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African agricultural mechanization

Myths, realities and an emerging research agenda

Thomas Daum and Regina Birner

Abstract

African farm systems remain the least mechanized of all continents. There were substantial state-led efforts to promote agricultural mechanization during the 1960s and 1970s, but these efforts failed, which led to a subsequent neglect of mechanization, both in practice and in academia. In practice, this situation has changed more recently as governments, development practitioners and private companies have re-discovered agricultural mechanization as a top priority. In academia, scholars are also gradually devoting more effort to study mechanization. However, there is still a large gap in the literature from several decades of neglecting mechanization. In this empirical vacuum, several claims around mechanization have emerged in the public debate. While some of them are accurate, many are too simplistic and some are plainly wrong or "myths". Such popular myths can mislead policies and programs to promote mechanization and lead to adverse effects on farmers. This paper presents a fact check on nine propositions regarding mechanization. Which ones are true? Which ones are false? To answer these questions, the study uses most of the recent literature on mechanization, thereby also providing a review of the current literature on agricultural mechanization in Africa. The paper draws up implications for future research and action.

Keywords: Agricultural Mechanization, Agricultural Intensification, Agricultural Development, Tractors, Machinery, Employment, Soil Erosion, Gender, Yield

JEL codes: J16, O12, O13, O33, Q13, Q16, Q18

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1 Introduction

Whereas many regions in the world fared considerably well in agricultural mechanization during the last decades, the African farm systems remain the least mechanized of all continents (FAO, 2016; Sheahan & Barrett, 2018 – see also section 2). As a result, African agricultural labour productivity – an important determinant of farmers' incomes – has largely stagnated over the years (Fuglie & Rada, 2013). There were substantial state-led efforts to promote mechanization during the 1960s and 1970s. However, these efforts, often involving state imports of machinery, largely failed due to governance challenges (Pingali, 2007). This resulted in the perception that Africa was not yet ripe for mechanization, which led to subsequent neglect of agricultural mechanization, both in practice and in academia (Diao et al., 2012, FAO, 2016).

This is slowly changing with the re-emergence of agricultural development in Africa's development agenda, which also led to a renewed interest in agricultural mechanization. In particular, governments show a strong interest to overcome the "hoe and cutlass" culture to make agriculture attractive for the youth (Mockshell & Birner, 2015). In addition, development partners aim to promote mechanization and the world's leading agricultural machinery companies have started to recognize Africa as an emerging market (Daum & Birner, 2017; FAO 2016; Oluwole & Odogola, 2018).

There are many new drivers for mechanization. In some countries, agricultural intensification and rising rural wages have created a labour bottleneck in land preparation (Diao et al., 2012), which has triggered the demand for labour-saving technologies "even among small-scale farmers" (Diao et al., 2014, p.168). According to Cossar (2016), population pressure, market access and agro-ecological conditions push farmers to adopt new technologies, leading to some highly mechanized pockets in Ghana, where up to 80% of farmers use machinery – thereby confirming agricultural development theories of Boserup (1965)[1] and Pingali et al. (1987)[2]. For Ghana, Houssou et al. (2014) found that 80% of the owners bought their tractors less than five years ago, suggesting a high speed of mechanization. In Ethiopia, Berhane et al. (2017) found that rising rural wages and costs of draught animals are positively correlated with mechanization. At the same time, with urban population growth, farmers face an increasing demand to supply agricultural products.

There are other new opportunities as well. Machinery prices have dropped lately since Indian and Chinese machinery producers joined the competition (FAO, 2016). Prices for solar panels have dropped, too, and renewable-energy-powered mechanization may be an interesting opportunity, especially for mechanization at later stages of agricultural value chains. In addition, the upsurge of medium-scale farmers, observed by Jayne et al. (2016), provides new prospects for mechanization service hire markets. Finally, "Uber"-like mobile tools may help to reduce the transaction costs of mechanization service markets.[3]

While there are new opportunities and efforts to promote smallholder mechanization in Africa, the neglect of mechanization by scholars during the past decades has resulted in a dearth of empirical studies. This leaves policymakers and practitioners involved in today's mechanization efforts ill-

[1] Boserup (1965) argued that population growth triggers farming system evolution that eventually leads to the adoption of animal or mechanical traction. Mechanization occurs when 1) population growth leads to a growing demand for output and thus intensification, which requires mechanization or when 2) rural-urban migration makes rural labour scare.

[2] Pingali et al. (1988) argue that the transition from manual labour to animal and mechanical traction becomes profitable only with higher intensities of farming (see also Boserup, 1965). They argue that this transition is motivated by labour-saving and area-expansion but not by yield-effects.

[3] See New York Times (17. October, 2017: How Do You Hail a Tractor in India? All It Takes Is a Few Taps on Your Phone) and Washington Post (11 September, 2015: Sowing self-sufficiency in Africa with Anacostia-based 'Hello Tractor').

equipped to design good policies and programs. More than that, in this empirical vacuum, several propositions around mechanization have emerged in the public debate.

The main thrust of many propositions is that mechanization should not be promoted in Africa because it will have negative economic, social and environmental effects. These propositions are expressed by actors such as non-governmental organizations. For example, as early as 1973, the International Labour Organisation warned about unemployment effects related to mechanization (ILO, 1973). This concern continues to be raised, along with other risks related to mechanization such as soil erosion and an exclusion of smallholder farmers (Malabo Montpellier Panel, 2018). As we show in this paper, most of those propositions are too simplistic and not supported by evidence, which is why we call them "myth".[4] There are also propositions that favour mechanization but are similarly not supported by evidence. This latter kind of myths is often embraced by governments in African countries that aim to support mechanization, thereby using strategies that are not particularly effective, as explained further below.

The emergence of these myths may have been promoted by the fact that agricultural mechanization has been one of the most controversial of all agricultural innovations – not only in contemporary times but also historically (Juma, 2016). While some of these myths reflect careful considerations, many are too simplistic or simply wrong, which can mislead policies and programs to promote mechanization. The objective of this paper is to provide a fact check of nine propositions around mechanization. Which ones are largely true? Which ones are oversimplified representations of complex problems? Which ones are outright false? And where is additional research needed?

To answer these questions, the authors refer to economic theory, the empirical literature on mechanization, and their own research experience on mechanization in Sub-Saharan Africa. Thus, this study includes a review of the literature on agricultural mechanization in Africa. Based on the analysis of nine propositions, the paper draws up implications for future research and action.

[4] We use the term "myth" in the sense of "an unfounded or false notion", see Merriam-Webster Dictionary (www.merriam-webster.com/dictionary/myth).

2 Current status and mechanization efforts

Agricultural mechanization is often associated with tractorization but it is more than tractors. Rijk (1999) defines agricultural mechanization as embracing "the use of tools, implements and machines for agricultural land development, crop production, harvesting, and preparation for storage, storage, and on-farm processing" (p.1). Some definitions also go beyond the scope of the farm and define agricultural mechanization as a process where human labour along the entire agricultural value chain is replaced by other sources of energy such as animal power, fossil energy or renewable energy (Malabo Montpellier Panel, 2018). This study considers different sources of energy, including animal power, fossil energy and renewable energy but focuses mainly on farm mechanization as this most directly affects productivity and livelihoods of farmers.

Generally, data on African mechanization is patchy and often outdated. Still, there is a strong consensus on the low levels of mechanization in Sub-Saharan-Africa. Pingali (2007) suggests that the number of tractors has remained below two per 1,000-hectare cropland, while this number reached six tractors per 1,000 ha in South Asia and ten in Latin America by 2002. Mrema (2008) even finds a decline in tractors owned in Africa during the past decades: from two tractors per 1000 ha of arable land in 1980 to 1.3 in 2003. According to Mrema et al. (2018), out of the 26 countries in Sub-Saharan Africa for which data is available, six have a tractor population of less than 1,000; six have a population between 1,000 and 2,000; ten between 2,000 and 10,000; and only seven have a tractor population of more than 10,000 – however, the referenced dataset dates between 1997 and 2008.

Ashburner and Kienzle (2011) assessed that African farmers largely rely on hand tools, which are used for 80% of the land area, while animal traction is used for 15% and tractors only for the remaining 5% of the land area. Kirui (2019) analysed the state of mechanization in eleven African countries, using a data set from 2004. He found that, on average, 12% of the sampled households have access to tractors, ranging from little above 0% in Senegal, Niger, and Cameroon to 12% in Kenya and Ghana and 57% in Egypt (Kirui, 2019). With data from 2010-2012, Sheahan and Barrett (2018) offered the latest cross-country data available for mechanization. According to the LSMS-ISA surveys[5] that they cite, only 1% of all households across six African countries (Ethiopia, Malawi, Niger, Nigeria, Tanzania, and Uganda) own or hire tractors.

Generally, little is known about machinery other than tractors. Since land preparation (using tractors) is typically mechanized first (Binswanger, 1986), mechanization of other farm operations is likely to be low. Sheahan and Barett (2018) estimate that less than 5% of all households across the six African countries mentioned above own irrigation equipment. Kirui (2019) finds that 9% of the farmers across his eleven countries own or hire diesel pumps, 7% own or hire threshers, and 3% own or hire choppers; however, all these numbers are largely driven by Egypt and South Africa.

State-led efforts

As a response to perceived low levels of mechanization, governments are actively promoting mechanization in several African countries by directly importing tractors. In Ghana, Nigeria, and Zimbabwe, among others, the government has imported and sold machinery at subsidized rates to farmers. In Benin, Ethiopia, and Cameroon, mechanization services are provided through state-led hire schemes. Some countries promote mechanization through private service providers, which receive state-subsidized tractors. Examples comprise the "Agricultural Equipment Hiring Enterprises" in Nigeria, the "Agricultural Machinery Service Stations" in Kenya, the "Agricultural Mechanization Service Centers" (AMSEC) in Ghana, and the "Agricultural Service Centres" (CSA) in Mozambique. Table 1 shows the mechanization efforts of five selected countries, indicating a heavy focus on importing machinery but a neglect of knowledge and skills development for machinery owners, operators, and

[5] Living Standards Measurement Study – Integrated Survey on Agriculture conducted by the World Bank.

technicians. Often the number of tractors imported largely exceed imports from private markets (see next section).

Table 1. Overview of state-led mechanization and training in selected countries

Country	Time period	Number of machinery imported	Number of persons trained in 2017 on mechanization in regular or project-funded programs
Mali	2016-ongoing	1,500 tractors + implements as well as water pumps, *motocultors*, threshers, dehullers	None
Nigeria	2010-ongoing	950 tractors + 150 implements as well as groundnut and melon threshers, water pumps, power tillers	560
Kenya	2016-2020	unspecified amount of tractors, implements and other machinery worth US$ 100 million	unspecified amount of persons trained on ad hoc basis (no regular training courses)
Benin	2008-ongoing	1,040 tractors as well as 360 rotor tillers	100
Burkina Faso	2015-ongoing	800 tractors + implements	300

Source: Own survey as part of the Program for Accompanying Research for Innovation (PARI) in collaboration with the Institut National des Recherches Agricoles du Bénin, the Kenyan Agricultural and Livestock Research Organization, the Institut d'Economie Rurale in Mali, the Agricultural Research Council of Nigeria and the Institut de l'Environnement et de Recherches Agricoles in Burkina Faso.

Market-led efforts

Private market actors include manufacturers, such as the world's leading agricultural machinery companies like John Deere and AGCO, and manufacturers from India, China, Brazil, Turkey, and some Eastern European countries as well as importers and dealers of machinery. Unless manufacturers sell machinery as part of government programs, they typically do not sell machines directly. For sales, they rely on a network of dealers, who are also responsible for after-sales services. The dealers typically need to finance their activities (provision of spare parts and repair services) from the sales revenue generated as they are financially autonomous from the manufacturers. Given that most tractor markets are small, many dealers struggle for their business to be economically viable (Mrema et al., 2018). In Zambia, for example, different dealers sell annually around 500 tractors of different brands. For comparison, 30,000 tractors are sold annually in Germany.[6] Besides markets which offer new tractors, many countries have markets on which used tractors are sold (Daum & Birner, 2017). Often these markets are of similar size as new tractor markets. For Ghana, for example, Houssou et al. (2014) described a vibrant used tractor market that imported 3,000 tractors in the decade up to 2012.

[6] https://www.agrarheute.com/technik/traktoren/traktor-markt-schrumpft-551077

3 Myths, realities, and an emerging research agenda

In this section, we identify major claims related to mechanization and discuss their validity drawing from the mechanization literature (for an overview see Table 2). Based on this, we distil neglected topics and key research questions. A rather neglected topic in research, mechanization studies presented here are concentrated in several countries. Most of the studies are located in countries where IFPRI governmental support programs are focused on mechanization (Ghana, Nigeria, and Ethiopia), where the FACASI (Farm Mechanization and Conservation Agriculture for Sustainable Intensification) project is located (Eastern Africa), and where the "Program of Accompanying Research for Agricultural Innovation" (PARI) has conducted research. Importantly, for some countries no literature exists and there may be a bias related to the choice of research countries.

Table 2. Myths, realities, and emerging research agendas for agricultural mechanization.

	Claim	Assessment	Emerging research questions
1	Mechanization increases unemployment	*Mixed evidence;* mechanization may increase or decrease employment depending on the technology and economic factors	Under which conditions does mechanization lead to rural unemployment? How can mechanization be used to create meaningful rural jobs?
2	Smallholder farmers cannot benefit from mechanization	*Not generally true;* they can benefit with the right technologies and institutions	Which technologies and institutional solutions are needed? What is the potential of ICTs? What is the role for two-wheel tractors and animal traction?
3	Mechanization is bad for the environment, leading to land expansion, deforestation, monocultures, soil erosion and emissions	*Partially true;* while some negative effects have been observed, most can, however, be addressed with appropriate policies and technologies	What type of mechanization (and associated agronomic practice) is best for which agro-ecological zones? What is the role of land-use planning, accompanying intensification and crop-livestock-forestry systems? How does mechanization affect farm diversity? How can traditional tree and root crops be mechanized? What is the potential of renewable energy?
4	Mechanization benefits mostly men	*Mixed evidence;* while men have better access to mechanization, labour effects seem positive for women	How can women's access to mechanization be ensured? What are the implications of mechanization on the intra-household allocation of time and income in different settings?
5	Financing mechanization is a challenge	*True;* however, costs for machinery are declining and there are new attempts to finance mechanization	What role can microfinance play? What is the potential of value chain finance involving three-way-solutions with banks and processors or manufacturers/dealers? How can governments support financing through adequate policies?
6	Governments need to import tractors because the private sector fails to import enough machinery	*False;* state-led programs face governance challenges; where private markets do not evolve public mechanization does not work and where private markets do evolve it is not needed and may crowd out private companies	How can the political will of governments be channeled from importing machinery towards creating a conducive environment for mechanization?
7	Governments have no role to play with regard to mechanization	*False;* governments need to create an enabling environment, for example, through fostering knowledge and skills	How can an enabling environment be created in the most cost-effective way? What is the role of public, private and third sector in this regard?
8	Mechanization only saves labour	*Not generally true;* mechanization also has an effect on yields	Under which conditions and to which extent does mechanization enhance yields?
9	Cooperatives are an easy way to share machinery	*Not generally true;* cooperatives face challenges related to joint machinery ownership; however, they can help to organize access to services, credit and training	Under which conditions and for which type of machinery do cooperative solution work? What is the role of cooperatives for the creation of an enabling environment for mechanization?

3.1 Myth or reality? Mechanization increases unemployment *(mixed evidence)*

The effects of agricultural mechanization on employment have been subject to a controversial discussion. In particular, some civil society organizations warn about mechanization causing rural unemployment (ILO, 1973; Malabo Montpellier Panel, 2018). Historical evidence shows that the labour effects of mechanization are ambiguous. Based on empirical evidence and economic theory, Binswanger (1986) formulated four scenarios under which mechanization can unfold (see Table 3).

Table 3. Effects of mechanization on employments

Forces leading to mechanization	**Immediate consequence of mechanization**	**Indirect effect on agricultural output**	**Indirect effect on agricultural employment**	**Examples**
Land available	Labour used on larger areas, production costs drop	*Expands*, the quicker it expands, the more elastic is the final demand	*Expands* if demand is elastic, stagnates or falls if demand is inelastic	19th century United States
Wages rising in response to non-agricultural labour demand	Production costs rise less than in the absence of mechanization	*Falls* (or grows more slowly), but less than in absence of mechanization[7]	*Falls*	United States after 1940; Japan, Europe after 1955
Unmechanized technique unprofitable	A new method of production becomes profitable	*Expands,* the quicker it expands, the more elastic is the final demand	*Expands,* the quicker it expands, the more elastic is final demand	Pumping in contemporary Asia
Subsidies on capital energy	Production costs may drop modestly or stay constant	*Small expansion at best*	*Falls, sometimes sharply*	Contemporary Brazil, Pakistan, China

Source: Based on Binswanger (1986, p. 33)

Referring to 19th century United States, Binswanger (1986) argued that if land is abundant and the demand for agricultural produce is elastic, farm employment may increase with mechanization. Mechanization might be a mere necessity under a different scenario: when driven by labour shortages due to non-agricultural labour demand. Mechanization can also stimulate agricultural growth - a scenario that Binswanger illustrated with the advent of pump irrigation. Pump irrigation increases output (e.g., additional fields can be cultivated and yields are higher) and hence the demand for labour. Similarly, when mechanization allows for more timely farming and a reduction of labour bottlenecks, output and overall labour demand may rise. Binswanger clearly articulates the danger that may arise if mechanization is not "driven by some form of labour scarcity" (p. 38) but by subsidies. In this case, the "reductions in the agricultural work force can be substantial" (p. 38).

Few recent studies have examined the employment effects of mechanization, most of which laid their focus on farm mechanization. Yukichi (2017) found that tractors reduce labour use during land preparation, but lead to a higher labour demand during the next farming steps. Adu-Baffour et al. (2019), analysing a service provider model in Zambia, found that mechanization did not reduce the demand for hired labour. To the contrary, demand for hired labour was amplified for two reasons. One reason was that farmers who mechanized land preparation cultivated a larger share of the land that

[7] Binswanger argued that "production costs rise because wages rise rapidly. Other things being equal, farming output will therefore fall (or grow more slowly), depending on the elasticity of final demand" (p. 33)

they own, thereby increasing labour demand for all activities that were not mechanized. The second effect was a shift from family labour (including child labour) to the use of hired labour, potentially because income effects. In more land-constrained countries, effects may be different, however. In Ethiopia, Berhane et al. (2017) found that mechanization of land preparation and harvesting is correlated with lower labour use. However, their finding is based on simple t-tests and they do not show whether labour reduction refers to family labour or hired labour. Kirui (2019) found largely mixed results: in some of the eleven countries analysed, mechanization increases the probability and amount of hired labour (such as Ghana and Zambia) but in others it reduces both (such as Ethiopia). Cossar (2019), focusing on Northern Ghana, found that tractors allow farmers to reduce the time for land preparation, which enables the cultivating of maize in new locations. She found no significant effects on labour during land preparation but an increase of the labour demand for other farming operations.

To sum up, the effects on employment depend on country and region-specific factors (such as wages, land availability and food demand elasticity) as well as on the type of mechanization, such that they cannot simply be generalized. Importantly, mechanization may reduce labour at certain steps of the farming season and the value chain (thereby addressing labour bottlenecks) while increasing labour at other steps. Effects depend on whether mechanization leads to a higher output, as this determines spill over effects on the rural economy, and it is based on foreign or locally produced machinery. Moreover, short and long-term effects can differ, and effects may be geographically heterogeneous (e.g., it may decrease employment in one place but create employment elsewhere). Lastly, effects depend on the current use of family labour versus hired labour, which is subject to debate. The FAO (2013) argued that African farming relies mainly on family labour. In such cases, mechanization would replace family labour (including child labour) but not lead to unemployment. However, Baudron et al. (2019) found in several study sites across four African countries that more than 50% of all households hire labour. Consequently, labour effects should be a prioritized area of future research considering that mechanization is so controversially discussed and that there are fears of rising unemployment in Africa in view of the "youth bulge" in Africa (Ahmed et al., 2016) and the projected need to generate jobs for the 12 million young people entering the job market every year until (AFDB, 2016).

3.2 Myth or reality? Smallholder farmers cannot benefit from mechanization *(not generally true)*

Unlike seeds and fertilizer, mechanization is associated with substantial economies of scale. Tractors, for example, are non-divisible and larger farmers are more likely to purchase one because they have better access to capital markets and are likely to face a stronger need for them (Binswanger, 1986; Feder, Just, & Zilberman, 1981). Excluding smallholder farmers from mechanization would lead to unequal distribution of wealth and land (Binswanger & Rosenzweig, 1986; Feder, Just, & Zilberman, 1985; Pingali et al., 1987). Given the key role of smallholder farming for agricultural development (Birner & Resnick, 2010; Hazell et al., 2010; World Bank, 2007), mechanization efforts must thus go beyond large-scale farmers. However, whether smallholder farmers can benefit from mechanization depends on technological and institutional solutions.

With regard to technological solutions, it is important to note that the world inventory of machinery includes small and cheap machinery such as two-wheel tractors, which drove mechanization in rice-producing Asian countries like Thailand or Bangladesh (Rijk, 1999). However, the potential of two-wheel tractors for mechanization in Africa with its heavy soils and outside rice production (where larger tractors face challenges), are debated. While some sceptical practitioners have argued that two-wheeled tractors only marginally reduce the drudgery of farming and are less efficient than larger tractors, two recent studies highlight their potentials. Kahan et al. (2017) argued that small, multi-functional two-wheel tractors are better suited for small farms because they require less knowledge and skills for operation, maintenance and repairs and because they are less expensive and more applicable to microfinance. However, they noted that two-wheel tractors only have a comparative advantage over four-wheel tractors on light soils, on fields free of stones, and where animal traction is

expensive. Baudron et al. (2015) also argued for small, multipurpose, easy-to-repair and inexpensive two-wheel tractors. While two-wheel tractors may not be strong enough to plough under rain-fed conditions, they are strong enough for conservation agriculture techniques that rely on rippers and direct seeders (Baudron et al., 2015).

Another technological solution, which may be more applicable for smallholder farmers – but which is currently neglected – is the use of animal draught power (ADP). While animals are less powerful than tractors, ADP also helps to overcome labour bottlenecks, achieve higher yields, and cultivate more land than possible based on mere human muscle power (Person and Vall, 1998). Compared to tractors, ADP provides additional benefits such as meat, milk, hide and organic manure for fields and biogas. Owning animals as compared to hiring tractor services also allows farmers to build assets and use animals for transportation, pumping water and running mills. Pingali et al. (1987) argued that the costs for de-stumping, support infrastructure, and knowledge and skills are higher for tractors and thus see limited potential to bypass the animal traction stage. Nevertheless, ADP also faces constraints. Feeding animals requires (increasingly scarce) pastures or setting aside parts of the owned land (and labour) for feed cultivation. Also, animal performance can be constrained by diseases, heat and water stress, and limited access to extension and veterinary services as well as vaccines (Pearson and Vall, 1998).

In addition to technological solutions, institutional solutions may help smallholder farmers to access mechanization. Historical evidence shows that institutions such as rental markets and cooperative exchange have played a key role in the history of the countries that are now industrialized (Olmstead & Rhode, 1993). In Bangladesh, a mere 2% of farmers own but 72% access two-wheeled tractors, which shows a highly sophisticated rental market (Diao et al., 2014 referring to Ahmed, 2013). In Africa, service markets are at an early stage of development. In some countries, service markets are picking up, however (see Berhane et al., 2017 for Ethiopia). Houssou et al. (2015, 2017) showed that mechanization in Ghana is driven by emerging medium and large-scale farmers who provide services to smallholder farmers to increase machinery utilization and to reduce the risks of machinery ownership. To reach economics of scale, many of these service providers travel to different rainfall zones and offer postharvest activities (e.g., shelling). According to Houssou et al. (2014), 4 out of 5 tractor owners in Ghana offer services to on average 60 farmers per year. Eventually, service receivers may afford their own tractors. Houssou et al. (2014) found that 85% of the tractor owners in their sample used tractor services before purchasing a tractor.

However, Daum & Birner (2017) found that tractor owners in Ghana are reluctant to offer services to smallholder farmers – because transaction costs are high as their fields are small and fragmented – as well as to females. Cossar (2016) showed the importance of kin networks and social networks for accessing services. Adu-Baffour et al. (2019) found mixed evidence with around half of the tractor owners in their sample providing services to smallholder farmers in Zambia and highlight the importance of intermediaries to organize smallholders. Takeshima (2015) argued that mechanization in Nigeria is driven by large-scale farmers who offer services. However, he speculated that the indivisibility of tractors and the lack of service provider's mobility cause market imperfections. Mrema et al., (2018) argued that, although medium-scale farmers offering services promise new opportunities for mechanization, such farmers are confronted with constraints and "may find it difficult to maintain and re-place equipment" (p.22).

Digital solutions may help service markets to work better. Various start-ups and tractor manufacturers have developed digital tools to link farmers with tractor owners, for example, Hello Tractor[8] in Nigeria and Kenya, EM3[9], Trringo[10] and farMart[11] in India, Trotro Tractor[12] in Ghana and Rent to own[13] in

[8] https://www.hellotractor.com/home
[9] http://www.em3agri.com/
[10] https://www.trringo.com/
[11] http://www.farmart.co/
[12] https://www.trotrotractor.com/
[13] https://rtoafrica.com/

Zambia. These models have been referred to as Uber for tractors, suggesting strong similarities with Uber for ride-hailing. For tractor owners, such Uber-type models promise to reduce the transactions costs of providing services and to spread fixed costs by reaching higher utilization rates. For farmers, such models promise to reduce the transaction costs of accessing mechanization services. While receiving a lot of advance praise and enthusiastic media attention, tractor uberization has not yet been rigorously studied. An exception is Daum et al. (forthcoming) who analysed Hello Tractor in Nigeria and Kenya as well as EM3 in India. While highlighting the potentials of such ICT-based solutions, the authors stressed that such business models are confronted with the thorny challenges of rural and agricultural markets – something urban Uber-type ride-hailing does not face. They also emphasized the continuous reliance on analogue solutions such as booking agents and the need for a supportive environment. Moreover, they found that the advantages over more traditional ways of organizing service markets are less clear than commonly assumed.

To sum up, while smallholder farmers, in principle, can benefit from mechanization, the institutional challenges of providing machinery services to smallholder farmers have not been studied extensively. The role of policies that nudge tractor owners to provide services to smallholder farmers has not been sufficiently explored. Also, it remains debated what type of machinery is most suitable under what conditions. In particular, there is lack of empirical evidence on the comparative advantage of using small machinery, such as two-wheel tractors, on individual farms over using larger machinery, such as four-wheel tractors, in sharing systems, e.g., contracting models. Research is needed to assess whether ADP can be bypassed or whether ADP needs to play a role during a transitionary phase towards the use of tractors. Questions include: For which type of farming systems should ADP be prioritized and which for tractors? What is the scope for mixed farming systems, frequently used during the early agricultural mechanization in many European countries, that use ADP for some farming operations (such as harrowing) and tractors for others (such as ploughing)?

3.3 Myth or reality? Mechanization is bad for the environment *(partially true)*

Some argue that mechanization is harmful to the environment, causing cropland expansion, monocultures, soil erosion and emissions from fossil fuel use. As environmental sustainability is a key pillar of sustainable development, all of these concerns need to be assessed carefully.

Some argue against mechanization because it may trigger cropland expansion, leading to a potential conversion of forests and Savannah, which would have negative effects such as changes in local climates, an increase in greenhouse gas emissions, and a loss in biodiversity (Ceballos et al., 2010, Searchinger et al., 2015). This concern applies less for land-scarce countries such as Malawi and Rwanda that have limited potential for cropland expansion. However, cropland expansion can, in principle, still take place in African countries, which have underutilized land resources. Scholars heavily debate where and to what extent underutilized land resources are available (Chamberlin et al., 2014).

Several authors have studied the effects of mechanization on cropland expansion but few have explicitly addressed its environmental implications. Takeshima et al. (2013) found that tractor use is associated with land expansion in the North but not the South of Nigeria; Adu-Baffour et al., (2019) found that mechanization leads to a doubling of the land size cultivated by farmers in Zambia; and Kirui (2019), studying eleven African countries, finds that mechanization leads to extensification and "significantly increases the amount of cropland cultivated" (p.x.). While cropland expansion, which may largely increase the incomes of farmers, can be the rational choice for farmers, it is associated with negative environmental effects if pristine nature is converted (Adu-Baffour et al., 2019). To avoid such negative effects, governments promoting mechanization need carefully designed land-use plans and they should promote mechanization together with practices increasing yields and profitability per hectare (Adu-Baffour et al., 2019). Also, mechanization may be promoted as part of more sustainable integrated crop-livestock-forestry systems, a strategy increasingly pursued in Brazil (Alves et al. 2017). Applied research is needed on how to best do this.

Mechanization has also been stated to lead to more monocultures. Few studies have explored this link for Africa. Kansanga et al. (2018) found that mechanized farmers in Ghana focus more on crops that are easy to mechanize such as maize (Kansanga et al., 2018). In Ethiopia, Berhane et al. (2017) found that farms with high crop diversities are less mechanized, thus providing further evidence of a link between mechanization and farm diversity. This may have environmental but also food and nutrition security consequences when farmers do not compensate for reduced farm diversity by buying diverse food from markets. Research on mechanization solutions for traditional African tree and root crops such as Cassava is needed, a topic which has been neglected. Also, research on the linkage between farm mechanization, crop diversity and consumption diversity is needed – the first link (between farm mechanization and crop diversity) has received limited attention but the latter link (between crop and consumption diversity) has received considerable attention (see Sibhatu & Qaim, 2018, for an overview).

There is a concern that mechanization leads to soil erosion, a concern which deserves particular attention in Africa where soils are susceptible to erosion due to shallow topsoils and heavy rainfalls. Cleary, mechanized tillage can lead to erosion as shown by the American Dust Bowl (Baumhardt, 2003). In Africa, mechanized tillage has been reported to lead to erosion by several authors. In Ghana, negative consequences were reported by Adjei et al. (2003), Benin et al. (2013) and Daum & Birner (2017), among others; similar effects have been observed in other countries. However, soil erosion problems are not related to mechanization as such but to a lack of skilled operators and, more importantly, the wrong choice of land preparation methods. Addressing both can largely curb erosion. For example, replacing disc ploughs with harrows, chisel ploughs or field cultivators can reduce negative effects. Moreover, mechanized Conservation Agriculture, which combines minimum tillage, crop rotation, and permanent soil cover, can reduce soil erosion by up to 99% (Labrière et al., 2015) and is thus recommended by most scholars (Baudron et al., 2015; Sims & Heney, 2017). Conservation Agriculture can easily be combined with mechanization, for example, by using tractor-drawn rippers or direct planters (Sims & Heney, 2017). Applied research is required to identify the most environmentally friendly form of mechanization depending on the agro-ecological zone, pests and diseases, and soil types.

Lastly, mechanization has been criticized for making farming less energy efficient because of the use of external (fossil) energy. This claim is not based on any evidence. To our knowledge, no study has compared the energy efficiency of human labour, with the energy source being food, as compared to animal draft, with energy coming from pastures and feed, and tractors, with the energy source being fossil fuel. Moreover, today's mechanization efforts must not be driven by diesel and conventional electricity alone. Solar-, wind-, hydro-, geothermal and bioenergy offer new potentials and may be particularly attractive for remote rural areas (De Vries et al., 2007; Winkler et al., 2017). Countries transforming their agricultural value chains should consider the potential of renewable energy from the beginning. With regard to agricultural mechanization, different renewable energy-based off-grid solutions, ranging from land preparation with electric two-wheel tractors to processing activities, such as shelling, drying, heating, and cooling, may be used. However, renewable energy may not be suitable to efficiently run all farm activities like, for example, power-intensive land preparation, and the effects depend on whether electricity from renewable energy sources is available. One key research question is thus find out to what extent and which off-grid, renewable energy solutions can power which type of machinery along value chains.

3.4 Myth or reality? Mechanization benefits mostly men *(mixed evidence)*

Some also argue that mechanization benefits mostly men and not women. This could be the case when men have better access to mechanization, because households rather mechanize "male" crops and activities, because of negative second-round effects of mechanization on the workload of women, or because of effects on women's control over income.

With regard to access, Kirui (2019) suggested that the gender of the household head has an effect on the access to mechanization. Daum & Birner (2018) also found that men have better access to mechanization in Ghana, which they partially trace back to the fact that women own smaller plots with land of a lower quality. With regard to preferences, Evers & Walters (2001) argued that households rather mechanize male crops and activities, and Eerdewijk and Danielsen (2015, p.51), studying four African countries, found that women are constrained to articulate their demand for mechanization solutions, which would reduce their workload, since they have limited control over resources.

With regard to the effects of mechanization on female labour, the evidence is mixed. Studying such effects is important, however, as new technologies target different crops and tasks, thereby influencing men and women differently (Arora, 2015; Doss, 2001). One concern is that the expansion of cropland, led by mechanized land preparation, may increase labour burden for activities that are not yet mechanized, such as weeding and harvesting, which are often carried out by women and children. Using qualitative techniques, Baudron et al. (2019) found that mechanization of land preparation benefits both men and women. Daum et al. (2018, 2019), using a picture-based smartphone application to collect detailed time-use data, suggested that mechanization reduces women's workload during land preparation and weeding as mechanized tillage suppresses weed growth and because households use animals and herbicides for weeding. Baudron et al. (2019) also found that mechanized land preparation reduces the need for weeding, a labourious task often carried out by women, and thus reduces women's high drudgery.

With regard to income effects, it remains largely unclear whether a mechanization-induced workload reduction for women is a sign of empowerment or disempowerment. One may speculate that once not needed in the fields anymore, women lose decision-making power over farm income (Daum et al., 2019). Daum et al. (2019) found that women in tractor-using households in Zambia increasingly pursue off-farm work. No study has quantitatively assessed income effects for women due to mechanization. Cleary, more studies are needed to explore mechanization and gender aspects in a wider range of settings. As highlighted by Eerdewijk and Danielsen (2015, p.54) "neither direct nor indirect benefits, hence, can be assumed, but have to be monitored".

3.5 Myth or reality? Financing mechanization is a challenge *(true)*

While prices have been on the decline given competition with manufactures from China and India (FAO, 2016), most agricultural machinery remains expensive. Given the large capital investment and long periods of depreciation, access to finance is the key to mechanization. However, markets often fail to provide agricultural finance because of a lack of collateral and the riskiness of rain-fed farming (Binswanger & Rosenzweig, 1986). Several studies have examined the role of agricultural finance for mechanization more recently.

Daum & Birner (2017) and Ströh de Martínez et al. (2016) found that financing mechanization in Africa is hampered by a lack of financial literacy, a lack of collateral, high interest rates, short repayment times, and repayment schedules that are ill-adapted to the characteristics of farming. Daum and Birner (2017) reported interest rates of up to 35% per year in Ghana. Microfinance may help for low-cost equipment but not for tractors. Given the difficulty to access loans from private banks, most tractors were reportedly financed by personal savings and loans from friends and relatives working outside agriculture. Similarly, Houssou et al. (2014) found that 87% of the tractor owners in their sample in Ghana financed their tractors through personal savings (4% used remittances and 2% used loans). Ströh de Martínez et al. (2016) argued that private ownership of machinery is only affordable for relatively few farmers.

While conventional financing of mechanization faces challenges, there are various new attempts to address these challenges, including leasing, value chain finance, nucleus outgrower schemes, and direct supplier credits from machinery dealers, among others. Ströh de Martínez et al., (2016) identified leasing as an option to finance mechanization but acknowledged that some limitations need

to be addressed to make this feasible, including solving legal bottlenecks and bottlenecks with regard to asset and weather index insurance. Middelberg (2017) conducted three case studies on value chain financing in Zambia, two of which focused on mechanization. According to her, both cases cannot be regarded as successful yet. She suggested that banks need to dedicate more resources to the screening of eligible farmers and to monitoring during repayment. Daum & Birner (2017) reported an example of private and third sector cooperation: a loan guarantee scheme run by the Danish International Development Agency (DANIDA) with tractor dealers and several banks. DANIDA takes over half of the default risk, thereby making it possible for banks to reduce their interest rates. The tractor dealers cover additional percentage points of the interest rate. Access to finance for this model is only given to farmers who offer services to smallholder farmers. However, such donor-funded approaches may not be sustainable. Adu-Baffour et al. (2019) highlighted an approach in which a machinery company and its dealer offered financial services and thus provided a better rate than banks because this will support their business of selling machinery. However, this approach was terminated given some challenges with regard to repayments and exchange fluctuations.

Daum & Birner (2017) emphasized the difference between financing machinery and financing machinery services. For the latter, financing may be less of a constraining factor. However, they found that farmers who want to finance machinery services face equal problems of access to finance in Ghana. Some can negotiate in-kind payments (using part of the harvest) with the tractor owners. Others borrow from relatives, moneylenders, and traders and the interest rates can reach up to 150% per year. Microfinance was found to be rare in rural areas. Similarly, to the finance of mechanization services, the financing of important after sales services is often neglected. Cleary, financial means are necessary for machine maintenance and repair, and these are often not taken into account by banks or other financing schemes – and may explain the short lifetime of tractors in Africa.

To sum up, there is a consensus that access to finance is the key to mechanization but it is often constrained, especially for larger machinery. However, there are numerous options and experiments to overcome the financial constraints, perhaps including ICT-based approaches; these options just need to be explored and studied more thoroughly. Research is needed on the potential role for microfinance, on the possibility to create three-way solutions involving banks and processors, on financial solutions offered by machine manufacturers, and on how the government can support financing through adequate policies.

3.6 Myth or reality? Governments need to import tractors because the private sector fails to import enough machinery *(false)*

In the 1960s and 1970s, there were substantial state-led efforts to promote mechanization in Africa's agriculture. They were promoted by colonial powers in the 1960s and by newly independent countries in the 1970s by importing machinery, providing machinery hiring services, and running state farms (Mrema et al., 2008; Pingali, 2007). By equating mechanization with modernization, mechanization was often seen as an end in itself. In their efforts, governments were often assisted by bilateral and multilateral aid agreements (Pingali et al., 1988). Reviewing different state-led mechanization efforts, Pingali et al. (1988) found that most of them failed, often because of governance challenges, such as rent-seeking and the lack of qualified operators and technicians (see also Pingali, 2007). Binswanger (1986) thus argued that the public sector should not import machinery. Pingali et al. (1988) argued that if private markets do not evolve, state-led mechanization does not work either and where private markets evolve state-led mechanization is not needed and would crowd out private actors. Mrema et al. (2008) formulated several major lessons from the past experiences of mechanization in Africa, emphasizing that mechanization must be market-led and that governments should focus on building supporting institutions. Despite this evidence, governments across Africa have renewed their activities in importing and distributing machinery (see above and Cabral, 2019), often arguing that markets are failing to provide enough mechanization. In their efforts, they are often supported by countries such

as China, India, and Brazil who provide concessional loans for tractors – often with the aim to promote their own tractor manufacturers (Cabral, 2019; Daum & Birner, 2017).

Several studies have analysed recent state-led efforts to directly promote mechanization. Ghana has received much attention in this regard. In Ghana, the government has imported and distributed tractors at subsidized rates to farmers and private entrepreneurs, who then run Agricultural Mechanisation Service Centres (AMSEC). Various scholars have studied these 88 AMSEC. Benin (2015) argued that the AMSEC improved access to mechanization and raised the average area mechanized by the surveyed farmers. However, he also noted that state-imported tractors break down more frequently (17-64% more often) compared to second-hand tractors; that their repayment rates are low; and that the erratic choice of brands makes the access to spare parts difficult, all indicating a lack of sustainability. Daum & Birner (2017) analysed the same AMSEC some years later. Compared to Benin (2015) who collected data in 2011, when most AMSEC tractors were new, they found more challenges and fewer benefits. According to Daum & Birner (2017), the AMSEC approach faces several governance challenges, including challenges related to spare parts supply, repayment of machinery, frequent breakdowns and political interest and elite capture. Some of these problems had already been identified by Benin (2015). For example, he found that AMSEC were more likely to be set up in districts aligned with the political party of the ruling government. Diao et al. (2014) also found challenges with the AMSEC approach: they argue that the program is a financial burden, encourages rent-seeking behaviour and hinders the role of the private sector. Diao et al. (2012) asked "what has gone wrong" with the AMSEC and argued that the AMSECs are "neither appropriate nor sustainable" (p.v). The authors concluded that the state should focus on supporting the private sector and the enabling environment. For other countries, little scientific evidence exists on comparable government programs. However, there is evidence confirming the challenges Ghana is facing (see Scoones, 2013 and Pfebve, 2015 for Zimbabwe and Takeshima et al., 2015 for Nigeria).

State-led efforts to directly promote mechanization are often based on the argument that markets are not addressing the mechanization needs of smallholder farmers. Consequently, some studies have analysed private markets for mechanization. Again, many of them focus on Ghana. Diao et al. (2014) saw private service supply (led by medium- and large-scale farmers) as a "promising model for sustainable mechanisation to reach farmers of all sizes" (p.180). They call the evolving Ghanaian tractor market, which is driven by second-hand machinery, a "quiet revolution". Houssou et al. (2014) studied the market for hired tractor services in Ghana. According to them, 90% of the tractor owners who offered hired services purchased their tractors on the private market (80% of whom bought second-hand machinery). 80% of the owners had bought their tractors less than five years ago, which suggests a high speed of mechanization. Cossar et al. (2016) argued that private markets are better able to reach smallholder farmers than government programs in Ghana. Takeshima et al. (2015b), focusing on Nigeria, found that farmers buying tractors from private markets are often more efficient than beneficiaries of tractors provided via government programs. Tractor owners who bought tractors from private markets provide services over longer distances, at a cheaper rate, and they also offer services during off-peak seasons. One advantage of buying tractors privately is that farmers are better suited to select machinery types fitting to their agro-ecological conditions. According to them, however, private-sector tractor-hiring services are also facing challenges such as economies of scale, seasonality, limited mobility, and heterogeneous inputs quality.

To sum up, private markets appear to be better suited to drive mechanization. However, despite the governance challenges of state-led mechanization, various African countries continue to pursue this road, partially driven by the perceived failure of private markets to provide mechanization but also because state-led programs offer "opportunities to extract rents and nurture patron–client relations" (Cabral, 2019, p.13). Understanding how to channel the political will of governments to promote mechanization from directly promoting mechanization to creating a conducive environment for mechanization will be an important research area with a focus on the political economy of mechanization.

3.7 Myth or reality? Governments have no role to play with regard to mechanization *(false)*

While there is a consensus in the literature that mechanization does not require direct government involvement in the provision of machinery (see previous section), we can confidently reject this myth outright. Governments do have an important role to play. Several studies have highlighted the role that the public sector has to play.

Oluwole and Odogola (2018) argued that institutional factors are key to promote mechanization. Diao et al. (2014) encouraged the state to design policies and programs that help the private sector to overcome market failures. FAO (2016) argued that creating an enabling environment is the key to mechanization. According to them, major constraints of mechanization, such as lacking knowledge and skills of operators and technicians, lacking enabling laws to facilitate business, complex fiscal systems, punitive import regulations and rigid labour laws, can all be addressed by the state (FAO, 2016). Using Ghana as a case study, Daum & Birner (2017) mapped all the actors and factors that influence agricultural mechanization. They argue that it is essential to invest in institutional development to strengthen the agricultural innovation system for mechanization and to support emerging private sector initiatives.

Knowledge and skills development may serve as an example of where governments can invest to promote mechanization but which remains a major bottleneck in most African countries (Daum & Birner, 2017; Diao et al., 2016; Thoelen and Daum, 2019). Houssou et al. (2013) showed that this can largely reduce the profitability of mechanization. Using data from 48 AMSEC and 88 non-AMSEC service providers, they find that the return on capital investment was often negative due to frequent tractor breakdowns, which are rampant because of poor maintenance, the lack of qualified mechanics and operators, and delayed repairs from missing spare parts. There are various studies on mechanization in Ghana by the Agricultural Engineering Department of the Kwame Nkrumah University of Science and Technology (KNUST) confirming the importance of knowledge and skill development (Aikins & Haruna, 2012; Aikins, 2012). Studying tractor breakdown among 123 tractor owners and operators in Tamale, Aikins & Haruna, (2012) revealed that 26% of the tractors in the sample broke down once during the farming season; 27% twice; 14% thrice; 15% four times; 5% five times; and 14% more than ten times. Major reasons identified for breakdowns were, in order, careless tractor operation and inadequate maintenance, aged tractor, poor roads to farms, and the use of fake spare parts for tractor maintenance and repairs. Interviewing 61 operators in Ejura in 2008, Aikins (2012) found that 48% had no formal education and that 36% of the operators had no valid license to operate a car, truck or tractor. 97% of the operators did not follow the recommended maintenance rules.

Given the lack of knowledge and skills, Daum et al. (2018) argued that setting up institutions to support skills development is essential for successful mechanization. The authors show that countries that are mechanized today, such as the United States and Germany, once faced similar challenges that many African countries face today. Using a historical-comparative approach, they investigate how these countries created the necessary institutions. According to them, in the United States, the development of knowledge and skills was largely driven by individual and private initiatives. Germany benefited from more systematic public sector support such as the DEULA school caravans, which travelled across the country to provide training for tractor operators and technicians. According to the authors, governments, private actors, farmer organizations, and development partners can all contribute to knowledge and skills development.

Clearly, mechanization requires an enabling environment that provides several support functions. How to create such an enabling environment in the most cost-effective way, however, remains an unresolved research and policy question. Moreover, governments may face political economy challenges with regard to the provision of an enabling environment for mechanization (Daum & Birner, 2017). For example, while importing and distributing machinery is politically highly attractive and creates media attention, knowledge and skill development is often neglected. More efforts are

required to identify how these challenges can be addressed effectively. So far, little research has focused on the role of training of machine operators, farmers, and technicians as well as extension officers. What are the most cost-effective approaches to build the knowledge and skills required to effectively pursue agricultural mechanization? What is the appropriate role for government, private and third sector? What role can certification of tractor operators and technicians play? What are efficient and innovative forms of training? What are the potentials of ICTs in this regard, for example, through text-message reminders about maintenance or the use of apps to monitor tractor operators?

3.8 Myth or reality? Mechanization only saves labour *(not generally true)*

Mechanization is often contrasted with land-saving, Asian-style, Green Revolution technologies (Nin-Pratt & McBride, 2014). According to Binswanger (1986), mechanization is essentially labour-saving and has little effect on yields. Fallowing this argument, mechanization would not contribute to the intensification of land use, thereby potentially triggering a conversion of additional land and would also not create additional employment along the value chain. But is this really true? In fact, the effects of mechanization on yields are debated. Theoretically, mechanization has the potential to raise land productivity. This is the case because it allows cultivation of heavier and more fertile clay soils, timelier planting, better plant spacing, better seedbed preparation suppressing weed growth, and better coping with weather risks during harvesting (World Bank, 1986).

Empirically, different studies come to different conclusions. Using data from eight study sites across four Eastern and Southern African countries, Baudron et al. (2019) found that a lack of draught or tractor power limits land productivity. Using propensity score matching, Adu-Baffour et al. (2019) found that mechanized households have a 25% higher yield compared to non-mechanized households, possibly due to the combined effects of better and timelier land preparation as well as the use of complementary inputs. In their study, the mechanized smallholders now use land which was previously left fallow because of a lack of labour; thus, they are able to crop their land more intensively. Similarly, Yukichi (2017) find a complementarity between tractor use and land productivity: tractors trigger the use of complementary inputs, which raises yields.

Kirui (2019), using a cross-sectional dataset from eleven African countries and a regression approach, reported yield increases for maize and rice yields by on average 487kg and 677kg per hectare. There are large fluctuations between the different countries, however. In a study by Benin (2015) in Ghana, 77% of the mechanized farmers reported a high increase in yield, but the magnitude is not quantified. Benin himself doubted that the yield effects are high, reasoning that "it is difficult to see how yields can be sustainably increased by introducing tractors merely for land preparation" (p.116). Berhane et al. (2017), using cross-sectional data and regression analysis with a dummy variable, reported ambiguous results: the adoption of combine harvesters was associated with higher yields (likely due to lower post-harvest losses) while the adoption of tractors for land preparation did not increase yields. No scientific study was found to support the claim – raised by machinery manufactures[14] – that mechanization can triple or even quadruple yields.

The yield effects of mechanization thus remain ambiguous and more research is needed to better understand to what extent and under which conditions mechanization increases yields. Importantly, mechanization has other benefits beyond labour and yield effects. Mechanization may reduce the riskiness of farming (i.e., using irrigation), the amount of heavy physical work and energy needs, food waste (e.g. by preservation and faster transportation) and it may also enable value addition (e.g., by peeling, chipping, grating, and drying) among other effects (Malabo Montpelier Panel, 2018).

[14] https://www.fastcompany.com/90227534/hello-tractor-and-john-deere-bring-10000-tractors-to-africa

3.9 Myth or reality? Cooperatives are an easy way to share machinery *(not generally true)*

In principle, community-based solutions such as cooperatives may help to pool capital to buy expensive machinery and to reach economics of scale. Several studies have looked at whether such solutions are promising with regard to smallholder mechanization. Ströh de Martínez et al., (2016) argued that cooperatives and joint ownership of machinery are often restricted by severe governance challenges. In a similar vein, Daum & Birner (2017) mentioned three reasons that might lead to "community failures" with regard to mechanization: (1) collective action problems, for example, the free-rider problem with regard to maintenance and disputes due to the synchronous timing of many operations; (2) exclusion of poor farmers and socially marginalized groups and women; (3) capacity and financial constraints.

In contrast to these two pessimistic studies, the FAO (2016) referred to examples where cooperatives have been found to be effective in promoting mechanization, one in Benin, and one in Nigeria. However, the Nigerian cooperative is not actually involved in the ownership of machinery but rather facilitates the access to credit and training (Abdulquadri & Mohammed, 2012). No additional information is provided on the Benin example. Balse et al. (2015) reported a cooperative network in Benin where agricultural machinery is jointly owned (supported by the French Coopérative d'utilisation de matérial agricole, CUMA). This network comprises 120 organizations and 1200 members. Official reports are largely positive. However, in a report by the National Federation of French Cuma (FNCuma), the Foundation for World Agriculture and Rurality (FARM), and the FAO, some challenges are mentioned. For example, 44% of all CUMAs are still in the process of building capital to acquire machinery and most of the others acquired their machinery only with the help of government program and NGOs. Also, most CUMAs do not have backup capital in case of breakdowns. No study has rigorously studied the CUMAs. Similarly, there are some women cooperatives in Ghana, which are successfully running AMSECs, apparently because of strong leadership.

Looking at such success stories may provide useful insights. Looking at success stories from other countries may also provide valuable lessons. In Germany, for example, Maschinenringe (machinery circles), in which small groups of farmers (often neighbours, friends, and relatives) share their machines successfully address collective action problems with the help of clear ownership patterns. Also, while studies looking at cooperative ownership of tractors often point to challenges, other types of mechanization may be more susceptible to be owned by cooperatives (for example stationary processing equipment). Also, cooperatives may help organize smallholders to access mechanization from service providers and to promote mechanization indirectly through access to credit or training. More research is needed on the role of cooperatives for mechanization, especially to what extent and under which conditions are they to be used to ensure smallholder famers gain access to mechanization.

4 Concluding remarks

As can be derived from this paper, mechanization has been one of the most controversial of all agricultural innovations, involving promises and pitfalls alike. Therefore, as Sub-Saharan-African countries are gearing up to promote mechanization, strong empirical evidence is needed to ensure that policies and programs are not based on misleading myths. Focusing on farm mechanization, this paper attempted to address some of these myths, some which contain truths and some which are completely false.

As shown, today's focus on mechanization on the policy agenda of many African countries needs to be accompanied with a new research agenda for mechanization, which comprises several key research areas: What are the employment effects? What should institutional solutions for smallholder farmers look like? How can women's access to mechanization be ensured? What is the potential of digital solutions to make mechanization more accessible for smallholder farmers? Under which conditions can cooperative solutions help promote smallholder mechanization? How can an enabling environment for mechanization be created? How should mechanization be financed? How can the agenda ensure that mechanization efforts minimize soil erosion problems and are environmentally sustainable?

When answering such questions, it should not be forgotten that agro-ecological conditions, such as rainfall patterns, crops, and soil types, and socioeconomic conditions, such as land sizes and rural wages, vary widely across and within African countries, which leads to different conditions for mechanization. It is thus important to understand where there is a real demand for mechanization, which type of mechanization is needed and also where, for example, draft animals have a comparative advantage. A location-specific understanding of mechanization conditions will be key for policymakers and development partners who promote agricultural development to ensure that public funds bring in the highest returns and best social outcomes. It is also important to avoid some of the potential negative effects of mechanization, such as unemployment, which can be triggered when mechanization is artificially pushed in areas where the frame conditions are not conducive (Binswanger, 1986; Pingali, 1988). Even if the socioeconomic conditions are correctly identified, finding engineering solutions that best fit specific smallholder farming systems, taking agro-ecological factors into account, will be essential for successful mechanization.

Addressing these research areas will help to find mechanization solutions that are economically, socially, and environmentally sustainable. The review has shown that the trade-offs between these dimensions are not well understood, partly because most studies focus on individual aspects. This review has also revealed a need for methods and tools to assess ex-ante and ex-post economic, social, and environmental impacts of different mechanization options, involving the challenge on how to organize interdisciplinary research for more integrated assessments of mechanization. The research agenda developed in this paper may be far from complete; nevertheless, we hope it will provide guidance for policy-relevant future research and address the wide-spread myths regarding mechanization, which may prevent smallholders from accessing a technology that could go a long way, both in improving their lives and contributing to global food security.

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