

Challenges and opportunities to scaling smallholder mechanization in Kenya, Malawi, Zambia, and Zimbabwe

Hambulo Ngoma¹, Esau Simutowe², Md. Abdul Matin¹, Christian Thierfelder¹

¹ International Maize and Wheat Improvement Center (CIMMYT), Harare, Zimbabwe

² International Maize and Wheat Improvement Center (CIMMYT), Lusaka, Zambia

Abstract

As governments heighten the drive to mechanize agriculture, critical information is required on (i) existing mechanization options, (ii) barriers and challenges, (iii) opportunities for scaling and effective demand for mechanization. This paper combines quantitative and qualitative surveys to help elucidate on some of these key issues in Kenya, Malawi, Zambia, and Zimbabwe where mechanization is part of national policy priorities. Data were collected through Qualitative surveys involving 484 participants in focus group discussions and 109 key informants. Focusing mainly on farm mechanization and irrigation options for smallholder farmers, we found that animal draft power is still dominant for land preparation, ahead of two-and four-wheel tractors. Common options for post-harvest management include shellers, improved granaries and hermetic bags. In terms of demand, there is nascent literature suggesting that farmers in Malawi, Zambia and Zimbabwe are willing to pay positive amounts for different mechanization services, indicating prevalence of effective demand and good opportunities for mechanization. Supply side barriers to scaling mechanization include limited availability of machines and spares, poor after sale, and repair and maintenance services in the vicinity of farmers. On the demand side, high capital requirements, limited awareness and technical knowledge and the high cost of hire services are some of the main barriers to scaling. Based on these findings, there is need for inclusive and innovative financing mechanisms, demand creation and awareness raising to scale up and scale out mechanization.

Introduction and background

Mechanization is central to making African agriculture more productive, commercial and less arduous (FAO and AUC, 2019). This is epitomized by the inclusion of mechanization in the 2014 Malabo Declaration during the African Union Summit on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods that aims to end hunger in Africa by 2025¹. Given past epochs of limited success to scale out large and expensive four-wheel tractor-based mechanization by national governments (Pingali, 2007),

¹¹ [31247-doc-malabo_declaration_2014_11_26.pdf \(au.int\)](https://www.au.int/sites/default/files/31247-doc-malabo_declaration_2014_11_26.pdf)

current efforts are more careful not to repeat the same mistakes. Instead of focusing on *tractorization*² – making tractor available – the current impetus focuses on scale-appropriate mechanization which in a broad sense implies adapting machines to the context of farmers and their farming conditions, and needs (Baudron *et al.*, 2015). Therefore, current focus of donors, governments, and international development in general is broadly on agriculture mechanization rather than farm mechanization. This distinction is vital. According to FAO and AU (2019), agricultural mechanization considers the whole value chain from manufacturing, distribution, and use of all types of tools, implements, machines and equipment covering the whole gamut from land preparation, crop management, production, harvesting and primary processing of agricultural produce whereas farm mechanization refers mainly to production activities for crops, livestock, and aquaculture within a farm unit.

A focus on agricultural mechanization takes care of both demand and supply side issues. On the demand side, there are efforts to create demand and raise awareness for mechanization and testing of different machinery and mechanization models that assure farmers' access to appropriate machines that can generate income. These activities are centered on the private sector as the main drivers, while governments, NGOs, research institutes and universities provide support functions including financing, research and development, policy and regulations (Daum and Birner, 2020). Often, the pace of mechanization is quicker and becomes more sustainable when the private sector takes center stage. This usually follows the initiation of mechanization activities funded by donors and governments. In essence, investments by donors and governments are necessary to kickstart and sustain mechanization activities until private sector actors are crowded in.

Increasing land scarcity, demand for food, population and rural wages, and the increase in the proportion of 'well-off' medium scale farmers (Jayne *et al.*, 2016; Daum and Birner, 2020; Jayne *et al.*, 2021) create a conducive environment for capital-intensive, labor-saving mechanized options (Ngoma *et al.*, 2021). For example, in Ghana, rising land-labor ratios, labor scarcity and the need to expand cropping area are driving up demand for agricultural mechanization through mechanization (Diao *et al.*, 2014). While current conditions favor

² Refers to the use of any type of tractor (single axle, two-wheel tractor [2WT]; two-axle, four-wheel tractor [4WT]; or track-type) of any power rating in agriculture (FAO and AU, 2019).

mechanization and the renewed optimism gives hope, questions remain on how large the effective demand for mechanization is in Africa and the capacity of African smallholder farmers to pay for mechanization services (Pingali, 2007). The effective demand and the extent to which farmers are willing to pay for mechanization is a function of farmers' socioeconomic characteristics, resources endowments, familiarity with and availability of machinery options.

This paper takes stock of current mechanization interventions in selected parts of Kenya, Malawi, Zambia, and Zimbabwe and assesses opportunities and barriers for scaling mechanization and offers some reflections on demand. Mechanization is defined broadly to include any non-human powered agricultural operations covering land preparation, production, harvesting, post-harvest processing and storage, and transportation. We used a mixed methods approach combining qualitative surveys (focus group discussions and key informant interviews) in all the four target countries and secondary data collected in another project (*Understanding and Enhancing Adoption of Conservation Agriculture in Smallholder Farming Systems of Southern Africa - ACASA*) in Malawi, Zambia, and Zimbabwe. This paper builds on recent literature that assesses the state and impacts of, and demand for mechanization in Africa (Daum et al., 2023; Ngoma et al 2023; Tufa et al., 2023; Daum and Birner, 2020; Adu-Baffour, Daum and Birner, 2019; FAO and AUC, 2019; Diao et al., 2014; Pingali, 2007). In essence, we review the quite rise of appropriate mechanization and identify barriers and opportunities for scaling.

Smallholder mechanization in Kenya, Malawi, Zambia, and Zimbabwe

The use of agricultural mechanization in form of large and expensive four-wheel tractors has been promoted in Kenya, Malawi, Zambia, and Zimbabwe from way before these countries attained their political independence (De Groote, Marangu, and Gitonga, 2018). Despite many years of promoting agriculture mechanization in Sub-Saharan Africa, the uptake of mechanization has been slow over the past decade (Daum, 2022; FAO, 2022).

In recent years, governments of Kenya, Malawi, Zambia, and Zimbabwe (among other African countries) have shown interest in promoting mechanization as reflected in their

current agricultural or mechanization policies. Kenya's Agricultural Mechanization Policy aims to raise and sustain the level of motorized power use to 50% by 2030 from the current level of 30% (Wawire et al., 2016; Ministry of Agriculture, Livestock, Fisheries and Cooperatives, 2021). Adoption of mechanization for smallholders in Kenya is limited to a few farm activities such as land preparation and transportation with other activities are done manually.

In Malawi, most of the farmers are still using basic hand tools such hoes for land preparation and weeding and have continued using hands for harvesting and processing crops. The National Agriculture Policy of Malawi therefore considers agricultural mechanization as one of the priority policy areas to promote mechanized cultivation, agro-processing and value addition. The policy supports market-based imports of agricultural machinery that is appropriate for the needs of the farmers in Malawi (Ministry of Agriculture, Irrigation and Water Development, 2016).

As is the case with Malawi, access to agricultural mechanization in Zambia is still very low (Adu-Baffour, Daum and Birner, 2019; Ministry of Agriculture and Ministry of Fisheries and Livestock, 2016; Nkonde, 2017;). Zambia's Second National Agricultural Policy (2016) aims to promote farm power and mechanization for smallholder farmers to increase crop production and productivity (Ministry of Agriculture and Ministry of Fisheries and Livestock, 2016). At the time of writing, a mechanization strategy was being developed for Zambia.

Similar to Kenya, Malawi, and Zambia, the use of agricultural machinery in Zimbabwe is also low (Kirui, 2019). Zimbabwe's Comprehensive Agricultural Policy Framework (2012–2032) has set increasing access to mechanization services by farmers as one of the key policy areas for the development of the Zimbabwean agricultural sector (Ministry of Agriculture, Mechanization, and Irrigation Development, 2012).

Methods

We used mixed methods, combining qualitative surveys and secondary data. Qualitative surveys included 48 focus group discussions (FGDs) with farmers and 109 key informant interviews (KIIs) in Kenya, Malawi, Zambia, and Zimbabwe (Table 1). Four FGDs were conducted per district/county disaggregated by gender and age group i.e., one for each of

female, male, youths, and mixed group (female, male and youth). Overall, 593 people participated in the qualitative surveys across the four countries (180 female, 177 male and 127 youth).

Table 1: FGDs and KIIs participants in four countries

Country	District/County	FGDs			KIIs
		Female	Male	Youth	
Kenya	Makueni	18	18	12	12
	Nakuru	18	18	12	10
Malawi	Nkhotakota	18	18	11	8
	Balaka	18	17	12	9
Zambia	Mazabuka	8	22	11	9
	Monze	27	16	10	10
	Chipata/Chipangali	16	7	10	9
	Sinda	17	13	8	8
Zimbabwe	Shamva	10	9	11	9
	Murewa	9	13	11	8
	Mutoko	11	15	9	9
	Masvingo	10	11	10	8
Total		180	177	127	109

The secondary data used in the analysis were collected through household surveys conducted in Malawi, Zambia, and Zimbabwe under the ACASA project. In consultation with national stakeholders, the ACASA surveys were conducted in Nsanje, Balaka, Nkhotakota, Chitipata, Dowa, Rumphi, and Zomba districts in Malawi. In Zambia, the surveys were conducted in parts of Choma, Siavonga, Mumbwa, Kaoma, Chipata, Mpongwe and Serenje districts. Ten districts were covered in Zimbabwe, including Chiredzi, Matobo, Bubi, Masvingo, Zaka, Gokwe South, Kwekwe, and Nyanga, Murewa and Shamva. This gave a sample of 1,512 in Malawi, 1,407 in Zambia and 1,455 in Zimbabwe. Results based on these data exclude Kenya because it was not part of the ACASA survey. Willingness to pay in Malawi was assessed using contingent valuation method while the Becker-DeGroot-Marschak (BDM) experimental auctions were used in Zambia and Malawi. Unlike contingent valuation which uses hypothetical scenarios in eliciting willingness to pay, BDM mimics a market scenario where participants bid for good and services using real money. This makes BDM incentive compatible. See (Tufa *et al.*, 2023) for details on the methods used in Malawi and (Ngoma *et al.*, 2023) for Zambia and Zimbabwe. The follow-up qualitative surveys in

Malawi, Zambia and Zimbabwe were done in a subset of districts covered by the ACASA surveys in these countries. As such, the two activities are complementary.

Results and discussion

Kenya

We identified 19 mechanization options that being promoted and used by farmers in parts of Nakuru and Makueni counties in Kenya (Table 2). These mechanization options include hermetic bags, four and two-wheel tractors, rippers, shellers and improved animal drawn implements. The cost of machinery is one of the key barriers to scaling mechanization in Kenya. There is a desire for more trainings on mechanization options (especially on the benefits and use of different machinery) to enhance scaling in Kenya. More details are in Table 2.

Table 2: Available mechanization options, challenges, and opportunities to scale in Kenya

Technology	Main barriers to scaling	Opportunities for scaling
Hermetic bags	- Cost of acquiring the bags - Gendered disparities in access to hermetic often in favor of men with better resource endowments to buy the bags	- Training and sensitization on the use of hermetic bags - Training more men as they are the ones with money - Training on bulk purchase through community-based groups
Four-wheel tractor	- High cost of purchase and hire of tractors - Old age and low literacy levels of farmers - Limited technical knowledge on the use of four-wheel tractors - High costs associated with sensitization of farmers	- There are opportunities to take advantage of cost sharing arrangements to access tractor offered by county governments - Training and sensitization of farmers on the operation and use of four-wheel tractors
Improved Animal Drawn Machinery	- Financial constraints	- Sensitization on adoption of minimum tillage to reduce draft power requirement
Ox-drawn rippers	- Lack of knowledge on the use of rippers - Cost associated with acquiring rippers - Uneven land topography makes the ripper unsuitable	- The Agricultural Mechanization Services (AMS) unit to offer trainings of other stakeholders to reduce the associated cost in the market - Group purchase of rippers through loans or cost sharing - Training private stakeholders who produce ripper to reduce costs of production
Shellers	- High costs of hiring shellers compared manual shelling	- Upscale the use of shellers by groups and not individuals. This will reduce transactions costs for the service providers and reduce costs for customers.
Tractor drawn rippers	- Uneven land topography of lands makes the ripper unsuitable Dependency on low-cost hand-based tools	- Exploring group hire options
Knapsack sprayers	- Difficult to carry the sprayer by old farmers - Inadequate training of farmers on how to use knapsack sprayers efficiently	- Training the youth to be involved in farming and to provide spraying services -
Roof water harvesting	- Expensive and labor intensive.	- Opportunities to access to loans from the county - Establishing demonstrations as learning sites
Shallow wells	- Most shallow wells dry up during the dry winter season	- Promote alternative water sources - Drilling boreholes to lift water throughout the yearPromoting sand dams
Lifting technologies (solar and motorized)	- Adoption rate is low due to high costs	- Cost sharing or access to loans through Sun culture, LIPA POLEPOLE and other sources - Sensitization and training on solar irrigation - Improving water harvesting
Water application technologies (Overhead and drip irrigation systems)	- Cost of drip lines - Lack of knowledge on irrigation - Labor intensive of some irrigation options like buckets	- Available government subsidies and loans through the county administration - Training on various irrigation options

	- Limited water availability	
Water sourcing (Water pans, water tanks and dam)	- High setup costs Limited water availability	- Linking small holder farmers to community-based organizations
Dam liners	- High setup costs - Limited water availability	- Promote alternative water sources like rain harvesting - Facilitation of access to savings and loans from rural microfinance organizations - Drilling of boreholes - Promotion of sand dams
Two-wheel tractors	- Poor government facilitation. - Shortage of operators - Limited after sale support and spares and mechanics availability. - Frequent machinery breakages - Limited know how. - Limited extension services. -	- Training and sensitization of farmers and operators - Help develop local mechanics and improve spares availability in local areas - Cost sharing from the county government - Financial support to purchase two-wheel tractors - Equipping the already existing machinery and offering regular trainings -
Farm ponds and terracing technologies (backhoe for terracing and farm pond)	- Limited knowledge and extension services	Capacitating and training of extension workers,
Hay making	- Limited uptake of commercial hay production due to limited buyers	- Training farmers on hay production
Gasoline powered pumps	- Cost of fuel is high - Water is not sufficiently available	-
Piping system of irrigation	- High setup costs - Poor management.	- Sensitization and training Of users
Poultry farming	- Poor marketing (middlemen) disadvantaging farmers - High costs of feed	- Improved market opportunities through better market linkages

Malawi

While there is a perception that mechanization is low in Malawi, we found some incipient mechanization activities in Balaka and Nkotakota districts. Hermetic bags, four-wheel tractors, rippers, shellers and knapsack sprayers among the 14 distinct mechanization options promoted and used by farmers in parts of Balaka and Nkotakota districts (Table 3). The main challenge hindering scaling up of mechanization in Malawi is limited number of machinery in use due to high purchase costs. High demand for mechanization in Malawi presents a great opportunity for scaling different mechanization options. Local entrepreneurs are taking advantage of this high demand in Nkotakota and are providing different mechanization services (Figures 1). See Table 3 for further details.



Figure 1: Locally fabricated groundnut (left) and maize (right) shellers in Mwansambo, Nkhotakota, Malawi. Notes: The maize sheller is mounted on a modified Motorbike for ease of mobility to provide door to door services

Table 3: Available mechanization options, challenges, and opportunities to scale mechanization in Malawi

Technology	Main barriers to scaling	Opportunities for scaling
Four-wheel tractor	- They are expensive to maintain - Lack of trained local mechanics (available only from Lilongwe or from Dwangwa Illovo Sugar Company) - Inadequate number of tractors to serve all farmers. For example, Nkhotakota district only has 4 tractors which are unable to serve all farmers' timely needs and requirements	- Rising demand for mechanization services
Shellers	- Inadequate number of shellers to meet demand - Inadequate funds to support operations and maintenance of shellers - Shellers are not affordable for most people either to buy or hire - High operating costs given raising fuel costs - They sometimes shell together unhusked cobs which brings another job of removing the cob husks	- The demand for shellers is very high and the available shellers can only serve a few people at a time while multitudes wait in line
PICS Bags	- They are expensive for most smallholder farmers - Some people are still not convinced on their importance compared to the local ones - They are not easily available in most areas; people need to travel long distances to find the bags - They are not conducive to be used to store seed for the next growing season; seed tends not to germinate	- Increased availability of information on PICS bags from various development partners and the the Ministry of Agriculture with support from World Food Programme and PROSPER - Most farmers have the technical knowhow on the importance of PICS bags - The World Food Programme and the UKAID provided farmers with PICS bags and gave them the cost benefit analysis on their usage
Oil processing equipment	- The available equipment only produces about 5 liters of oil in a day because there is not enough sunflower grown - It uses electricity to operate; with the electricity outages the country is experiencing, the production process is being reduced to a great deal	- Availability of land that can be used to grow sunflower and opportunities to engage farmers in contract farming
Irrigation scheduling	- Challenges to schedule for different crops planted in the same block area by different people - Pumps fail to work well with low water levels - Shortage of irrigation service staff, which reduces availability of technical assistance Inadequate water supply as some areas do not have enough water reservoirs and where they exit, they dry up during the dry season	
Engine driven pumps	- They are expensive and costly to maintain due to high cost of spare parts and fuel	- Availability of water bodies that be used as water sources - Availability of land suitable for irrigation

	- High operation costs due to high fuel price. - Some spare parts are not easily available, and people have to travel long distances to other towns to find them	
Solar powered pumps	- High initial capital injection as they are expensive to buy - Farmers have not mastered their operations yet. For example, farmers are finding it challenging to find the right size of pump to be used - Theft of solar panels - Solar system depends on sunlight, and this limits the irrigation times - Unavailability of finances to scale up distribution of solar pumps	- The availability of good sunlight over extended periods which allows the pumps to operate in sunny days. - Easier and cheaper to operate as there are no other costs incurred such as fuel costs - Availability of the dams permits more farmers to cultivate in the dry season. - Availability of wetlands that allow for cultivating in dry season. Wetlands are usually close to dams or other water bodies and that gives people opportunity to irrigate
Rehabilitation of irrigation schemes	- Lack of financial resources To fund rehabilitation	
Gravity feed irrigation	- Inadequate water reserves to channel water downstream	
Water sourcing	- Water sources run dry after the rainy season	- High water table which it easy to access water even by digging shallow wells
Water shed management	- Low participation by the communities	
Treadle pumps	- High labor demand and time consuming - They can only be used to cater for a small piece of land as its discharge capacity is low compared to solar or engine powered pumps - Their suction and delivery pipes don't last long, and they are expensive to replace - The pump works well needs where there is adequate water	- Availability of water and land for irrigation

Zambia

Participants in FGDs and KIs in four districts in Zambia identified 21 mechanization options being promoted and used by farmers (Table 4). Example mechanization options two – and four-wheel tractors, hermetic bags, solar irrigation, shellers, etc. (Table 4). The main barriers to scaling include lack of finance to buy and hire mechanization equipment, inadequate knowledge on the benefits of mechanization equipment and limited access to mechanization equipment. There is potential for scaling mechanization options in Zambia due to high demand as most of the farmers appreciate the benefits of mechanization and there is plenty of arable land that can be exploited using mechanization.

Table 4: Available mechanization options, challenges, and opportunities to scale in Zambia

Technology	Main barriers to scaling	Opportunities for scaling
Hermetic bags	- Very expensive compared to the ordinary bags - Lack of interest from the farmers because they do not really know the benefits - Hermetic bags are difficult to find	- No chemicals are used to preserve the harvest, thus reducing costs - Provides a safe way to keep crops from being attacked by termites as there is no oxygen that is left in the bag - Can store up maize for a long time
Four-wheel tractor	- Four-wheel tractors are very expensive to buy or hire as most small-scale farmers do not own them. Hiring charge can go as far as ZMW 1,000 per hectare - High fuel costs and maintenance - Tractors destroy the soil as they make furrows in the field - Promotion programs only target farmers with a certain of production capacity - Requirements to be considered in promotion programs requires consideration of a business plan - Tractors are retrieved from the farmers when they don't reach the set agreements within time - Land in the area is not titled and thus cannot be used as collateral for one to access mechanization inputs - Tractor use requires a large land size otherwise it gets underutilized which is a waste of resource. Some small-scale farmers have small pieces of land to use a four-wheel tractor - Absence of a variety of credit schemes - It is difficult to use a four-wheel tractor in the muddy field when there has been too much rainfall and the process becomes slow because the tractor cannot move faster as compared to how it moves normally on a dry field - Lack of knowledge on the use of tractors and tractors contribute to soil erosion	- It makes rip lines deeper than those of ox-drawn rippers. ADP rippers struggle to reach the required ripping depth in the hard pan - Those without animals but have money are able to borrow and plough large pieces of land - People are still using ploughs which takes a lot of time even when they know that tractors are fast - Farmers are willing to pay for hiring services for tractor ripping service provision - The use of four-wheel tractors reduces on human labor, farmers get to use tractors to ease their work. - Knowledge has been made available to farmers on the use of tractors and hence a lot of farmers are willing to use tractors - Availability cooperatives that can help with access to tractors
Shellers	- Shellers are expensive to buy and hire for most small-scale farmers. In particular, hiring of the shellers is very expensive and many farmers are discouraged by high prices - The available shellers are not enough for the number of farmers needing the service	- High grain production for which shelling services are required - Shelled maize is clean when compared to one shelled using hands - A lot of maize can be shelled within a short period of time - Farmers are aware of the benefits of using shellers - Availability of local materials that be used to fabricate shellers

	- There are no follow ups by promoters to enhance the knowledge of how the sheller can be made - Lack of knowledge of the use of shellers While shellers have good fuel consumption, solar powered shellers would reduce running costs - -	
Rippers	- It leaves a lot of weeds between lines compared to conventional methods. - There is a lot of spacing in between the rip lines - Some people are stuck with the old ways of farming, and don't want to adjust. - Ripping is done before the rainy seasons commences while a lot of people would only start farming when they have seen the rainfall starting. - People don't have money for hiring rippers and cows to pull the ripper. - The fields that are cultivated are little and harvests are small as there is too much space left in between rippers. - Some farmers don't know the benefits associated with ripping. - Ripping technology goes hand in hand with the use of herbicides for weed control, without proper planning for the purchase of herbicides, the implementation of the technology is not successful. - Lack of knapsack sprayer hinders the successful utilization of the ripping technology - Knowledge gap on the correct types and use of herbicides. - Rippers are very expensive to buy and hire. - Some farmers or camp officers personalize rippers given to the community by some stakeholder to help the community. - Lack of shops that stock rippers in the communities.	- High yields from ripped plots motivates farmers. - Crops don't easily die out when there is drought as rip lines retain moisture. - Lion head weed does not grow with vigor. - Rip lines holds moisture for the crops. - It does not destroy the soil structure as those planting stations are the only areas that are disturbed in the field. - We have agro shops that stock rippers in the nearby towns. - There are some people with bigger animals that can lend others to help with ripping. - Land availability. - It does not promote soil erosion and keeps the fields in one shape. - Not very labor intensive. - Some NGOs have donated some rippers to various community - People have been learning about conservation agriculture thus they have the knowledge on how to use these technologies. - They can be hired from those who own them.
Electric solar fenced Kraal (Secure fencing)	- They are expensive and a farmer needs to raise at least K7,000 for the equipment. - There is no credit facility.	- The prevalence of cattle in the area and need to secure animals from theft or loss creates a demand for this technology. - Framers have adequate land for this kraal model. - There is general willingness by farmers exposed to this technology to procure if there is a pay-slow or credit facility for the item.

Water harvesting (Roof top water harvesting).	- Limited to farmers with iron roofing sheets. - The tank size of the technology is not large enough for the amount of water the gutters are able to collect from the rainwater. - The gutters used on the roof to harvest the rainwater are not easily found in local shops.	- There is a good number of farmers that are using the iron roofed houses. - The willingness by farmers to harvest water for irrigation is high.
Milking cans	- Very expensive for small scale farmers. - Milking cans are not easily accessed	- Dairy improved companies provide access to milking cans. - Makes the transportation of milk to be hygienically safe.
Solar powered submersible pump	- The initial cost of acquiring the needed solar equipment and borehole sinking is out of reach for many smallholder farmers. - The challenge of water in some areas makes it difficult to implement. - Lack of credit schemes to support solar irrigation.	- There are a good number of areas available in the communities where solar pumps can do well. - There are points within the communities that have boreholes and therefore would only require a tank for irrigation purposes. - Through the AWARE project, a good number of farmers have acquired the knowledge of sourcing ground water technology.
Water application technologies (Overhead and drip irrigation systems)	- The cost of acquiring a drip and sprinkler system is quite high for a smallholder farmer, as there are many parts including a tank that should be set-up. - This irrigation system is limited to farmers that have access to a source of water. - A large water storage capacity is required to achieve the water pressure levels required particularly for the sprinkler system.	- It is possible for community members facing challenges with irrigation, to work together and afford the irrigation system. - Common methods of irrigation among farmers in gardens such as buckets are laborious. The drip and sprinkler systems are less laborious.
Water harvesting using concrete slab reservoir	- Infrastructural cost is high for the smallholder farmer as it requires materials such as polythene plastics, conforce wire, cement, blocks sand and crushed stone. - Limited positive attitude by the farmers because of the many requirements needed. - Lack of knowledge on how to set it up. - Lack of interest from some farmers.	- There are many farmers willing to be trained in water harvesting due to lack of water for irrigation in many areas. - Water comes out in drops which helps to conserve water; there is no wastage of water. - Crops can be planted throughout the year. - Can work on large pieces of land.
Two-wheel tractors	- The tractor is expensive for most smallholder farmers to buy them. - People need to book in advance to have a tractor work on their field because of having few tractors in the community. - The farmers who wone these tractors live in distant places making it difficult for some farmers to access them. - The price for hiring is way too high. - They are labor intensive. - More rip lines are created using a plough than a tractor.	- A lot of seed is planted within a short period when a tractor is used compared to ox-drawn plough. - A tractor works as long as there is fuel, it does not tire like a cow or donkey. - There is proper spacing when a tractor is used, and this leads to good breathing space and good harvest. - Work is made easy on the farm and people admire that.

		- Less labor is hired as only one person moves with the tractor. Cows need someone to help the one ploughing. - The two-wheel tractor is a dual purpose as it plants and rips at the same time. - There have been demonstrations on how the tractor ripper performs and so a number of farmers have been sensitized on it. - There is local demand for 2-wheel tractor powered machinery by farmers in the area.
Dairy equipment - Cans	- Lack of feed for dairy animals leading to poor milk production limits the need to acquire improved milk cans. - The number of farmers owning dairy animals has reduced. - Cans are very expensive to buy. - Non-members of the cooperative mostly do not have access to the cans.	- The private company Bonnita through farmer cooperatives has a credit facility that enables access to milk cans by smallholder farmers who cannot afford direct purchase. - There are buyers for milk making cans have relevance. - Dairy feed is available in some cases that would increase milk yield and therefore create a demand for the milk cans among the smallholder farmers. - Traditional methods of holding or transporting collected milk deteriorates the milk quality at a higher rate.
Silos (Plastic material drum)	- It is a capital-intensive practice at procurement. - The promoted silo has a limited capacity of storage as it holds only up to 8x50kg bags of grain weight. - Lack of shops stocking this equipment. - Lack of sensitization on the use of Silos.	- Current use of chemicals for storage by farmers does not preserve the stored maize grain longer than silos drum can.
Treadle pumps	- A few farmers have learnt about the pump and thus there is little knowledge about it. - Some farmers are just lazy to attend meetings and try out these treadle pumps. - They are very expensive to buy or hire and can't be afforded by most farmers. - The physical energy which is required to operate a treadle pump is high. - Most gardens are controlled by women and thus can't pump as they are hard for them to pump. - Lack of water sources such as rivers and dams are a limiting factor as current streams of water easily dry out soon after the rainy season. - High maintenance costs and spare parts for the equipment are not readily accessible.	- A large portion of land is watered at a given time. - There are a lot of gardens in the area that would benefit from the use of treadle pump technology. - Male farmers already possess the knowledge on how to operate treadle pumps. - There are shallow water points in some areas where the treadle pump can be used. - Farmers can access on loan. - The current use of cans is laborious. - There are few farmers who have treadle pumps who can scale-up this practice. - Helps to supply water in the community when pipes are connected. - Does not to use fuel to pump water.

	- The treadle pump safer has a tendency of easily getting clogged by weeds making this a technical challenge with the equipment. - They are very expensive to buy and set up.	
Gradient irrigation	- This practice was promoted for upland rice production, but rice seed is not readily available to farmers. - Limited to the amount of water that can be harvested for the upland rice.	- Extension services are available under the ministry to assist farmers on slope gradient measurements to trap water. - There are many areas that have slopes where water run-off takes place.
Watering cans	- Watering cans are expensive for some smallholder farmers; one water cane costs ZMW 130. - Very labour intensive because they have to be carried with hands from one point to another. - Risks of falling into the dam or well when drawing water.	- It is commonly used and very easy to use; no technical knowledge needed to use them. - They are not very expensive to buy, and they can be used for a very long time.
Hammer mill	- When the hammer mill does not grind well, people tend to avoid using it. - Solar hammer mills are not very effective when there is no sunlight. - Hammer mills are expensive as farmers are charged ZMW 12 per ton. - A few individuals own hammer mills and people have to travel long distances to access them. - It is expensive to run diesel hammer mills as not all communities have electricity. - Hammer mills are expensive to buy. - Lack of mechanical services to repair them when they get spoiled. - Traditional beliefs have hindered scaling up, they believe if they use hammer mill to grind their maize the mealie meal loses its natural scent.	- It doesn't take a lot of time and it is hygienic compared to using stones. - They are within the communities and government has also provided solar hammer mills. - The maize bran that remains is used to feed livestock. - Hammer mills are good for the production of maize meals. - We leave maize meal residues for feeding our animals. - There is a lot of maize grown in the communities. - Farmers can get hammer mills and pay back bit by bit if given small loans.
ADP ripper	- Limited access: not many farmers have rippers. - Agro-shops that stock rippers are far. - There are areas that do not have the animals required to draw the rippers. - There is a challenge of weeds in minimum tillage. - Lack of sensitization on application of herbicides. - ADP rippers struggle to reach the required ripping depth in the hard pan.	- There are stakeholders that are promoting ADP rippers. - There are some farmers that have animals. - There has been evidence of the benefits of minimum tillage observed by many farmers, and most have developed the interest. - ADP rippers are accessible in some areas for interested farmers. - Most farmers cannot afford to hire tractor powered rippers and ADP is an affordable practice more farmers can use. - Current conventional methods of land preparation are time consuming. Ripping improves the work rate of land preparation.

Zimbabwe

We identified 25 mechanization options being promoted in the four districts visited in Zimbabwe (Table 5). In addition to common ones in other countries like two- and four-wheel tractor, we found metal silos, mango dryers, multi-crop shellers, direct seeders, etc. As in other countries, the main barriers to uptake include high cost of equipment, limited availability, limited technical knowledge and in some instances, limited availability.

Table 5: Available options, challenges, and opportunities to scale mechanization in Zimbabwe

Technology	Main barriers to scaling	Opportunities for scaling
Hermetic bags	- Only a few can afford due to its high price - Uptake is very low. - Farmers do not understand the technology behind.	- There is need for affordable hermetic bags as people are interested in it. - There is need for more farmer awareness and trainings on management of post-harvest losses. - More technical support to smallholder farmers in terms of post-harvest storage management can increase its uptake. - More strategic partners scaling are needed.
Four-wheel tractor	- The cost of tractors is very high for an average farmer. - The land youth farmers own are usually small making it is uneconomical for a single youth to own a tractor. - High maintenance costs. - The uptake of the hiring model is very low, and this has constrained the viability of tractor renting services. - The cost of hiring the tractor service is still high for the average Zimbabwean farmers.	- Group ownership can increase usage of tractors. - Introduction of affordable credit services to buy or hire tractors. - There is need for awareness and trainings on the importance and benefits of using tractors. - Partners should come up with business models that will address the issue of affordability of the services on the side of the farmer.
Shellers	- Farmers have been slow in adapting shellers. - Lack of income to pay for shelling services and some farmers are not willing to pay opting for manual shelling. - The cost of buying a sheller is relatively high. - At times it is not economical to use a sheller since the yield and harvest is low. - The government department of mechanization is incapacitated to visit and help farmers and raise awareness of the technology. - There are a few available shellers located in strategic positions (stationary), and farmers find it difficult to carry their cobs to the shellers. - There are conditions attached to accessing shellers.	- There is need promoting adoption, creating demand and affordability of shelling equipment - They are very quick and can shell maize, cowpeas, sorghum, small grains, rice, and wheat making people have time for other activities. - They are easy to use by all age groups and women. - Farmers are looking forward to bigger shellers which can at least service a number of farmers in a single day. - There are local model plots where farmers can learn and experience modern technologies. - The young people are eager to adopt mechanization. - More initiatives aimed at increasing the number of shellers are needed.
Rippers	- They need animal draught power to be able to function. - Most farmers lost their livestock due to diseases.	- The ripper should be modified for two-wheel tractor - Need for increased access of rippers at affordable prices.

Technology	Main barriers to scaling	Opportunities for scaling
	- Very few rippers available in the farming community - Only a few farmers can access the ripper due to its low capacity	- The technology needs to be promoted more intensely for its increased uptake. - There is need for a better design which makes sure that every seed is covered even in mulched fields
Jab planter	- They are very few jab planters available. - Not easily accessible by farmers. - Hard to use as it strains the hands; this has discouraged its uptake.	- Increase availability. - There is a need to improve the design to make it easy to use especially by woman farmers.
Mango dryer	- They are usually only given to lead farmers some of who do not share it with group members. under their group. - Very few dryers are available, and this has reduced farmers interest in the technology. - Most young people do not own mango trees since the trees belong to their parents. - The business model is not clear as to how the farmer will then get money and how much will they be getting.	- There is a need for provision of more dryers. - Lead farmers need more training on operation of the mango dryers. - More training on how the business model operates. - Young people being given land for plantations. - Lead farmers needs to be held accountable to make sure they carry out their responsibilities.
Nutrition gardens	- There is competition and conflict between garden users and the community on usage as most of the times a community borehole is put on solar for garden use hence ownership challenges.	- A constitution must be written governing contact and relationship between garden users and community. - Technical support is needed; an extension officer must be assigned to each garden.
Communal irrigation scheme	- Farmers struggle to pay electricity bills.	- Alternative power sources like solar are ideal.
Lifting technologies (solar and motorized)	- There is no backup plan if the system fails. - The water pump pumps water from the dam into storage tanks. - The garden project may not have the money at that particular time forcing it to relay on external help. - Many people can't afford to set them up. - The water source is overwhelmed.	- There is need for funding schemes. - There is need for strategic relationships with the service providers. - Backup pumps are needed in case of breakdowns. - Assistance with construction of dams.
Water application technologies (Overhead and drip irrigation systems)	- Drilling of boreholes and setting up the scheme is very expensive.	- Assistance in form of funding and credit is needed especially for young people. - There is need for proper monitoring of projects.

Technology	Main barriers to scaling	Opportunities for scaling
	- There was no coordination between Agritex officer and the project implementers. - Such projects are usually targeted towards a few individuals and young people are hardly part of the projects. - Lack of water source - Overheard is spreading diseases as compared to drip irrigation	- There is a need for strong coordination with local extension officers. - Assistance with drilling boreholes. - To avail credit facilities to support irrigation schemes.
Water sourcing (Water pans, water tanks, dam)	- There is only one irrigation scheme in the area with no room for expansion. - It is difficult for newcomers to enter the scheme. - The dam is at high risk of siltation. - Some smaller gardens apart from the cooperative garden have seasonal water sources which dry during the dry season.	- There is need for more dams to be constructed. - Boreholes should be drilled. - There is need for proper fencing of the dam area so as to prevent free range cattle from entering the area. - More awareness is needed among community members so as to instill a sense of responsibility. - For some smaller dams that dry, proper siting needs to be done. - Promotion of drip irrigation will save labour and conserve water.
Two-wheel tractors	- Very expensive for the smallholder farmers (USD\$ 3 000). - Servicing parts are very expensive, and they have a short warrant period. - Service parts are found in Harare. - Very difficult when turning at the end of the field. - Difficult and tiresome to walk around the field planting. - Cranking to start the tractor is difficult. - Expensive to hire. - The 2-wheel tractor need people who appreciate importance of specific calibrations for maximum benefits. - Most of them have brake problems. - Tyres are unsuitable for hot weather.	- Provision spare and servicing parts at affordable prices. - Provision of credit and affordable payment plans for buying tractors. - Modifying the tractor by adding an ignition key. - Adjustments need to be done to ease turning. - Add a third wheel enable sitting while operating the tractor. - Provide spares at affordable prices - Provision of credit institutions and affordable payment plans. - Local versions of the imported technology will increase productivity and make repair parts readily available.

Technology	Main barriers to scaling	Opportunities for scaling
	- When travelling at night, the tractor light can't focus on the road when reaching a high ground. - Fuel is expensive.	- Mechanized conservation agriculture has the potential to double/triple yields. - Government promotion of conservation agriculture. - With death of cattle due to tick bone diseases, it's easier to shift to mechanization unlike to wait for 2-3 years to build a herd. - More two-wheel tractors should be made available.
Planter	- Servicing parts are expensive. - Calibration problems – wastes too much time - Leaves some seeds uncovered, prompting covering follow up- extra labour. - The planter gets clogged.	- Provide spares at affordable prices. - Very advantageous as it plants seed, fertilizer and cover the seed - Even a single individual (including the elderly) can operate it. - It can widely be adopted if well promoted. - Calibration trainings need to be conducted.
Multi crop thresher	- Servicing parts are expensive	- Provide service parts at affordable prices.
Metal silo	- The metal sheets are expensive top buy. - Poor yields reduce the desire to build metal silos. - The trained individuals who are supposed to make the silos charge high prices. - They have a minimum size at which they can be constructed, and that size is above the quantity of grains to be stored by communal farmers. - The programme of silos was initially for chiefs.	- Provide at affordable prices - The metal silos are very ideal and cut costs as there is no chemical application leading to low storage costs - The metal silos are portable. - They need to be made affordable. - People can form groups and buy silos. - The department of agriculture has the technical capacity to fabricate the metal silos and to install - Farmers can have a centralized place where the silo can be constructed. - Silos are more ideal for relatively bigger farmers. - Local artisans were trained to make metal silos.
Water application technology: water troughs and buckets	- It is laborious and sometimes a straining and painful process especially if the area to be irrigated is big. - A lot of water is lost in irrigating portions with no plants.	- Drip irrigation technology is needed; Not only will it only increase water use efficiency but will also be suitable for women farmers.

Technology	Main barriers to scaling	Opportunities for scaling
	- Water from the storage tanks goes into water troughs where it is then fetched by buckets. - Fetching water from the water troughs is often and uncomfortable process for woman as they must bent down in the presence of man - It very difficult to fetch water when the water levels in the troughs are low. - Bucket system is for those near water bodies.	- There is need for other improved irrigation technologies other than the bucket system. - It is easier to set up drip irrigation systems as there are already storage tanks. - Partners that can come in to install the system are needed.
Treadle pumps	- Inadequate knowledge on how it works.	- Linking farmers to service providers and making sure they have a full understanding on how the machine works.
Granaries	- It is expensive to construct a granary. - The uptake of the modern design which is constructed with bricks is still very low.	- The modern granary being promoted by the department of agriculture has a much longer service life since bricks are more durable than wooden poles which have proven to be susceptible to wood weevils' attack - The department of agriculture has the technical capacity to construct the granaries. - Granaries are the most preferred post-harvest storage method in the ward.
Direct seeder	- It is heavy and labour intensive. - They are expensive to buy and only a few are available in most areas making it difficult for everyone to access them.	- Innovation to make it user friendly. - There is demand.
Water sourcing (ground water, boreholes)	- Inadequate resources to drill more boreholes. - Very few individuals have boreholes. - Drying and siltation of the few available boreholes. - The water points are very limited or few. - Farmers are still struggling to adopt techniques or technologies that use irrigation water efficiently. - High cost of inputs making projects not feasible even under irrigation.	- Collective action at drilling boreholes so that it becomes affordable for farmers. - Collective action by farmers at water sourcing is needed. - More water points are needed if irrigation is to transform the local agribusinesses - It will be possible to increase water access points if water can be piped from the boreholes. - Other localized gardens in different villages can be created - De-siltation of dams will increase their carrying capacity allowing more water to be used for irrigation

Technology	Main barriers to scaling	Opportunities for scaling
	- The water is not that safe for drinking because of high amounts of iron underground where the Borehole is located.	- Farmers can be trained on drilling wells - There is the abundance of sunlight for solar powered boreholes.
Improvised plough	- There are no implements to drill holes.	- Government is trying to liaise with companies like Grownet for self-powered implements like direct seeder so as to mechanize conservation agriculture and enhance adoption. - The government is encouraging farmers to remove moldboard plough to be left with only the shear so as to only open a furrow. - Some few farmers bought ripper tines, and these are mounted on ox ploughs.
Water harvesting	- Inadequate water storage facilities like tanks. - Most the farmers cannot afford to buy storage facilities. - Gradient and trenching resources are also a constraining factor. - Lack of mobility resources by the department of agriculture.	- Initiatives are needed to help farmers with water storage facilities. - Strategic partners should come in and work with the AGRITEX officers in helping farmers in the construction of water harvesting trenches.
Gradient irrigation	- Only suitable for farmers that are downstream. - Initial set up is very expensive and cost of pipes is high. - Youth don't have access to own such type of land unless it is by inheritance. - Older people feel threatened of losing their lands.	- There is need for strategic partners that can come in with an irrigation installation facility. - Farmers can be allowed to pay back in instalments. - Farmers need to group themselves and approach developmental organization for help in setting up the irrigation scheme. - Youths have identified areas that if given permission and resources permitting, they are ready to set up youth community gardens. - There is need for linkages to high value markets.
Ox drawn ploughs	- Lack of animal traction has minimized the use of ploughs. - Most farmers are still using hand hoes.	- Farmers still need other mechanization options for a more contemporary approach to farming.

Technology	Main barriers to scaling	Opportunities for scaling
Siphoning system	- Few individuals who can afford it are using this technology. - Those who can afford it are leaving others out as they are fencing their facilities.	- Construction of dams so as to increase water sources for farmers.

Demand for mechanization and willingness to pay

Prevalence and use of mechanization in Malawi, Zambia, and Zimbabwe

Using survey, we found that draft animals were the most popular source of farm power owned by 19%, 37%, and 57% of households surveyed in Malawi, Zambia, and Zimbabwe, respectively (Figure 2). Four-wheel tractors are the second most known and second least ever used. Despite some 32–62% of households surveyed in Malawi, Zambia and Zimbabwe saying they know about two-wheel tractors, less than 2% ever used two-wheel tractors in Zambia and Zimbabwe, while none in Malawi. These findings are line with those in Sims and Kienzle (2017) and **FAO, AUC (2019)** that draft animal power is the most important form of farm power in sub-Saharan Africa.

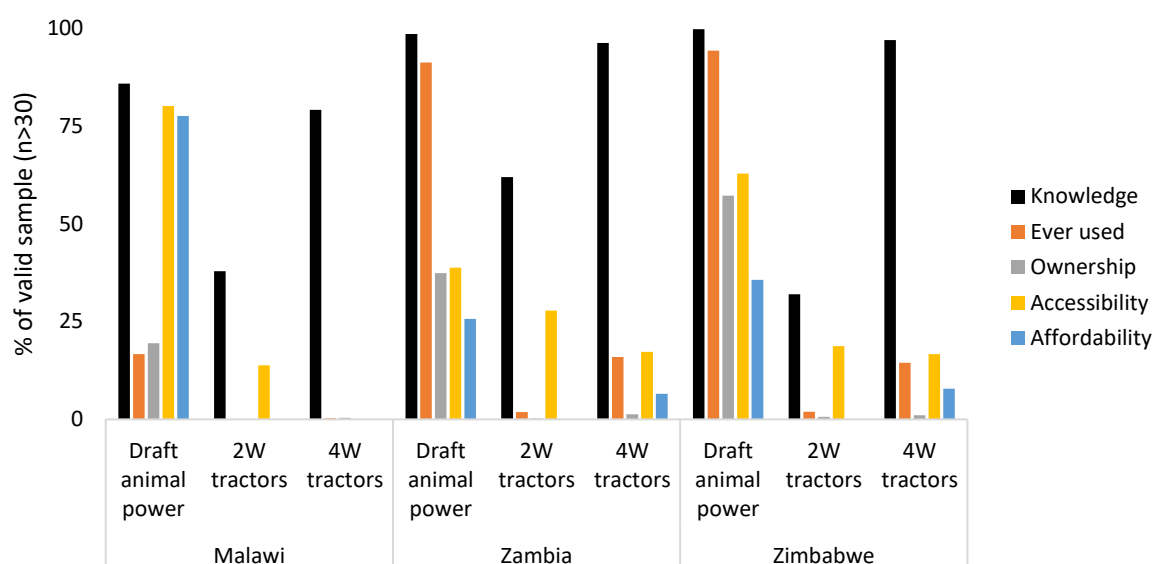


Figure 2: Prevalence and use of draft animal power, two-wheel tractors and four-wheel tractors among the surveyed households in Malawi, Zambia, and Zimbabwe

Notes: Usage (ever used) and ownership are computed for those who know a particular farm power. Accessibility was computed for those farmers who did not hire mechanization services for the 2020/21 season but have used before while affordability was computed for those who know about the mechanization option and think it is possible to hire. ^ statistically invalid, n < 30.

Source: (Ngoma *et al.*, 2023) and (Tufa *et al.*, forthcoming) based on ACASA Survey 2021.

Willingness to pay for mechanization services in Malawi, Zambia, and Zimbabwe

As stated, different approaches were used to estimate willingness to pay for mechanization in Malawi, Zambia, and Zimbabwe during the ACASA survey. And different aspects of mechanization were assessed in Malawi compared to Zambia and Zimbabwe. In Malawi, the surveys elicited willingness to pay for mechanized land preparation, tied ridging, shelling per 50 kg of maize or groundnuts and transport per trip using contingent valuation, see Tufa et al

(forthcoming). The surveys used BDM auctions to elicit willingness to pay for ripping, ripping and seeding, direct seeding, and transportation of a 0.5 ton load within a 20 km radius in Zambia and Zimbabwe, see Ngoma et al (forthcoming).

Households in Malawi are willing to pay US\$69/hectare for land preparation, US\$2.6 per trip for transportation, and USD0.5–USD1.2 for shelling 50 kg maize or groundnuts (Table 6). These amounts are similar to market prices at the time of the survey, indicating that the estimates are realistic. And a large proportion of male respondents than female respondents were willing to pay the market rates then (Tufa *et al.*, forthcoming).

Table 6: Average willingness to pay (USD) for different mechanization services in Malawi, Zambia, and Zimbabwe

Mechanization service	Zambia	Zimbabwe	Malawi
Ripping per hectare	19.00	51	-
Ripping and seeding per hectare	28.00	69	-
Direct seeding per hectare	26.00	58	-
Transport 0.5 ton load	6.30	12	-
Land preparation per hectare	-	-	68.89
Transportation per trip	-	-	2.60
Groundnut shelling per 50 kg	-	-	1.23
Maize shelling per 50 kg	-	-	0.58

Source: (Ngoma *et al.*, forthcoming) and (Tufa *et al.*, forthcoming) based on ACASA Survey 2021.

Based on BDM auctions, willingness to pay for most services is higher in Zimbabwe compared to Zambia. On average, households interviewed in Zimbabwe were willing to pay USD 51, USD 69, USD 58 per hectare for ripping, ripping, and seeding, and direct seeding, respectively; and USD 12 for transportation of 0.5 tons per 20 km radius, while sample households in Zambia were willing to pay USD19, USD28, and USD26 per hectare for tillage-based services and USD 6 for transportation per 0.5 ton within a radius of 20 km. See Ngoma et al (2021) for details. While these estimates are in nominal terms, it would appear that farmers in Zimbabwe have a higher willingness to pay for mechanization services than those in Zambia.

Conclusion

As governments heighten drive to mechanize agriculture, critical information is required on (i) existing mechanization options, (ii) barriers and challenges, (iii) opportunities for scaling and effective demand for mechanization. This article combines quantitative and qualitative

surveys to help elucidate on some of these key issues in Kenya, Malawi, Zambia, and Zimbabwe where mechanization is part of national policy priorities. We focus mainly on farm mechanization and irrigation options. There are common mechanization options whose uptakes are at different levels in these countries. Animal draft power is still dominate for tillage in all these countries. Other unpopular options include two-and four-wheel tractors. Shellers, improved granaries and hermetic bags are common for post-harvest and dryers in other contexts. Farmers in Malawi, Zambia and Zimbabwe are willing to pay positive amounts for hiring different mechanization services, indicating existence of effective demand. Supply side barriers to scaling mechanization in Kenya, Malawi, Zambia, and Zimbabwe include limited availability of machines, poor after sale and repair and maintenance services in the vicinity of the farmers. On the demand side, high capital requirements, limited awareness and technical knowledge and the high cost of hire services are some of the main barriers to scaling mechanization. These findings imply a need for affordable machinery and to devise innovative financing mechanisms such as value chain financing, equipment leasing and group ownership to allow marginalized farmers access mechanization in a n inclusive and equitable manner. There is also scope for demand creation and awareness raising for different mechanization options.

Acknowledgements

This work was carried out with support from the [CGIAR](#) initiative, [Ukama Ustawi \(UU\): Diversification for Resilient Agri-food in East and Southern Africa](#), and we would like to thank all the funders who support this research through their contributions to the [CGIAR Trust Fund](#). To learn more about Ukama Ustawi and other initiatives in the CGIAR research portfolio, please visit <https://www.cgiar.org/research/initiatives-dashboard/>. Further financial support is from the ACASA project supported by the Royal Norwegian Government through the Norwegian Agency for International Development (NORAD), grant P1925 under the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). We thank the different teams that carried out fieldwork, the ministries of agriculture and other stakeholders that participated or facilitated the surveys in the four countries.

References

- Baudron, F., Sims, B., Justice, S., Kahan, D.G., Rose, R., Mkomwa, S., Kaumbutho, P., Sariah, J., Nazare, R., Moges, G., Gérard, B., 2015. Re-examining appropriate mechanization in Eastern and Southern Africa: two-wheel tractors, conservation agriculture, and private sector involvement. *Food Security* 7, 889-904.
- Daum, T., Birner, R., 2020. Agricultural mechanization in Africa: Myths, realities and an emerging research agenda. *Global Food Security* 26, 100393.
- Diao, X., Cossar, F., Houssou, N., & Kolavalli, S., 2014. Mechanization in Ghana: Emerging demand and the search for alternative supply models. *Food Policy*, pp. 168-181.
- FAO, AUC, 2019. Sustainable agricultural mechanization: A framework for Africa – Synopsis. Food and Agriculture Organization (FAO) and African Union Commission (AUC), Addis Ababa, Ethiopia.
- Jayne, T.S., Chamberlin, J., Holden, S., Ghebreyesus, H., Ricker-Gilbert, J., Place, F., 2021. Rising land commodification in sub-Saharan Africa: Reconciling the diverse narratives. *Global Food Security* 30, 100565.
- Jayne, T.S., Chamberlin, J., Traub, L., Sitko, N., Muyanga, M., Yeboah, F.K., Anseeuw, W., Chapoto, A., Wineman, A., Nkonde, C., Kachule, R., 2016. Africa's changing farm size distribution patterns: the rise of medium-scale farms. *Agricultural Economics* 47, 197-214.
- Ngoma, H., Angelsen, A., Jayne, T.S., Chapoto, A., 2021. Understanding adoption and impacts of conservation agriculture in Eastern and Southern Africa: A review. *Frontiers in Agronomy, agroecological cropping systems*.
- Ngoma, H., Marenja, P., Tufa, A., Alene, A., Chipindu, L., Matin, M.A., Thierfelder, C., Chikoye, D., forthcoming. Smallholder farmers' willingness to pay for two-wheel tractor-based mechanization services in Zambia and Zimbabwe. *International Maize and Wheat Improvement Center (CIMMYT)*.
- Pingali, P., 2007. Chapter 54 Agricultural Mechanization: Adoption Patterns and Economic Impact. In: Evenson, R., Pingali, P. (Eds.), *Handbook of Agricultural Economics*. Elsevier, pp. 2779-2805.
- Tufa, A., Alene, A., Ngoma, H., Marenja, P., Matin, A., Thierfelder, C., Chikoye, D., forthcoming. Demand for agricultural mechanization services for smallholder

farmers in Malawi: A contingent valuation analysis. International Institute for Tropical Agriculture (IITA).