conducted soil analyses (less than 10% had tested the soil every 3–10 years), and less than 20% have any written nutrient management plan or any record of fertilizer application. Highlighted reasons for not conducting soil analysis are lack of knowledge, high costs, lack of access to a soil testing laboratory, and soil testing being not considered a farm priority (Table 1). In contrast to farmer perceptions, soil analyses (Figure 4) indicate that all sampled soils were at least diagnosed with at least three or more limitations requiring improved, and/or adjusted management, as most plots display relatively low total nitrogen (77.5%), low cation exchange capacity (66.7%), low phosphorus availability (85.6%), and low calcium (65.8%), sulfur (100%), and boron (92.8%) levels. On the other hand, magnesium, manganese, copper, and zinc levels were mostly optimal, and organic matter levels were generally optimal to high (Figure 5). Results of the soil analyses indicate significant differences of several parameters ($p < 0.001$) among the agro-ecological zones. To manage soil health and nutrients, most of the farmers use organic manure (72.4%) which is positively influenced by farmer age (Tables 1, 2), and many implement environmentally friendly soil conservation practices like proper drainage, installing erosion bands, mulching, integrating crop residues, planting cover crops, and minimizing tillage. Interestingly, almost all growers (93.7%) never use mineral fertilizers, which is positively stimulated by field size (Table 2), and in contrast to the use of organic manure not influenced by farmer age. Only a few farmers (1.8%) are guided by soil analyses, mostly for larger fields (Table 2), while the rest follow general crop nutrient guidelines or standard blanket rates to apply manure and/or fertilizers. Hence, most of the farmers usually apply the same type and amount of manure/fertilizer every year, irrespective of the health condition or limitations of the avocado trees (Table 1 and Figure 3).

3.1.4 Water use and management

Water use and management were assessed by analysing the number of farmers who use irrigation, monitor water application rates, test irrigation water quality, protect water sources, and have authorization to extract water for irrigation (Table 3). Results indicate that less than half of the farmers (39%) irrigate their avocado plots which seems to be positively influenced by the age of the orchard, and that most of them do not monitor water application rates or test water quality. Only a small proportion of the farmers claimed to protect water sources, and only a limited number have permits to extract and use ground water for irrigation (Table 3). While the use of irrigation water in avocado plots seems positively influenced by the age of the orchard, adoption of drip irrigation technology is used by 26% of the farmers and positively influenced by field size (Table 2), the rest use furrow (2.2%) or manual irrigation (11%). Rivers are the main source of irrigation water, followed by groundwater, and lakes (Table 3).

3.1.5 Pests and diseases impacting avocado

Assessment of pest and disease prevalence and management considered farmer's knowledge and perceptions on the most damaging species and the control practices implemented (Table 3).

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TABLE 2 Results of the logistic regressions presenting the coefficients (β) with *p*-values and standard error (s.e.) for the retained explanatory variables of the best models.

	Hired labor		Family labor		Mechanisation		Access to certified planting material		Use of manure		Use of mineral fertiliser		Conducts soil analyses	
	Coef. (β)	s.e.	Coef. (β)	s.e.	Coef. (β)	s.e.	Coef. (β)	s.e.	Coef. (β)	s.e.	Coef. (β)	s.e.	Coef. (β)	s.e.
Intercept	-0.18^{ns}	(0.51)	2.23***	(0.60)	−11.41**	(3.47)	−0.13 ^{ns}	(0.52)	−2.25$^{0.05}$	(1.15)	−2.85***	(0.85)	−3.03***	(0.45)
Field size	−0.01^{ns}	(0.02)	−0.06$^{0.07}$	(0.03)	0.38**	(0.12)					0.08**	(0.04)	0.04**	(0.01)
Farmer age					0.13*	(0.05)			0.06**	(0.02)	−1.48 ^{ns}	(1.03)		
Gender (M)														
Tree age	0.60**	(0.22)					−0.24 ^{ns}	(0.16)						
Member of farmer organization (Yes)	0.50^{ns}	(0.49)	−0.53 ^{ns}	(0.55)			0.60 ^{ns}	(0.48)						
Agroecology (NESaSGP)			17.45 ^{ns}	(3585.29)	−22.95	(2740.08)	−17.34 ^{ns}	(2231.11)	0.32 ^{ns}	(1.45)				
(NMF)			17.06 ^{ns}	(6522.64)	−16.82 ^{ns}	(6522.64)	−17.57 ^{ns}	(3956.18)	−19.58 ^{ns}	(3956.18)				
(SELKB)			16.69 ^{ns}	(2647.59)	4.52**	(1.49)	−16.91 ^{ns}	(1558.49)	−0.80 ^{ns}	(1.00)				
(SWGF)			−1.71*	(0.83)	−2.92 ^{ns}	(2.67)	1.03 ^{ns}	(0.81)	16.75 ^{ns}	(1194.81)				
(WMHF)			16.99 ^{ns}	(1863.22)	0.41 ^{ns}	(1.26)	1.08 ^{ns}	(0.72)	−0.95 ^{ns}	(0.72)				
(WMAFSF)			−0.88 ^{ns}	(0.57)	−4.5*	(2.03)	1.54*	(0.52)	0.77 ^{ns}	(0.55)				
AIC	116.51		115.63		52.17		138.54		123.11		37.79		55.80	

(Continued)

TABLE 2 (Continued)

	Irrigation		Drip Irrigation		Pesticide use		Access to agronomic advice		Access to advice on food safety and quality		Having certifications	
	Coef. (β)	s.e.	Coef. (β)	s.e.	Coef. (β)	s.e.	Coef. (β)	s.e.	Coef. (β)	s.e.	Coef. (β)	s.e.
Intercept	−1.55**	(0.54)	−3.31***	(0.67)	−6.08***	1.84	−3.48***	(0.81)	−19.51 ^{ns}	(1444.49)	−5.07*	(2.20)
Field size			0.03*	(0.01)	0.01	0.01	0.1*	(0.05)	0.03*	(0.01)	−0.01 ^{ns}	(0.02)
Farmer age					0.05$^{0.09}$	0.03			0.01 ^{ns}	(0.03)	0.04 ^{ns}	(0.03)
Gender (M)									16.50 ^{ns}	(1444.49)		
Tree age	0.25$^{0.09}$	(0.15)	0.25 ^{ns}	(0.20)					0.09 ^{ns}	(0.20)	0.60*	(0.29)
Member of farmer organization (Yes)					1.43$^{0.09}$	0.85			−0.17 ^{ns}	(0.67)		
Agroecology (NESaSGP)	1.67 ^{ns}	(1.29)					−16.40 ^{ns}	(3529.93)			1.04 ^{ns}	(1.35)
(NMF)	−14.52 ^{ns}	(1455.40)					−15.39 ^{ns}	(6522.64)			−19.66 ^{ns}	(17730)
(SELKB)	0.80 ^{ns}	(0.91)					2.38*	(1.15)			1.46 ^{ns}	(1.072)
(SWGF)	−0.94 ^{ns}	(0.94)					1.81 ^{ns}	(1.04)			−21.54 ^{ns}	(4682)
(WMHF)	−0.54 ^{ns}	(0.87)					−15.86 ^{ns}	(1863.00)			−19.02 ^{ns}	(4759)
(WMAFSF)	1.34**	(0.49)					0.68 ^{ns}	(0.89)			−19.08 ^{ns}	(2629)
AIC	149.21		67.66		62.30		77.49		74.81		65.24	

If a *p*-value is less than 0.05, it is flagged with one star (*). If a *p*-value is less than 0.01, it is flagged with 2 stars (**). If a *p*-value is less than 0.001, it is flagged with three stars (***).

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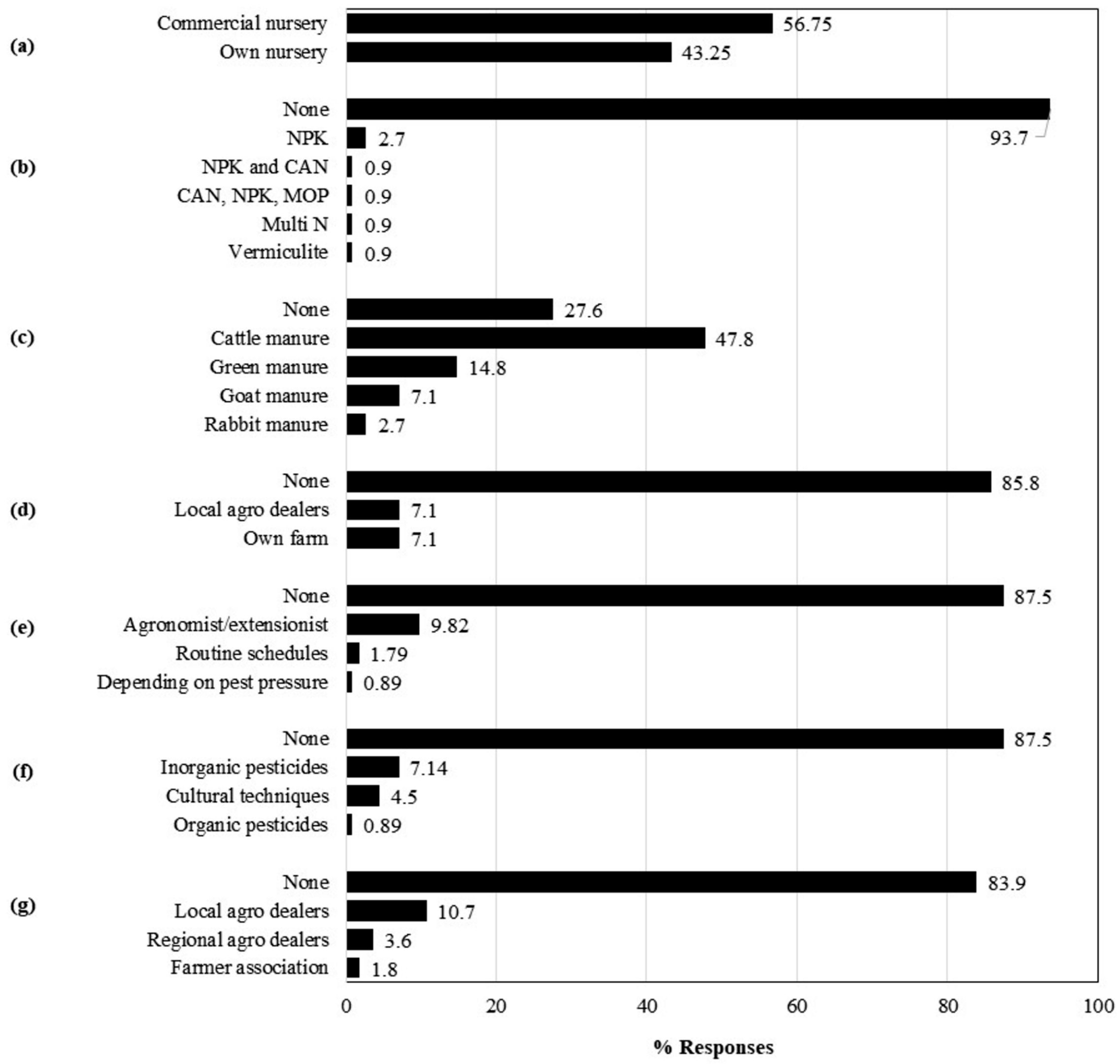


FIGURE 3
Information on the use of agro-inputs for avocado production in Uganda: **(A)** source of planting materials, **(B)** type of mineral fertilizer used, **(C)** type of organic fertilizer used, **(D)** sourcing of fertilizers/manure, **(E)** advice on Plant Protection Product (PPP) application, **(F)** type of PPPs used, **(G)** sourcing of PPPs.

Farmers consider the most damaging pests to be fruit flies (Diptera - *Tephritidae*), false codling moths (Lepidoptera - *Thaumatotibia leucotreta* - Meyrick), caterpillars (Lepidoptera), aphids (Hemiptera - *Aphidoidea*) and mealybugs (Hemiptera - *Coccoidea*), while root rot (*Phytopthora*) and wilt (*Fusarium & Verticillium*) are the most devastating diseases (Table 3). A significant proportion (40%) of the farmers indicated a lack of knowledge of the most important pests and diseases in their avocado fields. Only 14% of the farmers claimed to implement an integrated pest management (IPM) strategy, and only very few farmers use inorganic (7.1%) or organic (0.9%) pesticides. The use of pesticides is positively influenced by farmer age and membership of a farmer organization (low significance level) (Table 2). Among those that use pesticides, only a few obtain advice from agronomists/extensionists or consider pest pressure, while most follow routine applications stipulated on labels (Table 3). Access to agronomic advice seems to positively relate with field size and being affected by location (agroecology) (Table 2).

3.1.6 Post-harvest management and traceability in avocado supply chains

Figure 4 and Supplementary Tables S6, S7 present information on post-harvest management and operations, including transportation of produce, the volume and cause of wastage, food safety, standards, traceability systems, certification and source and type of technical advice. Most of the farmers (96%) use private means (car or truck) to transport avocado produce from the farm to the market (Figure 4). Only 6 % reported post-harvest losses, which were attributed to poor fruit quality and lack of market access. The rest of the farmers (94%) have limited insights into the amount and causes of post-harvest losses.

Most of the farmers (89%) indicated that they do not receive any advice on food safety standards, Good Agricultural Practices (GAPs), or Maximum Residue Levels (MRLs) of plant protection products (PPPs), and having access to this type of advisory services is only positively affected by field size (Table 2) and not by farmer age, gender,

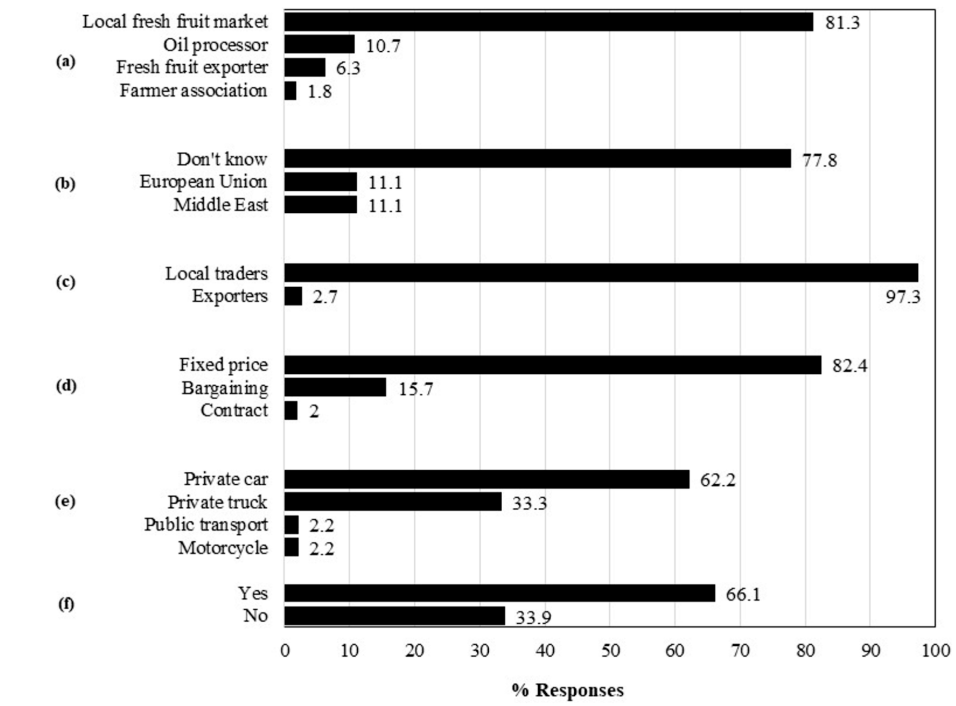
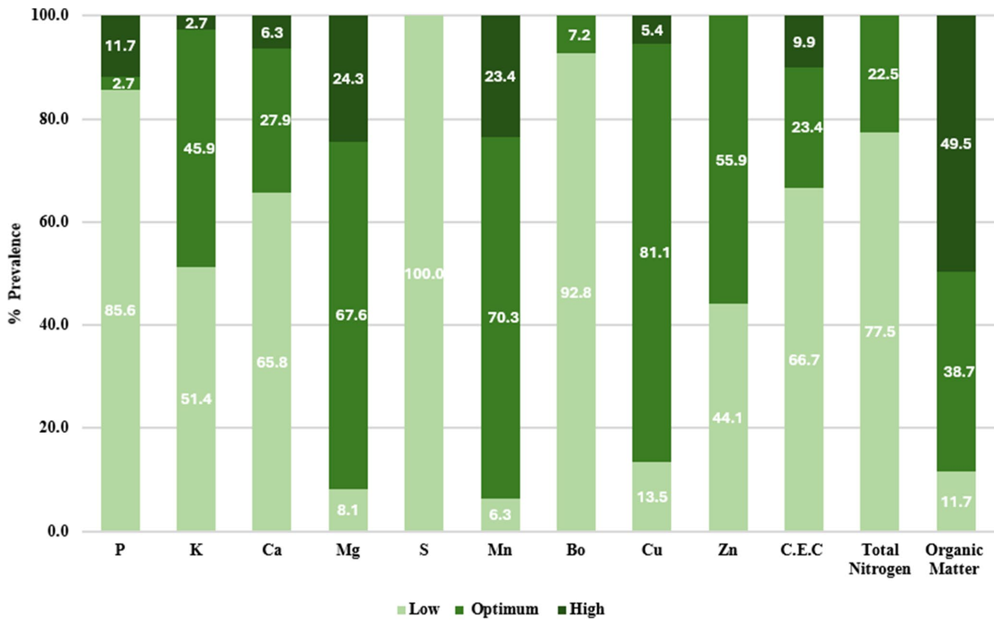


FIGURE 4
Information on markets and transportation of produce: **(A)** target markets of producers, **(B)** export markets, **(C)** main trader, **(D)** selling method, **(E)** transport of produce, **(F)** farmer interest in joining a marketing company with a packhouse in Uganda.



Optimal Ranges Considered

P	K	Ca	Mg	S	Mn	Bo	Cu	Zn	CEC	Total Nitrogen	Organic matter
[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[mg/kg]	[meq/100g]	[%]	[%]
50-100	192-513	1970-2300	197-355	20-200	30-250	1-2	2-10	2-20	15-30	0.2-0.5	3-4

FIGURE 5
Share of samples (%) classified with too low, optimum, and too high values for the analyzed soil parameters. Optimal ranges were set for each soil parameter according to Chandrasekaran et al. (2010), with values below or above being considered as 'too low' or 'too high'.

TABLE 3 Information on water and pest management.

Water information	Responses (%)	Pests/diseases	Responses (%)
Producer irrigates		*Major pests/diseases*	
Yes	39.3	Fruit flies	20.5
No	60.7	False codling moths	8.9
Producer monitors water application rates		Root rot (*Phytophtora*)	8.0
Yes	9.8	Caterpillars	6.3
No	90.2	Aphids	3.6
Producer tests the quality of irrigation water		Mealybugs	3.6
Yes	3.6	Wilt (*Fusarium/ Verticillium*)	3.6
No	96.4	Thrips	1.8
Producer protects water sources		Stink bugs	0.9
Yes	14.3	Botrytis	0.9
No	85.7	Stem cankers	0.9
		Mites	0.9
Producer has permits to extract and use water sources other than rainfall		Do not know	40.1
Yes	10.7	*Decision on PPP application*	
No	89.3	Advice from agronomist/ extensionist	10.7
Method of irrigation		Routine schedules	7.1
Drip	26.1	Pest pressure	2.7
Furrow	2.2	None	79.5
Manual	11.0		
None	60.7		
Source of irrigation water		*Producer implements IPM*	
River	76.9	Yes	14.3
Groundwater (Borehole)	17.3	No	85.7
Lake	5.8		

orchard age, location or membership of a farmer organisation. Only a few farmers (11%) receive advice from private consulting companies. Similarly, a few farmers (8%) sometimes source avocado from out growers (side buying) and they generally do not separate side-bought produce from their own produce to ensure traceability. Most of the farmers (90%) and all consulted traders mention the lack of a traceability system, which they attribute to the absence of training. However, most farmers (60%) expressed interest in establishing a traceability system to trace produce along the value chain. In addition, only 11.6% of farmers have any certifications (e.g., Global G.A.P., Organic, SMETA, GRASP, Rainforest Alliance etc.), with increased probabilities for older orchards (Table 2). Almost all (92%) farm certifications are organic and interestingly, possession of certification was not significantly influenced by field size, farmer age, or membership of a farmer organisation.

TABLE 4 Avocado farmer organization and extension in Uganda.

Category	Responses (%)
Producer is member of a farmer organization or association	
Yes	48.2
No	51.8
Perceived benefits of farmer organizations	
Training and knowledge dissemination	57.3
Access to market information	26.8
Credit financing	10.8
Soil sampling and advice	5.1
Source of technical advises	
Private agronomist (external)	75.0
Family and friends	23.3
Farm technical advisor (internal)	1.7
Type of advice and support farmer would like to receive in future	
Market information	41.5
Pest and disease management	29.3
Weather information	20.7
Fertiliser recommendations	2.9
Irrigation	2.4
Orchard management	2.0
Transport	0.8
Financial assistance	0.4

3.1.7 Farmer organisation and marketing of avocado

Table 4 and Figure 4 present information on farmer organization, extension, and trading details. About half of the farmers interviewed (48%) belong to an avocado sector organisation (like an association, cooperative, or farmer group), with the major perceived benefits being the access to training and knowledge, and market information.

Most of the Hass avocado farmers (81%) currently sell produce to middlemen on local fresh fruit markets in Uganda, followed by oil processors (11%), and less than 10% directly sells to fresh fruit exporters. Therefore, most of the farmers (77%) did not know if their produce is exported and to which final markets. Only a few farmers mentioned produce going to markets in the European Union (EU) (11%) and Middle East (11%). Marketing seems mostly coordinated by local traders (97%) who act as middlemen and few exporters directly purchase avocados from the farmers. Buying involved fixed pricing (82%), bargaining (16%) and rarely contracts (2%). At least 66% of the farmers expressed high interest in joining a marketing company with a packhouse in Uganda.

3.2 Challenges faced by the avocado sector in Uganda

Several challenges for the avocado sector in Uganda were acknowledged and highlighted by the targeted farmers (Supplementary Table S1). The top five challenges limiting avocado production according to 51.7% of the farmers are: (1) poor knowledge of irrigation needs and water management (12.2%), (2) poor access to soil analysis and nutrient management recommendations (11.1%), (3) poor knowledge of avocado production requirements and pests and diseases management (10.4%), (4) lack of knowledge about farm record keeping requirements (9.8%), and (5) poor knowledge of post-harvest management and waste reduction (8.2%). The rest of the farmers (48.3%) highlighted lack of irrigation infrastructure (6.7%); lack of traceability systems (5.8%); lack or weak agricultural extension services (4.5%); heavy reliance on middlemen to market farmers' avocado fruits (4.4%); lack of access and knowledge on fertiliser and manure analyses and use (4.0%); lack of advice on food safety standards, GAPs and MRLs (4.0%); low access to certification (4.0%); limited direct access to export markets (3.5%); lack of available packhouses for handling, sorting, grading and cold storage (3.0%); poor access to avocado farmer groups, associations or organizations (2.3%); low access to certified avocado seedlings (1.9%); climate change (1.8%); poor access to finance (1.6%) and low mechanization (0.7%) as number one priority.

4 Discussion

Results of this study characterize small- and medium-sized Hass avocado production systems in Uganda. The relatively young age of orchards indicates the many recent investments made in the sector. Consultations with key public and private stakeholders (i.e., NARO, AAU, Hortifresh, and Masindi Avocoop) confirm, validate, and support the study findings. Furthermore, results demonstrate increased adoption of the Hass variety, which can be seen as a positive development, since Hass and Fuerte were first unsuccessfully introduced in Uganda during the early 1990s, followed by several promotion and support programs in the early 2000s (Sseruwagi, 2011) and more recently by the National Agricultural Advisory Services (NAADS) in 2024. Uganda's avocado farming systems can mostly be characterized by mixed cropping, where two or more crop species and/or cultivars are grown simultaneously on the same fields, so leading to beneficial diversification both environmentally and economically (Gururani, 2017). Such diverse production systems are rather unique compared to the prevalent avocado monocropping systems elsewhere in the world (Serrano and Brooks, 2019; De la Vega-Rivera and Merino-Pérez, 2021) and this could be considered as comparative advantage for marketing. Comparing Hass production systems in East Africa, significant differences due to variations in altitude, climate, soil, farming practices, market orientation, infrastructure and levels of commercial development are indeed exhibited among Uganda, Kenya, and Tanzania. Uganda's avocado sector is currently rather focused on traditional varieties for local markets and has currently limited commercialization and export capacity. In contrast, Kenya leads avocado exports with well-developed farming systems, infrastructure, and a well-established focus on Hass production with adoption of good agricultural practices and intensive production techniques (including increased attention to practices of pruning, training, and staking). Being in between both situations, Tanzania seems an emerging player, balancing both local and export markets, with increasing investments in more intense production practices and technology adoption.

Similar as in Kenya (Muriithi and Kabubo-Mariara, 2022), the avocado sector in Uganda is currently dominated by middle-aged male farmers, who own small to medium sized fields engaging both family and hired labor (Dijkxhoorn et al., 2019). In contrast, male farmers in Kenya were younger and more educated than female and had more access to resources (Quisumbing and Pandolfelli, 2010), which according to Geoffrey et al. (2013) enabled them to engage in production of profitable high-value crops like avocado,

Farm and field size positively influences mechanization, implementation of soil analyses, input use (i.e., mineral fertilisers, pesticides, drip irrigation technology), and access to agronomic and food safety and quality advice. The latter aligns with the findings of Muriithi and Kabubo-Mariara (2022), identifying farm size as a key collateral that determines the resources (time and finance) a farmer invests in agricultural technology and the decision to participate in commercial farming. This advocates for further intensification of production or expansion of the avocado farms (Marinus et al., 2022).

It is striking that almost all avocado farmers in Uganda have the perception of having suitable and fertile soils for avocado production, while only few of them ever conducted soil analysis and while low soil fertility and soil degradation are identified as major limitations for agricultural production in East Africa (Lal and Singh, 1998; Cobo et al., 2010; Abugri and Fatunbi, 2024). In contrast to farmer beliefs, soil analyses in this study showed great variability among agro-ecological zones and avocado plots, with all soils showing limitations and/or reduced soil fertility, as also reported by Rusoke et al. (2000). The overall medium to high prevalence of organic matter in the avocado fields corresponds to the widespread use of organic manure, but attention is needed to the overall low levels of total nitrogen and low phosphorus, calcium, sulfur and boron availability. The blind application of organic manure regardless of the source and soil needs poses several risks, including contamination, nutrient imbalances and deficiencies, and the introduction of pests and diseases. Also, the observed irrational use of mineral fertilisers (i.e., too low or too high rates, in this study mostly too low or absent) may lead to nutrient mining and further soil degradation (Bashir et al., 2013; Wei et al., 2016; Haberman et al., 2020; Mitra et al., 2021; Kagumba et al., 2023). Tackling the high cost of laboratory services and advisory and investing in awareness and training on soil fertility management come out as key priorities. Therefore, future support is urgently needed to ensure that avocado farmers in Uganda get access to soil analyses and tailored soil management recommendations, which aligns with the Nairobi Declaration 2024 and the related action plan concluded at the *Africa Fertiliser and Soil Health Summit 2024* (Abugri and Fatunbi, 2024). Although most of the farmers lack a soil management plan, there are effectively noticeable attempts and incentives to manage soil with environmentally friendly conservation practices like ensuring proper drainage, installing erosion bands, mulching, integrating crop residues, planting cover crops, and minimizing tillage. In contrast, Kenyan Hass avocado farmers generally possess more advanced knowledge and adopt more advanced practices in soil and nutrient management compared to their Ugandan and Tanzanian counterparts. The latter is largely attributed to better access to training, resources, and market incentives. While Tanzanian Hass avocado farmers are making progress in adopting improved soil fertility practices, Ugandan farmers lag behind primarily due to limited access to information and resources. Uganda's climate is ideal for avocado production, with two rainy seasons, mean temperatures of 19–25°C, and an annual rainfall of 500–1,500 mm (Freshela, 2024; von Loeben et al., 2023), which is much higher than in other major avocado producing areas [like Peru (~100 mm)]. This reduces the need for irrigation and together with the vast freshwater resources of the country (i.e., 15–18% of surface area) (Konrad-Adenauer-Stiftung, 2019) it gives Uganda a competitive advantage over drier regions that rely heavily on irrigation. It is therefore also believed that avocado can be produced in Uganda in a 'climate-smart' way. Nevertheless, irrigation of avocado is still required for plant survival during younger stages and to achieve the genetic yield potential (Fermont and Benson, 2011), which is needed to transform from subsistence to commercial farming (Wanyama et al., 2017). Irrigation is also needed to adapt to the perceived effects of climate change, which are expressed as persistent droughts and unpredictable rainfall patterns. While less than 1 % of Uganda's farmland is irrigated (FAO, 2012; Wanyama et al., 2017), the relatively high prevalence of (mostly drip) irrigation in avocado systems reflects the recent investments, but poor water management practices still prevail (i.e., not monitoring application rates, not having permits for water extraction, not testing water quality) and are not always aligned with Uganda's National Water Policy (Ministry of Water and Environment, 1999). The latter was previously highlighted as a major risk arising from increased economic development (Nsubuga et al., 2014; Wanyama et al., 2017) and may pose risks of soil salinization (Karamage et al., 2017; Turyahabwe et al., 2022; Omuto et al., 2024) and contamination by organic and trace elements in used surface water, so negatively affecting crop productivity and food quality and safety (Mangiafico et al., 2009; Malakar et al., 2019). Therefore, as the avocado sector rapidly develops in Uganda, technical advice and training on sustainable water management practices is urgently needed.

Most damaging pests for avocado according to farmers in Uganda include fruit flies, false codling moths, caterpillars (Lepidoptera), aphids and mealybugs, while the major diseases include root rot and wilt (Kagumba et al., 2023). Surprisingly, a considerable number of farmers lack knowledge on key pests affecting avocado, and only a few farmers claim to implement IPM strategies. Indeed, smallholder farmers often tend to use traditional pest management practices (e.g., intercropping, hand-picking pests, etc.) that are often (though not always) regarded as eco-friendly, without actually realizing that these are theoretically classified as 'IPM'. Additionally, while chemical pesticides are the most widely used control measures by farmers in Uganda (Rwakipamba et al., 2020; Andersson and Isgren, 2021; Yahyah et al., 2024), only very few avocado growers currently use chemicals or biopesticides, which strongly contrasts to the high and controversial pesticide usage in other major avocado production areas elsewhere in the world (Merlo-Reyes et al., 2024; Rosa et al., 2024). Indeed, avocado trees are naturally more resilient and face fewer pest challenges compared to other crops, and it is additionally reported that several production zones of avocado in East Africa naturally bear higher levels of biodiversity, resulting in reduced levels of pest insects (Toukem et al., 2022). The latter offers an additional comparative marketing advantage, but strengthened advisory services are still urgently needed to advise farmers in pest control and GAPs to ensure they can continuously meet local and international consumer demands and standards (Gonzalez, 1999; Van Boxstael et al., 2013; Granatstein et al., 2016; Hejazi et al., 2022; EFSA, 2023). Enhanced support would also help prevent any misuse associated with certain traditional methods that can negatively impact the environment and beneficial organisms. A notable example is the practice of tree smoking for insect control, observed in Kenya, False Codling Moth and Fruit Flies remain major challenges, mainly on Hass avocado, but farmers lack knowledge of the pest biology, spread patterns, and effects on the plants. It is therefore necessary to develop and disseminate sound IPM packages that are pest -, location-, and season specific. For sustainable pest management, there is an urgent need for establishing alert systems on emerging pest and diseases, and the provision of technical assistance and advice on such IPM strategies.

Interestingly, none of the consulted farmers and stakeholders mentioned the thematic of pollination management during development, implementation, and evaluation of these surveys, while it was earlier reported that optimizing pollination can increase productivity and enhance the quantitative (fruit weight and size) and qualitative (oil content) parameters of avocado fruits, thereby increasing market value (Sagwe et al., 2022; Sagwe et al., 2023). In contrast to reports from Kenya (Sagwe et al., 2021), pollination deficits are currently not widely reported in Uganda, possibly due to diverse agroecological landscapes and natural pollinator populations which may be well sustained by prevailing agroforestry- and mixed farming systems. In any case, a lack of awareness also contributes to this minimal attention to the role of pollinators in avocado yields among farmers and extension workers. Pollinator supplementation should therefore be implemented along with IPM to result in synergistic effects that can positively affect individual farmers household income (Muriithi et al., 2024). Post-harvest management of avocado is key to maintain the quality of fresh produce (Kader and Rolle, 2004; Kassim et al., 2013; Bill et al., 2014; Pokhrel, 2020), but results evidence lack of awareness which may partly be attributed to the immaturity of the sector. With only a few farmers properly understanding the production and quality aspects of Hass, urgent interventions are also needed to guide post-harvest handling. Current prevalent means of transportation and storage facilities used often lack cooling and sanitation systems, further exposing fruits to quality deterioration (Woolf et al., 2000; Kassim et al., 2013; Bill et al., 2014; Mukama and Abaasa, 2024) causing damage and post-harvest losses (Mandemaker et al., 2006; Magwaza and Tesfay, 2015). The latter calls for investments in improved infrastructure such as central cooled and sanitized packhouses and transportation chains.

With poor advice on food safety standards, GAPs, and MRLs, the observed high prevalence of side buying and mixing produce, and the absence of traceability systems, the sector currently strongly risks non-compliance possibly leading to loss of markets, as argued by Mol and Oosterveer (2015). Correspondingly, certification like GlobalGAP, Organic, SMETA, GRASP, Rainforest Alliance etc., is currently low, though dominated by organic. However, the observed production characteristics (e.g., mixed farming with low to no chemical inputs etc.) would most likely qualify for such certifications if well facilitated, advised, and record keeping improved.

Marketing of avocado fruits is currently coordinated by middlemen and a few exporters, which corresponds with Schoonhoven-Speijer et al. (2017) who highlighted the big role of middlemen in food trade systems with weak supply chains in sub-Saharan Africa. Hass produced in Uganda is currently delivered to fresh produce exporters selling to the European Union and the Middle East and domestic oil processors who also absorb excess and low-quality fruits. However, the relatively low volumes exported contrasts with the situation in Kenya, where exporters supply large volumes of branded Kenyan Hass avocados to international supermarket chains (Heher and Steenbergen, 2021), and it is assumed that part of Ugandan produce is absorbed in this Kenyan value chain.

The observed fixed prices benefit mostly middlemen and exporters (Minot, 2011; Oya, 2012), leading to lower prices and revenue for farmers. Using several econometric models, Niguse and Mebratu (2023) showed that commercialization, pricing, and revenue of avocado by smallholder farmers in Ethiopia was influenced by the age of the household heads, land and family size, market distance and information, access to media, and volumes produced. Furthermore, the study indicated that effective use of the scarce resources like land, labor and market information increased the value of avocado fruits, and it was proposed to establish avocado market centers within growing communities to increase market participation. Also in Uganda, consolidation and better organization of avocado producers seems needed to strengthen the position of farmers, Farmers' expression of interest in joining a marketing association or group with a central packhouse should be responded to ensure better trading relationships and compliance with sanitary and phytosanitary market requirements and standards (Siméon, 2006). Also, farmers partnering in organized production and marketing groups (BMOs), associations and cooperatives generally obtain increased margins (Candemir et al., 2021). With only half of the avocado producers in Uganda currently belonging to sectoral organisations (e.g., Avocado Association of Uganda, Suluma Foods, Avocare, or Masindi Avocoop cooperative) or out-grower schemes, these structures are mostly fragmented and poorly organized with limited resources. In contrast, the more prevalent participation of farmers in avocado BMOs in Kenya indicated that farmers with bigger orchards were more willing to join farmer organisations and contract farming than those with few trees (Muriithi and Kabubo-Mariara, 2022).

The avocado sector in Uganda shows lots of opportunities and has several comparative advantages to deploy as indicted in this study and Lutta et al. (2024) report. However, there is an urgent need for further consolidation, organisation, and support of the sector, and a large need to train farmers in responsible business conduct and sustainability of operations as advocated for by FAO (2024).

4.1 Recommendations for future interventions and support

The following recommendations and areas for future interventions are derived from the gaps and challenges identified above:

4.1.1 Improved training and capacity building

Stronger extension systems would need to be developed for the sector to provide comprehensive trainings and knowledge on farm record keeping, avocado agronomy (including tree pruning), pest/disease management (including development and dissemination of IPM strategies combined with pollinator management), soil and manure testing, and irrigation management. This includes extension of proper practices for fertilization, and integrated pest management, as well as post-harvest management like handling, packaging, and transportation.

4.1.2 Support seedling nurseries and access to certification

Establish and certify avocado seedling nurseries in each district. Growers should be supported to get access to certification, possibly through farmer associations.

4.1.3 Strengthen farmer associations, joint infrastructure and collective marketing

Encourage the development and organisation of avocado farmer groups or associations for better coordination, collective marketing, branding, value addition, and price negotiation. This should include the investment in central joint infrastructures needed for sanitized and cooled export chains.

4.1.4 Establish financial support systems and public-private partnerships

Develop affordable, farmer-centered financial systems, possibly subsidized by the government and strengthen public-private partnerships to offer extension services.

5 Conclusion

This study characterizes the small- and medium-sized avocado farming systems in Uganda. Overall, there is increasing adoption of Hass avocado targeting international export markets. Production mostly occurs under mixed cropping with limited to no use of chemical inputs or irrigation and frequent organic manure applications, which contrast to major avocado production systems elsewhere in the world, leading to several comparative advantages and opportunities. Field size positively influences the adoption of GAPs, use of inputs and mechanization, and access to agronomic and food safety advice. Several identified challenges indicate the need for more and better support and training on pest control, soil -, water-, and post-harvest management. Better organization of producers should benefit stronger marketing and investment in joint infrastructures.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

Surveys were used for data collection on the socio-economic, and environmental context of farmers, however, authors confirm that no potentially identifiable images or data are directly presented, and that data are only presented in an aggregated form. All participants were well informed about the content, goal, and end-use of the survey, and gave their consent before participation. The studies were conducted in accordance with the local legislation and institutional requirements.

Author contributions

PeS: Writing – original draft, Writing – review & editing. EL: Conceptualization, Funding acquisition, Investigation, Project administration, Resources, Supervision, Validation, Writing – review & editing. PaS: Conceptualization, Investigation, Methodology, Project administration, Resources, Supervision, Writing – review & editing. GD: Methodology, Project administration, Validation, Writing – review & editing. JC: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Software, Visualization, Writing – review & editing. PB: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

PeS, EL, and PB were employed by COLEAD, PeS was employed by Gittands Agro Ltd., PeS was employed by the Avocado Association Uganda, and JC was employed by eProd Solutions Ltd.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2025.1500012/full#supplementary-material

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