Chapter 9

MECHANIZATION OF AGRICULTURAL PRODUCTION IN KENYA: CURRENT STATE AND FUTURE OUTLOOK

Pascal Kaumbutho and Hiroyuki Takeshima

Agricultural mechanization is the use of machinery, equipment, and implements—rather than human or animal power—to carry out agricultural practices. When the use of mechanization is sufficiently high, it can help improve the overall efficiency of food systems, reduce the costs of producing outputs and providing services, enhance economies of scale, and raise labor productivity and incomes (FAO and AUC 2018; Diao, Takeshima, and Zhang 2020). While mechanized practices are traditionally thought of in terms of tilling, seed drilling, and spraying, in recent years mechanization has been considered to include broader applications along the food system, such as irrigation, postharvest cleaning of harvests, cold storage, value addition, and processing.

Agricultural mechanization is considered one of the critical tools to achieve Kenya's broader agricultural development strategies (Kenya, Ministry of Agriculture, Livestock, Fisheries, and Irrigation 2019). In particular, agricultural mechanization is expected to contribute to the scaling-up of larger commercial production; increasing the productivity and incomes of small farmers, pastoralists, and fisherfolks; supporting aging farmers and attracting youth into modern farming; and facilitating the growth of industrial agroprocessing. It may also facilitate the adoption of other modern inputs and practices like irrigation, improvements in food system resilience, stability of food supplies, sustainable use of land and natural resources, and climate change adaptation (ibid.). Also, suppliers of mechanized equipment, service providers, and processors are regarded as critical change agents to improve market access to inputs and offtake (including transportation).

As part of its agricultural development strategy, Kenya's latest National Agricultural Mechanization Policy (Kenya, Ministry of Agriculture, Livestock, Fisheries, and Cooperatives 2021) prioritizes a range of approaches to modernize mechanization. These include the development of machine and equipment value chains, fostering the machine development and fabrication industries, stimulating machine investments through e-voucher-based subsidies and supplementary financing mechanisms, and quality assurance for machines through enhanced regulatory capacity. The policy also emphasizes increased R&D on mechanization; technology development; modern mechanization; sustainable and climate-smart mechanization; and improving knowledge and skills on machines, machine operations, and mechanization practices. In addition, it promotes the expansion of high-quality mechanization service provision, in combination with e-voucher-based subsidies and registration of service providers eligible for voucher redemption, as key instruments to improve access to mechanization technologies for smallholders. Lastly, the policy highlights the goal of addressing gender equality in mechanization use.

However, optimal promotion of agricultural mechanization in Kenya requires careful assessments of demand levels, and the identification of an appropriate public sector role in mechanization sector growth if such demand is sufficient. Overall demand for agricultural mechanization depends on the level of farming system intensification, which affects returns to more frequent land preparation and tillage, as well as relative costs of mechanization compared with substitutes like human labor and draft animals (Diao, Takeshima, and Zhang 2020). Desirable forms of mechanization can vary considerably across different food production environments. And increased mechanization may be beneficial under only certain conditions. Mechanization may not make economic sense in a more subsistence-based system (temporal). As later sections discuss, shifting cultivation and fallow remain more productive methods than tillage in parts of Kenya where the population density remains low. Excessive mechanization that displaces labor can reduce labor productivity and income. Mechanization adoption also often follows a particular sequence depending on the farming operation. For example, it typically starts with the mechanization of power-intensive, static operations, and then involves the mechanization of more control-intensive, mobile operations (Pingali, Bigot, and Binswanger 1987).[1]

1 Agricultural mechanization processes generally move from manual operations to animal-powered and onward to motorized (engine-powered) applications. This progression taps into the existing technological and industrial advancements and market demand prevailing at a given time. For example, FAO and AUC (2018) illustrate the mechanization process in six stages. In the first stage, draft animals or relatively simple machines assist in hand-tool (manual) operations. Mechanization in stage 2 substantially replaces manual operations, except for in control-intensive operations like weeding. Stage 3 mechanization advances into precision planting and spraying operations, calling for machine calibration. This approach can accommodate or influence cropping patterns, from multiple crops to monocropping systems, for operational efficiency. Stage 4 mechanization involves adapting the farming system and production environment in response to mechanization. Land management that exploits economies of scale becomes important, sometimes promoting the consolidation of small farms. This stage also often involves mechanization for poultry and livestock production. Approaches like conservation agriculture systems of reduced soil manipulation and retaining cover on the soil surface may become more relevant. Stage 5 mechanization involves adapting crops to improve machine performance efficiency. Crops are bred for better height and less lodging to be suitable for mechanical threshing and to resist bruise damage during mechanical harvesting. Stage 6 involves automation leading to workable higher levels of mechanization, with many production operations tapping into machine intelligence. Mechanized operations at this level are used for feeding systems in livestock production, automated application of fertilizers and other chemicals, and GPS-positioned machinery in planting, spraying, and the like.

While this chapter focuses primarily on the potential roles of mechanization in Kenya and suitable strategies for the Kenyan government's mechanization promotion policies, these are relevant only if demand for each stage of mechanization has risen sufficiently in the relevant food production environment. Where demand is indeed sufficient, appropriate supply-side strategies are required to identify and address key market failures in the agricultural mechanization sector while minimizing government failures so the industry remains efficient and competitive.

With this background, this chapter describes current challenges and strategies for an optimal mechanization approach in Kenya. The first section reviews recent trends in mechanization in Kenya and general mechanization practices in comparison with other African countries. The chapter then discusses key drivers of mechanization and potential roles in the future. Finally, it describes key policy issues with regard to mechanization growth in Kenya, including functions of the public sector and key principles of support approaches.

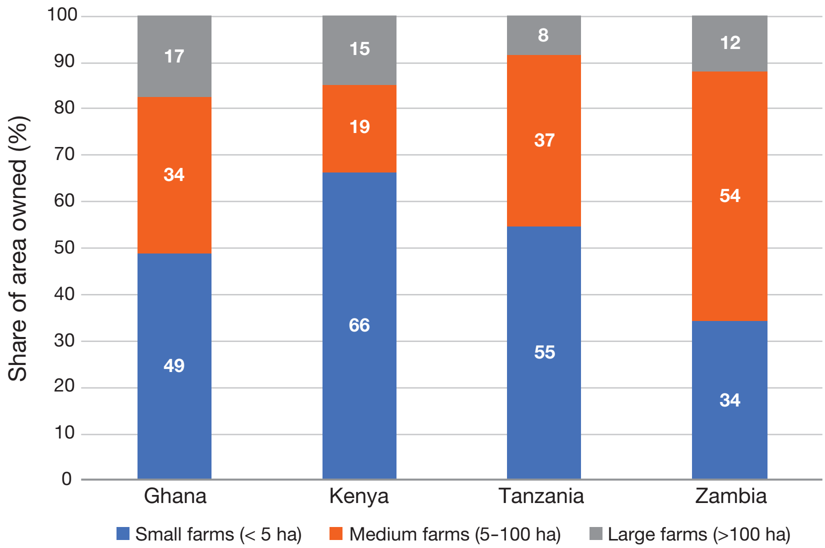
Mechanization status in Kenya

Farmer typologies and mechanization

Agricultural mechanization in Kenya dates back to the 1954 Swynnerton Plan, famous for the land demarcation policy implemented to commercialize small-scale agriculture in the country. In this plan, native farmers were settled on newly cleared 10–20 acre farms in the Highlands, considered to be of sufficient size to be viably mechanized (Swynnerton 1954; IBRD 1960). Farmers were given deeds to their newly acquired land. This plan facilitated the establishment of vibrant agroenterprises and industries anchored on small and medium-scale farms after independence. Since then, the Kenyan agriculture sector has consisted mainly of four broad types of farmers—namely, peasant subsistence farmers, small-scale commercial farmers, medium-scale farmers, and large-scale farmers.

Peasant subsistence farmers typically cultivate less than 2 ha. They rely on family labor and hand-tool technologies for land preparation and crop husbandry tasks. Few of these farmers hire tractors or draft animal power for land preparation. Small-scale commercial farmers, who have a bit more land (cultivating 2–10 ha), typically use draft animal power where available, or sometimes tractors and machines for rotating paddy fields, planting, or shelling maize. Some may own a four-wheel tractor (4WT) and offer a tractor-hiring service to other small-scale commercial farmers.

FIGURE 9.1 Area under different farm sizes in Ghana, Kenya, Tanzania, and Zambia, 2015



Source: Adapted from Jayne and Ameyaw (2016).

Medium-scale farmers typically cultivate 10–100 ha. They are more likely to own a 4WT and an assortment of implements, although some rely on hired services if available. If they own a 4WT, they often offer a tractor-hiring service, including off-farm activities such as transportation, since they are unlikely to attain economical use rates on their farms alone.

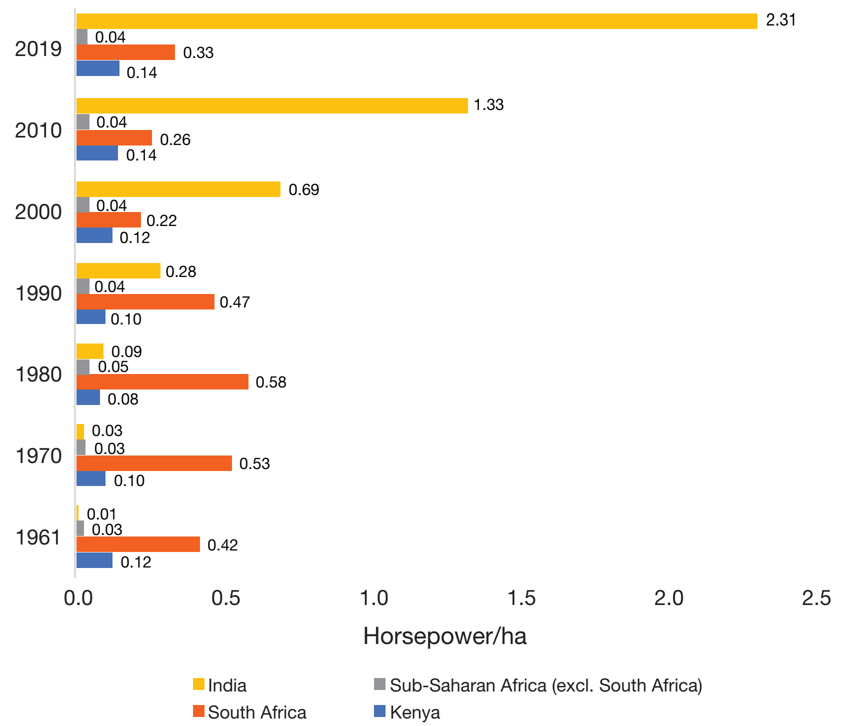
Large-scale farmers (typically cultivating 50–2,000 ha) often own a range of 4WTs with their assorted implements, and operate a significant proportion of the tractor fleet in the country (De Groote, Marangu, and Gitonga 2020). They may also hire specialized machinery like combine harvesters. Also, they may offer a tractor-hiring service on a contract farming basis. Historically, large-scale farmers have produced cash and/or industrial crops such as coffee, sisal, tobacco, pyrethrum, flowers, and horticultural products like tea, maize, rice, wheat, dairy, beef, and sugarcane, among others (Mayne 1955; Eicher and Baker 1982). At independence in the 1960s, large farmers were predominately settler farmers and transnational corporations. During the 1970s and 1980s, they consisted of many government-owned state and private farms. After the economic structural adjustment programs of the 1990s, most state farms were privatized.

At independence in 1963 and immediately thereafter, most cultivated land was owned by peasant subsistence farmers, small commercial farmers, and large colonial settlers. However, this situation changed over time, especially from the beginning of the 21st century, as in other African countries. Medium- and large-scale farmers have recently grown to account for one-third of farmland in Kenya, following patterns occurring in countries like Ghana, Tanzania, and Zambia (Figure 9.1). The growth in the medium-scale farmer group has been driven by effective demand for agricultural products generated by urbanization, income growth, off-farm employment opportunities, rising wage rates, and enhanced demand for mechanization (Clarke and Bishop 2002). All of these types of farmers—peasant, small commercial, medium- and large-scale—coexist in Kenya, with neither small nor large farms dominating (Muyanga and Jayne 2019).

Stocktaking of mechanization in Kenya

As measured by horsepower per hectare of farmland, the mechanization level in Kenya has remained relatively stable during the past six decades (Figure 9.2). It

FIGURE 9.2 Growth of major agricultural machinery inventories in Kenya and other selected countries/regions



Source: Authors' calculations using USDA (2022).

Note: Cultivated land includes cropland and area under permanent crops. Major machineries include tractors, combine threshers, and milking machines.

increased slightly from 0.08 hp/ha in 1980 to 0.14 hp/ha in 2019, mechanizing slightly faster than the whole of sub-Saharan Africa (excluding South Africa). However, the rate of change has been much lower compared with that in Asian countries like India.

MECHANIZATION OF LAND PREPARATION

Most Kenyan smallholder farmers still rely on hoe-based operations or oxen-hauled mouldboard plows (De Groote, Marangu, and Gitonga 2020). A survey in 2012 based on representative samples of farm households in a significant maize production region in Kenya indicated that only 2 percent of maize farmers owned tractors, 33 percent owned oxen, and 28 percent owned plows. However, the last two shares exhibit a significant increase since 1992, from 12 and 17 percent, respectively (De Groote et al. 2020). The use of oxen and plow has been more common in dry or moist mid-altitude zones, while the use of tractors has historically been concentrated in highland maize areas (De Groote et al. 2020, Figure 12.4). Except in places like the North Rift region, smallholders are most likely to plant large seed crops like maize and beans by hand.

Figures from selected countries' nationally representative farm household survey data suggest that the level of mechanization in Kenya is also relatively consistent with that in other major sub-Saharan African countries (Table 9.1). In Ghana, Nigeria, Tanzania, and Uganda, shares of farm households using tractors in the late 2010s are not more than 13 percent. While relatively more

TABLE 9.1 Use of tractors and animal traction for all crops and rice farming in selected sub-Saharan African countries in the mid-2010s

	Share of farming households (%)			
	Tractors	Animal traction	Hand hoe	Data
Ghana	13	N/A	N/A	2017 Ghana Living Standard Survey
Nigeria	10	25	65	2018 Living Standards Measurement Survey: Integrated Surveys on Agriculture
Tanzania	9	37	54	2014 Living Standards Measurement Survey: Integrated Surveys on Agriculture
Uganda	< 1	7	93	2018 Living Standards Measurement Survey: Integrated Surveys on Agriculture
Kenya (ownership)	2	33	< 65	2012 (De Groote, Marangu, and Gitonga 2020)

Source: Authors using De Groote, Marangu, and Gitonga (2020); Takeshima and Mano (2022).

Note: Figures for Kenya are the share of farm households owning tractors and animal traction tools, rather than the share of farm households using them, and representative within maize production areas only (De Groote, Marangu, and Gitonga 2020).

common, the share of farm households using animal traction remains about one-third or less in these countries. Mechanized land preparation, used in Kenya, often combines disc plow and harrow. Several runs of the plow are often applied, followed by several passes of the harrow to break the clods. Tractors are used mainly by cereal growers, although some medium-scale farmers may have mechanized maize or wheat planters to follow the harrowing.

MECHANIZATION OF LAND MANAGEMENT

Agricultural mechanization of operations other than land preparation has lagged in Kenya. However, small hand-held motorized tools are gradually replacing manual labor, allowing more focus on land management activities that are more attractive to youth (Kaumbutho 2016). These tools include brush cutters, motorized knapsack sprayers, fence cutters, weeders, and power tillers in irrigated rice schemes (Diao, Takeshima, and Zhang 2020; Mano, Njagi, and Otsuka 2022).

Typically, control-intensive farming operations like weeding are conducted primarily by hand, mainly using family or hired women's labor in developing countries in Africa (Takeshima and Diao 2021), and this is expected to be the case in Kenya as well. Mechanized crop maintenance, like hiller weeding in potato farming and spraying herbicides and pesticides, is rare for smallholder farmers in Kenya. Mechanized spraying through knapsack sprayers is occasionally done for pest and disease control. This has attracted some youth to form "spray gangs" to serve farmers for a fee. Some have progressed to using motorized knapsack sprayers and brush cutters for weeding and tidying farms with overgrown bushes (Kaumbutho 2016).

MECHANIZATION OF POSTHARVEST HANDLING PRACTICES

Harvest and postharvest mechanization varies widely, depending on the size of the enterprise, the value chain involved, and the market. Combine harvesters are used chiefly for cereal crops, mainly maize, wheat, and barley, and recently rice. Some combine harvester service providers travel 200–300 km to service customers. Similar custom hiring services for mechanized harvesting provided by migratory service providers to smallholders have been emerging in Asia and other African countries like Ethiopia, albeit to a limited extent in the latter (Diao, Takeshima, and Zhang 2020). Some youths have developed businesses ferrying around small shellers and threshers made locally by informal sector artisans to provide services. A few companies have introduced harvesting machines for tuber crops like Irish potatoes (Kaumbutho 2016).

The *tuk-tuk* (three-wheeler) and *bodaboda* (motorbike) transport service sectors have also grown in the postharvest transport arena (ibid.).

Modern rice milling machines have also spread, albeit slowly, in rice production regions, including in the Mwea Irrigation Scheme in Kenya (Mano, Njagi, and Otsuka 2022; Takeshima and Mano 2023). These modern milling facilities, equipped with destoners and grading machines, among other features, have often been imported by private sector entrepreneurs. The machines significantly reduce per unit milling costs and improve milling quality, increasing the supply of better-quality milled rice at lower prices (Mano, Njagi, and Otsuka 2022). Importantly, however, a steady and sufficient supply of raw materials (paddy) enabled through well-functioning irrigation infrastructure has been critical to the viability of these modern mills. Outside a few successful irrigation schemes within sub-Saharan Africa, an insufficient supply of paddy has often crippled the economic viability of modern milling, for example, in Nigeria (Gyimah-Brempong, Johnson, and Takeshima 2016).

MECHANIZATION IN THE FORAGE SECTOR

The dairy industry in Kenya has progressed well, and by large strides compared with neighboring countries. Mechanization application for forage production and harvesting is also an important part of the initial mechanization of the livestock sector (for example, Gürsoy 2017; Benoit and Mottet 2023). A farmer with fewer than three animals may manage with only a machete and a chuff cutter for the hay or Napier grass, brachiaria, sorghum, or lucerne harvests. A more advanced farmer may have the services of a hayseed broadcaster, mower, rake, baler, or chopper for animal feed. Recently, it has become possible to chop fodder and pack it directly without the need for ensiling. More modern farmers may even access a feed mixer or a mini or full-size milking machine.

MODALITY OF MECHANIZATION SERVICE PROVISION

All these mechanization activities in Kenya are enabled through private sector custom hiring mechanization services. *Nomadic service providers* use tractors and disc plows to serve farmers in several localities. They traverse the land following rainfall isohyets in search of land needing plowing. These providers can travel some 700 km across the country and be away from home for around eight months a year. Elsewhere in sub-Saharan Africa, mechanization service providers of similar characteristics typically serve on the order of 100 ha in a year, such as in Nigeria (Takeshima et al. 2015). In Kenya, too, they are likely to remain critical providers of mechanization services to smallholders who have demands but cannot own machines themselves. Nomadic service providers are likely to continue to dominate in the short term, where high-tech service provision is still underdeveloped.

Some *government service providers* also offer mechanization services within their respective county boundaries, using county government-owned tractors and implements. These government-operated providers may be less efficient than the nomadic providers, as has been experienced in other African countries (Diao, Takeshima, and Zhang 2020).

In recent years, digital technologies have enabled a new type of service provider: *the innovative and modern tech-backed provider.* These service providers work in a given locality and particular value chains. They often establish a working base near farmers and use technology to manage and coordinate services, serve farmers more effectively, and provide more presence and accountability to their customers. These private sector service providers, particularly modern tech-backed providers, have significant potential to improve the availability, accessibility, affordability, accountability, and climate-smartness of mechanization services (Balyamujura, Kaumbutho, and Karu 2018). Innovative service providers in Kenya include Hello Tractor Ltd and Agrimech Ltd. Hello Tractor uses GPS-based monitoring devices to remotely monitor tractors and digital booking platforms that match farmers with the nearest tractors (Daum et al. 2021). Agrimech Ltd. manages the fleet of these device-installed tractors. In Nigeria, where Hello Tractor operates similar services, these modern methods have significantly reduced transaction costs in mechanization service provisions (Daum et al. 2021). While such modern tech-based service provision is still nascent in Kenya, it has potential to improve the affordability and accessibility of mechanization services for smallholders.

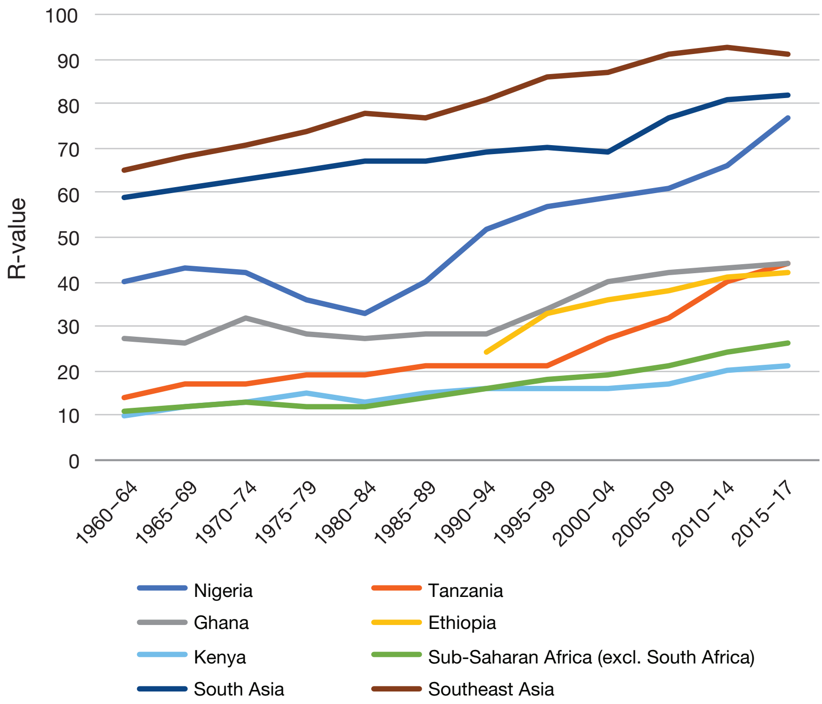
Considerations for agricultural mechanization into the future

Future drivers of demand for mechanization

FARMING SYSTEM INTENSIFICATION

Demand growth for mechanization in Kenya in the near future depends on the intensification levels of farming systems. In parts of Africa where the intensification level is low, such that most farmland is cultivated only once in a few years and left fallow most of the time, shifting cultivation remains cheaper than mechanized tillage to clear land (Diao, Takeshima, and Zhang 2020). Based on an index called R-value (which proxies the level of farming system intensification), farming systems in Kenya are less intensive than in many other African

FIGURE 9.3 R-values in African countries and developing regions, 1960–2017

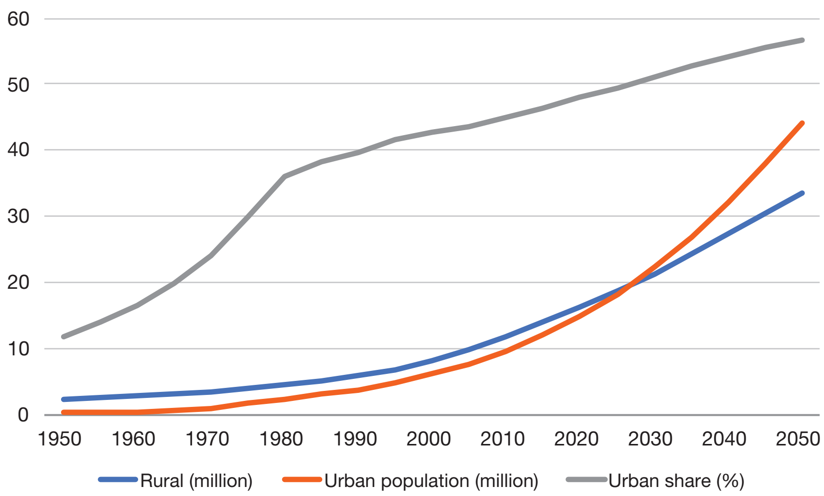


Source: Authors' calculations using FAOSTAT (2022).
Note: Rvalue = (Harvested area of all crops summed) / (Arable land + Permanent pasture and meadows) * 100.

countries. Still, the intensification level is gradually increasing (Figure 9.3). This may explain why, for a majority of land in Kenya, animal traction remains more viable than tractors for the foreseeable future (De Groote, Marangu, and Gitonga 2020).

However, the national figures mask considerable heterogeneity in farming systems. There are pockets within Kenya where farming systems are sufficiently intensive to generate significant returns from investment into mechanization. For example, the maize agroecological zones and the low tropics zone (the coastal area in southeast Kenya) have seen relative growth in tractor ownership in recent years, while ownership has stagnated in other zones (De Groote, Marangu, and Gitonga 2020). Better understanding the heterogeneity of farming systems and varying mechanization potential within Kenya is a crucial part of designing mechanization support efforts. Recent studies have also identified pockets of areas like Machakos and Kisii counties in Kenya, where the

FIGURE 9.4 Population growth (rural and urban) and urban share in Kenya



Source: UN DESA Population Division (2018).

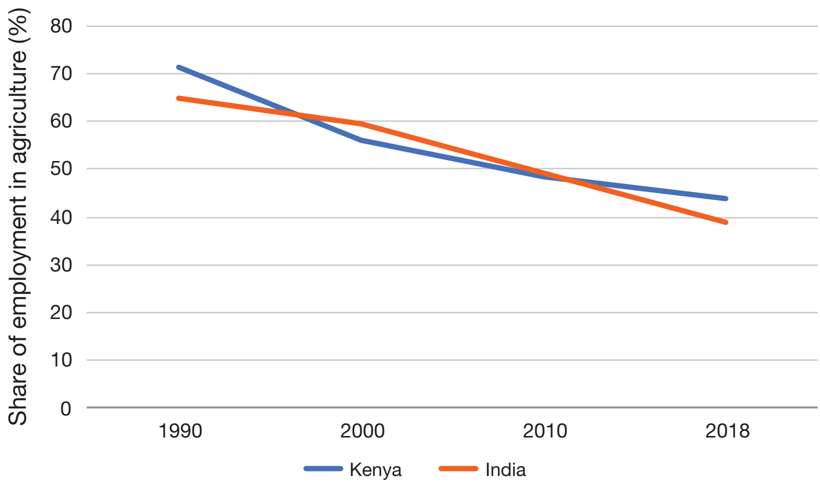
need for more sustainable land management becomes vital as a result of rising population density (for example, past 600 persons/km^2) (Willy, Muyanga, and Jayne 2019).

DEMOGRAPHIC OUTLAY

Urbanization and labor movement out of the agriculture sector will intensify and drive demand for mechanization. The urban population in Kenya, which currently accounts for around 48 percent of the total population, is expected to reach 57 percent by 2050, putting pressure on rural labor to be ever more productive (Figure 9.4).

Figure 9.5 shows that the employment share of the agriculture sector in Kenya has been declining over time. This pattern has been consistent with other sub-Saharan African countries where the share of full-time employment in farming has dropped to less than 50 percent, with an increasing number of jobs shifting to off-farm employment such as agroprocessing and trade (Jayne et al. 2016). Figure 9.5 also shows that the share has been comparable with that in India, where mechanization has grown considerably (with 90 percent of land preparation currently done by tractors) (Diao, Takeshima, and Zhang 2020). These trends in Kenyan agricultural transformation suggest that, demographically speaking, the potential of mechanization is rising.

FIGURE 9.5 Employment share of the agriculture sector in Kenya and India



Source: de Vries et al. (2021).

Growing urbanization in Kenya can also affect investments in land and machines by local entrepreneurs and foreign investors, including emerging medium-scale "absentee" or "telephone" farmers. These "farmers" notice that the original farmer is aging and unable to perform many manual tasks, as evidenced by the statistics of falling food volumes. They also have an in-built passion for agribusiness but carry the label of a corporate worker, "stuck" at their office job accumulating resources that can be invested in farming, alone or with partners (Kaumbutho 2016). Such absentee farmers are also consumers of organized and accessible mechanization services and inputs on hire. Mechanization, combined with irrigation and other rural infrastructure such as road improvement and storage facilities, can help well-resourced midlife farmers to fill the labor shortage gap. These farmers will likely create a more enabling environment for investments in agricultural mechanization in Kenya in the near future (ibid.).

Evolving roles of mechanization to address emerging challenges

PRODUCTIVITY, EFFICIENCY, ECONOMIES OF SCALE, AND SCOPE

Agricultural mechanization can provide various benefits in appropriate contexts of sufficient demand and affordable costs of machines and hiring services. These benefits include reduced food production costs (Diao, Takeshima, and Zhang 2020), increased productivity through better land preparation timing

(Kosura-Oluoch 1983), increased returns to intensive tillage, and reduced harvesting losses and/or higher processing and milling efficiency (Takeshima and Liu 2020; Zheng, Ma, and Zhou 2021; Mano, Njagi, and Otsuka 2022). Mechanization can enhance economies of scale and returns to specialization (see examples from Ghana in Takeshima, Houssou, and Diao 2018). Recent studies also show that mechanization can improve economies of scope in a particular farm setting, facilitating crop diversification and, thus, resilience (see examples from Nigeria in Takeshima, Diao, and Aboagye 2020).

SUSTAINABILITY AND CLIMATE CHANGE RESILIENCE

Exploring the roles of mechanization in achieving environmental sustainability is an important consideration. Climate change, carbon dioxide emissions, and how these are related to overall farm production, specifically mechanization technologies, chemical use, and precision farming, will all need to be tracked to ensure the sustainability and resilience of food system goals are met (Mrema and Rolle 2003). Climate changes, particularly rising temperatures, are found to increase weeds on maize plots in Kenya (Jagnani et al. 2021), where suppressing weeds through mechanized land preparation could play a greater role. In parts of Kenya, community-based electric micro-grids have enabled cold storage (Kirubi et al. 2009), which, if combined with renewable energy like solar power, could be another example of mechanization enhancing climate resilience during storage through sustainable energy sources.

Soil degradation has been contributing to the loss of agricultural productivity by 1 percent a year or more in extensive areas in Kenya (World Bank 2008). Conservation agriculture (CA) is considered a resource-preserving method that can benefit from improved mechanization technologies (Friedrich 2013). CA is found to improve on conventional practices in drier climates with seasonal rainfall at less than 600 mm and seasonal temperatures above 20°C, and in other humid subtropics, given good management (Laborde et al. 2020), which can apply to much of Kenya. Recently, the Conservation Agriculture Sustainable Agriculture Rural Development Project, in collaboration with African Conservation Tillage Network, piloted the use of CA machinery in Kenya (Kenya, Ministry of Agriculture, Livestock, Fisheries, and Cooperatives 2021). The Kenya Draught Animal Technology Project promoted draft animal use and/or small-motorized CA machinery (ibid.). The Common Market for Eastern and Southern Africa (COMESA) has supported using land preparation CA equipment. Further knowledge bases should be built through these initiatives, including assessing where CA technologies are particularly effective and viable in Kenya.

Once such niches are identified, business models for CA mechanization hiring services can be promoted. In the Indo-Gangetic Plain in Asia, for example, zero tillage has spread considerably among smallholders in recent decades: around 5 million ha out of 13 million ha under the rice-wheat system have adopted such practices (Chauhan et al. 2012; Keil, D'Souza, and McDonald 2016). There, zero tillage technologies have been provided to smallholders through custom hiring services using zero till drills attached to 4WTs (Keil, D'Souza, and McDonald 2016). The experience in India can serve as a roadmap for Kenya. It is, however, important to note that CA mechanization technologies may not be suitable in areas where shifting cultivation is still common and tillage practices are rare (Pingali 2007).

GENDER AND YOUTH INCLUSIVITY IN RURAL DEVELOPMENT

If successfully promoted, mechanization can contribute to gender- and youth-inclusive rural development in Kenya. Optimally empowering rural youth through mechanization is worth exploring to boost agricultural production (Mrema et al. 2017; Daum and Birner 2020). Historically, tractor operations worldwide have been considered masculine and are often targeted at men (for example, Brandth 1995). Consequently, mechanization strategies should pay more attention to providing mechanical technologies suitable for women. Gender-sensitive mechanization programs can increase women's labor productivity and reduce the struggle associated with on-farm and postharvest operations typically performed by women. For example, some women in Kenya grow crops on smaller, fragmented plots for risk mitigation purposes (wa Gĩthĩnji et al. 2014), and mechanization technologies that are more suitable for such production practices may be needed for these women. Some focus group-based studies indicate that women in Kenya may value better land preparation and weed suppression, increased time for nonfarm activities, reductions in drudgery, and reduced production costs as key benefits of mechanization, while more men expect farmland expansion and higher crop diversity as main benefits (Daum et al. 2020). Gender-inclusive access to mechanization is also important because, in Kenya, households headed by single, divorced, or widowed women have less access to mechanization services compared with women with male household members, who have a better social network to access such services (Wanjiku et al. 2007). Importantly, promoting mechanization in a gender-inclusive way in Kenya should consider potential benefits in broader rural development and smallholder livelihoods that include the nonfarm sector, in addition to on-farm activities. Recent evidence from sub-Saharan Africa and Asia suggests mechanization (such as increased use of tractors) may benefit farm households by releasing women from arduous farm labor activities to engage more in nonfarm activities (see Takeshima and Diao 2021).

The food sector is expected to continue providing a critical source of employment for youth in Africa in the near future (Christiaensen, Rutledge, and Taylor 2021). In some African countries, like Ghana, access to mechanization has allowed youth to enhance their autonomy in farm decision-making by reducing the need to secure support from village chiefs and/or elders (Amanor and Iddrisu 2022). In Kenya, anecdotal evidence shows that youths become more interested in working in agriculture because of mechanization opportunities (Marechera and Muinga 2017; Makini et al. 2020). Training programs designed to build capacity to access and effectively and profitably operate and maintain mechanization equipment can be targeted at youth. Supporting and strengthening training programs, including technical vocational education and training (TVET), can help youth master knowledge of intensive farming and postharvest handling operations, machine operations, and mechanization service provision (Makini et al. 2020).

Policy guidelines for mechanization programs and projects

The role of government

The Kenyan government's mechanization policy goals as described earlier can facilitate mechanization to fulfill various potentials, also described above. In addition to providing specific support, the government's general roles are to address critical market failures while minimizing the risks of government failures.

Several key policy lessons for mechanization can be gleaned from experiences in Asia and other more advanced countries in sub-Saharan Africa over the past five decades (Mrema, Baker, and Kahan 2008; Singh 2013; FAO 2014). Mechanization should be viewed strategically within a longer-term timeframe as part of broader economic development and agro-industrialization strategies (Diao, Takeshima, and Zhang 2020). Mechanization planning in Kenya, therefore, should ideally be through cross-ministry partnerships among ministries like agriculture, environment, trade, industry, ICT, and others (FAO and AUC 2018).

At the same time, the government may need to recognize that its capacity may be limited with regard to customizing support in different ways for heterogeneous agroecological and socioeconomic conditions. Elsewhere, successful mechanization development has not depended on the government's direct involvement in machinery supply, financing, or mechanization hire service provision. Instead, governments have succeeded by supplying information, knowledge, and institutional infrastructures and encouraging market-based competition (Diao, Takeshima, and Zhang 2020). These general principles should guide the Kenyan government as well. Below, we discuss specific applications of these principles to the Kenyan government's mechanization policy goals.

Supporting hire services

Promoting the growth of mechanization hiring services is one of the policy goals of the Kenyan government. One of the most influential roles for the government lies in strengthening support to training on machine operations, field inspections for problems like tree stumps that can cause machine breakage, and maintenance/repair, which can enhance the efficiency and reduce the costs of service provision, as experienced in Ghana (Diao, Takeshima, and Zhang 2020). Growing evidence points to significant variations in efficiency among service providers in African countries, implying that there is scope for enhancing overall efficiency through appropriate training on operation skills in Kenya (see Takeshima et al. 2015 on mechanization service providers in Nigeria and Diao, Takeshima, and Zhang 2020 on Ghana). As stipulated in the National Agricultural Mechanization Policy (Kenya, Ministry of Agriculture, Livestock, Fisheries, and Cooperatives 2021), this training can be provided in TVET institutes, universities, and research institutes, in particular the Agricultural Mechanization Training Institute.

In doing so, it is important to incorporate the knowledge of existing private sector hiring service providers, whose experiences and expertise are specific to their local business environments. This is because the viability of hiring service businesses depends on there being a sufficient annual use rate (Diao, Takeshima, and Zhang 2020), and existing private sector providers often have the knowhow to achieve high rates (for example, Takeshima et al. 2015). This is critical in Kenya, where available tractors are typically large, with an average of 100 hp (Diao et al. 2016), requiring sufficient use rates to achieve viability.

For financial support to machine investments, value chain financing (credit provided by agricultural equipment dealers to buyers) has been one of the most common models used elsewhere, and should be promoted in Kenya (Animaw et al. 2016). Subsidies for machines should generally be avoided. If needed, they should be made available to a broad type of equipment (while keeping subsidy rates low to keep subsidy budgets minimal) so that the equipment market remains competitive. Similar subsidy models have been used in India, leading to growth in mechanization (Diao, Takeshima, and Zhang 2020).

The government can also invest in gathering and sharing information about promising models of innovative financing mechanisms emerging in and outside Kenya. For example, asset and finance leasing and pay-as-you-go schemes that allow lessors to monitor the repair and maintenance of the machinery closely have been found to be promising (Balyamujura, Kaumbutho, and Karu 2018).

Supporting local industry

The Kenyan government is also prioritizing the development of machine and equipment value chains as well as fostering machine development and fabrication industries as part of its mechanization policies (Kenya, Ministry of Agriculture, Livestock, Fisheries, and Cooperatives 2021). In this effort, it is critical to understand the expected sequence of the manufacturing sector's growth process. Based on historical experience, manufacturers of spare parts and simple machine attachments/implements extend gradually to cover more sophisticated equipment and machines because greater skills and knowledge are required for the latter stage (Ito 1986; Adubifa 1993; Diao, Takeshima, and Zhang 2020). In other words, viable development of the machine manufacturing sector is unlikely before the development of spare parts and simple attachment manufacturing.

Currently, most tractor dealers sell fewer than 30 tractors yearly but many more spare parts are sold in Kenya (Kaumbutho 2016). The Kenyan government should therefore focus on developing the local manufacturing of spare parts first. For example, developing local spare parts manufacturing for commonly used types of tractors can contribute significantly to increasing the availability of spare parts, which would otherwise have to be imported with added transaction costs. Doing so is also critical for some old but popular tractors marketed in domestic secondhand markets, for which spare parts may no longer be manufactured in foreign countries (Diao, Takeshima, and Zhang 2020). Developing local spare parts manufacturing is also important for other technologies, including mechanical irrigation like drip irrigation technologies in Kenya (Kulecho and Weatherhead 2005; Malabo Montpellier Panel 2018).

Promoting social capital

Effectively mechanizing smallholder farmers requires their exploitation of the power of aggregating their demand, as observed in other sub-Saharan African countries like Ghana (for example, Diao et al. 2018). Higher levels of mechanization can disadvantage smallholder farmers and other small actors within value chains in favor of large, commercialized farmers. Such players must come together to lower the costs of access to and service of machinery.

Once organized in groups, smallholders can access larger and more organized markets. For example, in Ghana and parts of Asia, recent studies show, smallholders increasingly use their internal and external social capital to access mechanization services collectively (Kansanga 2017; Diao et al. 2018; Müller 2020). Promoting and mobilizing social capital appears to be more successful in coordinating such mechanization timing than other modes like joint ownership of machines, which often suffer from overuse and insufficient maintenance (Diao, Takeshima, and Zhang 2020). Improving communication using ICTs is also found to facilitate collective action (Binswanger and Deininger 1997). For example, in China, local governments worked with mobile companies to set up group message platforms for mechanization service providers who provide migratory services together. This reduced communication costs among service providers significantly (Zhang, Yang, and Reardon 2017). Similar support to facilitate collective action among various stakeholders along agricultural mechanization value chains by local governments in Kenya could be effective.

Social capital also plays an essential role in knowledge diffusion. Promoting such social capital among potential adopters of mechanization could be important given that recent studies in low-income countries indicate significant exposure gaps in potential mechanization benefits among farmers who could otherwise consider adopting the technology (for example, Brown, Paudel, and Krupnik 2021).

Supporting applied research and development

The public sector plays a significant role in R&D related to agricultural engineering, economics, and a broader set of related technologies and institutions. Holistic mechanization research efforts should be designed involving departments of agriculture (mechanization research, soils, postharvest, irrigation, and so on), trade and industry (industrial research, manufacturing, patenting, standards, trade licensing, and so on), energy (energy generation and distribution, alternative fuels, and so on), and higher education (research and education on all aspects of mechanization in schools of agriculture and engineering). Linkages between the public and the private sectors in R&D activities must be strengthened.

Legislative changes should be guided by impact assessments and the collection, compilation, and analysis of gender-disaggregated data on labor, income, decision-making, control of resources, and other indicators. Enhancing institutional capacity on mechanization R&D remains key, including through a tractor census or the collection of additional data to monitor the status of various aspects of mechanization sector development, as well as the capacity development of professional bodies of agricultural engineers and agricultural economists who play essential roles in policy advocacy for agricultural mechanization (Diao, Takeshima, and Zhang 2020).

Outside Kenya, sub-Saharan African governments have assigned local institutions general R&D tasks, including engineering or the development of new equipment designs (Takeshima, Hatzenbuehler, and Edeh 2020). For example, mechanization units of state-level agricultural and extension organizations in Nigeria and the National Centre for Agricultural Mechanization have been mandated to coordinate R&D. International organizations such as the United Nations Industrial Development Organization and the United Nations Economic Commission for Africa contribute to similar R&D efforts (Takeshima et al. 2020), which can potentially provide knowledge and information that individual countries like Kenya can use for their further adaptive R&D on agricultural mechanization.

In Kenya, establishment of the National Agricultural Mechanization Data Management Information System, as prescribed in the National Agricultural Mechanization Policy (Kenya, Ministry of Agriculture, Livestock, Fisheries, and Cooperatives 2021), should be pursued. In addition, the capacity to conduct cost-benefit analyses of mechanization adoption for different types of farms based on size and cropping systems, among others, should be strengthened at multiple research agencies, including the Agricultural Mechanization Research Institute, Agricultural Technology Development Centers, Kenya Marine and Fisheries Research Institute, and Kenya Forest Research Institute, all of which the National Agricultural Mechanization Policy mentions as key research agencies.

Lastly, Kenya needs to support research on how public–private partnerships can foster the development of sustainable agricultural mechanization. An understanding of the supply of and effective demand for machinery and mechanization services and how to link mechanization to output marketing services is needed. National and county research should determine what works best under prevailing conditions. This should be guided by the three "Ws": *Who* has been successful, *Where* was the success, and *What* made it successful. Government bodies like the Agricultural Finance Corporation could collaborate with private companies and banks such as Quipbank, Rentworks, and Rentco, to facilitate impact studies in the agricultural mechanization finance sector. Such studies could reduce uncertainty among these entities with regard to extending mechanization-related loans.

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