# Trends in Agricultural Mechanization in Kenya' s Maize Production Areas from 1992-2012

by
Hugo De Groote
h.degroote@cgiar.org

Cliff Marangu

Zachary M. Gitonga

International Maize and Wheat Improvement Centre (CIMMYT)
PO Box 1041-00621 Nairobi
KENYA

## Abstract

Agricultural intensification is key to feed the rapidly increasing African population. While the use of improved varieties has increased substantially over the last twenty years, the use of land-saving technologies such as fertilizer and labor-saving technologies such as mechanization has lagged behind. This study provides a literature review and analyzes the evolution of agricultural mechanization in Kenya, based on four household surveys conducted in Kenya between 1992 and 2012. The results show persistent low levels of agricultural mechanization: in 2012, most farm households still used only hand tools. More than a quarter of farmers (28%) had a plow (either for oxen or tractor), but very few (2%) a tractor. From 1992 to 2012 the percentage of farmers with oxen increased from 17% to 33%, but those with tractors decreased from 5% to 2%. Tractors were most important in the highlands, but animal traction was most important in the dry areas and moist mid-altitude zone. Adoption of tractors increased with income, acreage and age. Adoption of animal traction increased with absentee husbands, income, age, sales of maize, livestock, family size, and access to extension; it decreased with land and with fertilizer use. Mechanization in Kenya is likely to continue depending on animal traction, which is not linked to farm size and complements labor, helps to reduce fertilizer and increase commercial maize production, and has room to grow, in particular in the highlands. Agricultural extension, development projects and research should consider the options in animal traction, and provide training and research on appropriate technologies and implements in areas with sufficient land area.

***Keywords:*** mechanization, Africa, agriculture, intensification

## Introduction

Despite recent economic growth in Sub-Saharan Africa (SSA), poverty levels in the continent remain alarmingly high, especially in rural areas. Most people still live on, and from, rural land, but the population is increasing fast, while demand for food and fuel is increasing rapidly, and the increased pressure on the land has led to deforestation and land degradation in many places. To feed a rapidly growing population, agricultural intensification is therefore urgently needed.

Other continents have experienced the green revolution with dramatic increases in agricultural production as well as a reduction in food prices (Evenson & Gollin, 2003), driven by technology and structural transformation, but this has not happened in SSA. While the use of improved varieties has increased substantially, the use of other land-saving technologies (such as fertilizers and irrigation) and labor-saving technologies (mechanization) remains limited. A recent study, covering representative households surveys in six SSA countries found that only one third of the cultivating households apply inorganic fertilizer and the average unconditional nutrient application rate is 26 kg/ha (as compared to 13 kg for the whole of SSA) (Christiaensen, 2017). Based on the same surveys, another study concludes that the use of organic and chemical fertilizers is too low to maintain soil fertility (Binswanger-Mkhize & Savastano, 2017).

Many studies have covered the adoption of improved varieties (Doss, Mwangi, Verkuijl, & De Groote, 2003; Smale & Jayne, 2003) and fertilizer (Jayne, Govereh, Wanzala, & Demeke, 2003) in East and Southern Africa. The return of input subsidies generated a range of studies, documenting that their costs can be high compared to the benefits (Jayne and Rashid, 2013), that subsidies can crowd out the private sector (Xu, Burke, Jayne, & Govereh, 2009) and that they are often used for political purposes (Mason and Ricker-Gilbert, 2013)

Agricultural mechanization in Africa has not received the same attention. The topic drew much interest in the 1980s, when several influential studies, argued that African countries were not yet ready for widespread agricultural mechanization (Binswanger, 1986; Pingali, Bigot, & Binswanger, 1987). Since then, the topic has not received much scientific interest, although the Food and Agriculture Organization (FAO) is trying to revive it (FAO & UNIDO, 2008). Recent studies in Ghana did not provide support for the classic government tractor-providing service program (Diao, Cossar, Houssou, & Kolavalli, 2014; Houssou *et al*., 2013). In Burkina Faso, however, animal traction was shown to increase both labor and land productivity (Savadogo, Reardon, & Pietola, 1998). A recent study in (Baudron *et al*., 2015) argues that sustainable intensification in Eastern and Southern Africa (ESA) will require more power which could be achieved through small, multipurpose power sources such as two-wheel tractors combined with energy saving technologies such as conservation agriculture and an enabling policies, but the number of these devices imported in the region remains small. A study of the Ghana government's Agricultural Mechanization Services Enterprise Centers (AMSEC), based on interviews with service providers, indicates the model is unlikely to be a profitable business model attractive to private investors even with the current level of subsidy, because of the low tractor utilization rate (Houssou *et al*., 2013). In Nigeria, analysis of household survey data shows how current tractor use is associated with input-intensive crop production, albeit with strong regional differences between the north, where it is associated with increased nonfarm income-earning activities rather than area expansion, and the South were it is highly concentrated among medium-scale rice producers data (Takeshima, Pratt, & Diao, 2013). However, no recent studies on agricultural mechanization based on household surveys are available for ESA.

To help the discussion on the possibilities of agricultural mechanization for the intensification of agricultural production in SSA, this study provides a review of the relevant literature, followed by a quantitative evidence of the evolution of farm mechanization in Kenya over the last 20 years, based on four consecutive representative household surveys, all covering the major agricultural zones of the country.

## Methods

### Conceptual Framework

Intensification of agriculture is generally driven by an increasing population, which requires communities to produce increasing amounts of food on a fixed land area (Boserup, 1965). Technology development tends to follow the direction of the scarcest resources, a process called induced innovation (Ruttan & Hayami, 1984). Mechanization, the replacement of human labor by machinery, tends to occur therefore where land is abundant or labor is scarce, as in many settler communities such as North America, but also under the conditions of large-scale settler farms in East and Southern Africa, in particular in the first half of the 20th century. However, when the population grows rapidly, as is the current case in Africa, land becomes scarce and labor abundant. These conditions are likely to remain until a structural transformation, the movement of large groups from rural to urban settlement and employment, driven by economic development and the creation of job opportunities in the cities. Only when rural labor moves to the cities, and the economy is sufficiently strong to absorb them and pay increasing wages, will labor become scarce in rural areas.

Animal traction has some benefits other than replacing labor: draught animals provide manure to replace expensive mineral fertilizer, and provide transport of inputs and produce within the farm and to and from local market centers. It reduces drudgery and offers an increase in agricultural production above family needs.

### Empirical Framework

This paper uses data from four household surveys conducted in Kenya over the last 20 years. We first analyze the use of farm implements in the last survey (2012), and their geographical distribution. Because of the different definitions of variables in different surveys, for analyzing the evolution of mechanization we charted the proportion of farmers who adopted tractors, plows and oxen over time, by agro-ecological zone. In our analysis, adoption of these implements was limited to their ownership, as data on rent or lease of the implements were not available. Only four-wheel tractors were considered, as no data on two-wheel tractors, a recent introduction in the country, were available. Plows for use with oxen as well as those for tractors were included, although the data did not distinguish between the two.

Finally, we use a logistic regression to analyze the factors that affect the adoption of mechanization. In the logistic model, the dependent variable is binary, in this case the adoption (yes or no) of one of the mechanization implements. Formally, the model specifies that the log-odds of the probability of adoption is a linear combination of independent or predictor variables.

In our model, the predictor variables include characteristics of the household head (age, education, and gender) and of the household (available land, labor and livestock), and access to markets and rural services (in particular access to extension and to microcredit).

**Data Sources**

The data were collected during rural household surveys conducted in Kenya over the last twenty years (1992, 2002, 2010, and 2012). The first three surveys were cross-sectional, while for the last survey the households of the previous one were revisited, with a rotation of 20% of the sample. All surveys were representative of the major maize-growing areas of the country, and used a stratified two-stage design, with agro-ecological zones as strata, sub-locations as primary sampling units, and households as the second stage. Each survey covered more than 1,300 households (**Table 1**, **Fig. 1**).

The first survey was conducted in 1992 by the International Maize and Wheat Improvement Centre (CIMMYT) and the Kenya Agricultural Research Institute (KARI) in the major maize agro-ecological zones of Kenya (Hassan, Lynam, & Okoth, 1998). The study redefined these zones into six major agro-ecological zones for maize production (**Fig. 1**). From the coast moving inland, the lowland tropics can be distinguished, followed by the dry mid-altitudes and the dry transitional zones. These three zones are characterized by low yields, below 1.5 tonnes per ha (t/ha). Although these zones cover 29% of Kenya's maize area, their maize production is only 11% of the country's total production. Central and western Kenya is dominated by the highland tropics (HT), bordered at the west and east by the moist transitional (MT) zone (transitional between mid-altitudes and highlands). These zones have high yields (more than 2.5 t/ha) and produce roughly 80% of Kenya's maize on 30% of Kenya's maize area.

The first survey was conducted in 1992 and covered 79 enumeration clusters, randomly selected from the sampling frame of the Central Bureau of Statistics, with 1407 farmers (Hassan *et al.*, 1998). The second survey, conducted in 2002, covered 185 sub-locations, randomly selected from the 1999 census report (CBS, 2001), and 1800 farmers (**Table 1**).

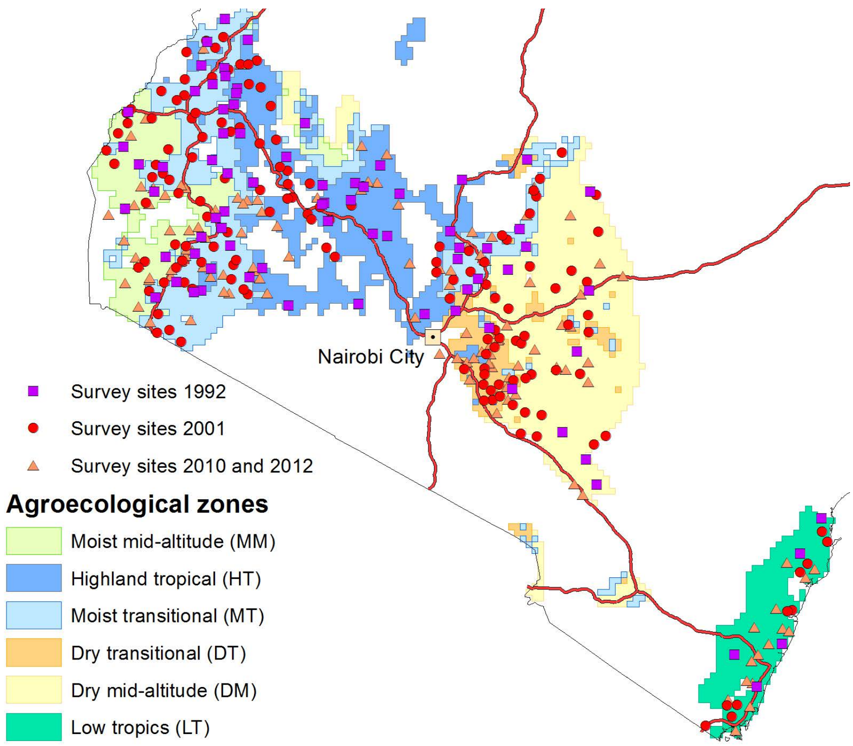


**Fig. 1** Map of primary sample units of the consecutive household surveys

**Table 1** Sampling design of the four surveys

| | 1992 | | | 2002 | | | 2010 | | | 2012 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Agro-ecological zone | PSUs | HH/ PSU | HH | PSUs | HH/ PSU | HH | PSUs | HH/ PSU | HH | PSUs | HH/ PSU | HH |
| Low tropics | 5 | 20 | 100 | 20 | 15 | 300 | 15 | 6 | 90 | 15 | 6 | 90 |
| Dry mid-altitude | 10 | 18 | 181 | 25 | 8 | 200 | 18 | 12 | 217 | 18 | 12 | 216 |
| Dry transitional | 4 | 20 | 80 | 20 | 5 | 100 | 17 | 12 | 203 | 17 | 12 | 204 |
| Moist mid-altitude | 9 | 20 | 183 | 25 | 10 | 250 | 20 | 12 | 240 | 20 | 12 | 240 |
| Moist transitional | 23 | 18 | 412 | 55 | 10 | 550 | 30 | 12 | 354 | 30 | 12 | 354 |
| High tropics | 28 | 16 | 451 | 40 | 10 | 400 | 20 | 12 | 240 | 20 | 12 | 240 |
| Total | 79 | | 1,407 | 185 | | 1,800 | 120 | | 1,344 | 120 | | 1,344 |

HH = number of households in the survey, PSU = primary sampling unit (clusters in 1992, sub-locations in the other years)

The third survey (2010) covered 120 sub-locations, with 1344 farmers. The fourth survey (2012), revisited the same sub-locations of the 2010 survey, and the same households except for a replacement of 20% of the households, randomly selected. This survey therefore had the same number of sub-locations (120) and the same number of households (1,344) as the previous survey.

## Background

**History of Mechanization in Africa**

Agricultural mechanization is the application of mechanical technology and increased power in agriculture, to enhance the productivity of human labor and other forms of capital to achieve results well beyond the capacity of human labor. Mechanization includes the use of tractors as well as animal- and human-powered implements and tools, and internal combustion engines, electric motors, wind energy, solar power and other methods of energy conversion. (FAO & UNIDO, 2008).

Agricultural engineering and mechanization were key enablers for the rise of large-scale industrial agriculture, historically delivering the step changes in productivity per unit of manpower which allowed countries to transform from agriculture to industry-based economies (Beddington, 2010). A fundamental scientific approach in crop science, supported by technology development for mechanization, has made it possible to considerably increase cropping intensities in the major crops of the world (Brussaard *et al*., 2010). Mechanization increases productivity per unit of man power, but it also improves timing, in particular for timely planting, weeding, harvesting, and pest control (Kislev & Peterson, 1981).

Most African countries have economies strongly dominated by the agricultural sector. Agriculture generates up to 50% of the gross domestic product (GDP), contributing more than 80% of trade in value and over half of the raw materials to industries (FAO & UNIDO, 2008). It provides employment for the majority of Africa's people. Despite these contributions, planning for sustainable agricultural mechanization is limited. In many cases where mechanization made a positive contribution to agricultural development, it has been a question of luck, not by credible project or program design (Rijk, 1989).

In spite of the contribution of agriculture to the economy of sub-Saharan Africa over time, there has been a significant decline in mechanization, or at least in the use of tractors and tractor hire services for farming, even among the countries that were the early trendsetters in mechanization, such as Kenya and Zimbabwe. Tractor use in sub-Saharan Africa was at 1.9 per 1000 ha of cultivated land in 1986 and has gradually declined to 1.3 tractors per 1,000 ha in 2002, compared to 9.1 tractors/1,000 ha in South Asia and 10.4 tractors/1,000 ha in Latin America for the same year (Pingali, 2007).

The process of mechanization has progressed from the most elementary devices such as levers to today's sophisticated machines. Throughout this progress, however, the constant purpose has been to supplement or complement human work efforts (Binswanger, 1986). For instance, farmers who embrace mechanization increase the power input to farm activities, they reduce toil in farming, thus making their farm work more attractive; they accomplish tasks that are difficult to perform without mechanical aids, improve the efficiency and timeliness in farm activities, and improve the quality and value of work and the end products, among others (Sims & Kienzle, 2006).

The use of animal traction in Africa started around 6000 BC, as shown in depictions of oxen and plows in Egypt and early Mesopotamian civilizations, some of the earliest records in the world. In North Africa and Ethiopia, animal traction has been a core part of farming and transportation for over 2,000 years. In South Africa, European travelers observed the Khoi-Khoi riding cattle and used them as pack animals in the fifteenth century (Joubert, 1995). In West Africa, the use of horses, donkeys and camels for riding has been popular for centuries, especially in the semi-arid areas (Starkey, 2000). However, in many sub-Saharan countries, especially in the east and the south, manual labor is still the main source of power in agriculture, and draught animals are a relatively recent introduction (Lawrence & Pearson, 2002).

However, animal traction in SSA, apart from Ethiopia, was only introduced during colonial times (Starkey, 2000), and manual labor remains the main source of power in agriculture. It has been argued that an increasing population and increased food demand asks for a more effective use of mechanization, and probably an increase, in particular for draught animals, especially in areas where tractors are not appropriate (O'Neill & Kemp, 1989). Animal power has a potential to enhance farmers' ability to use renewable practices such as manure, crop rotation, ridging and other renewable practices. They allow the cultivation of larger areas, and increase household production, food security, and the likelihood of a marketable surplus (Bishop-Sambrook, 2005).

In the late 1990s, 65% of the cultivated area in SSA was prepared by hand, 25% by draught animals and 10% by tractors (FAO & UNIDO, 2008). In Kenya, the main draught animals are oxen and donkeys, which are well-distributed throughout the country. Tractors were only introduced shortly after World War II and, in the first two decades after independence, the government promoted motorized mechanization through state-sponsored tractor-hire and -credit schemes, to increase crop production (Guthiga, Karugia, & Nyikal, 2007).

The adoption of tractors in SSA went through roughly three phases over the period between 1945 and 1981. These phases were significant in increasing the number of tractors in use, with intermediate periods of slow growth (Pingali, 2007). In the first phase (1945-1955), the use of tractors was promoted in several countries under their colonial regimes, including Zimbabwe, Kenya, Zambia and Malawi. These can be labeled the first generation of tractor users, and adoption spread from settler farms to farms owned by Africans. In the second phase, between 1958 and 1970, mechanization was sponsored by newly-independent countries such as Tanzania, Ethiopia, Ghana, and Cote d'Ivoire. In many of these countries, tractors were provided through cooperative, state farms or tractor-hire services. In the third phase (1970-1980), exporters of oil and other resources, such as Nigeria, Cameroon and the Democratic Republic of Congo tried to re-distribute the export profits to rural areas. Tractors were provided to farmers through either subsidized credit schemes or state-sponsored hire schemes (Pingali, 2007).

The adoption levels of tractors declined after 1981, however. The collapse of the government-sponsored tractor-hire services was mainly attributed to poor performance, lack of infrastructure and poor management of the schemes. The area cultivated per machine were small and fixed costs were high, while lack of technical know-how and spare parts resulted in poor maintenance and expensive and lengthy repairs (Bishop-Sambrook, 2005). Further, most farmers could not afford tractors, and organization of cooperatives or farmer groups to access credit and obtain tractors was rare (Lamidi & Akande, 2013).

It has been argued that tractors could have a negative impact on employment in the agricultural sector and would therefore not be suitable to densely-populated areas with labor surpluses, especially in SSA, although unemployment also depends on many other factors, in particular the policy environment (Pingali, 2007). Loss of employment was most pronounced under inappropriate mechanization policies in areas where it was not needed. In many countries, government tractor services collapsed after externally-funded projects ended (Pingali, 2007). After the collapse of tractor projects, more attention was given to drought-animal power as a more sustainable option. In Kenya, such a program was established in 1970, covering the selection and training of draught animals, farmer training and development of specialized equipment (Onyango, 1990). However, efforts to accelerate the use of mechanization produced mixed results. Compared to other regions, Africa did not have large-scale investments in agricultural infrastructure, such as irrigation and other inputs needed for intensification (FAO & UNIDO, 2008). Further, past agricultural mechanization efforts in developing countries have been criticized because of ineffective programs, and for increasing rural unemployment and causing other adverse social effects (Rijk, 1989). For maize production in East Africa, the promotion of mechanization projects only saw limited success in Kenya, but not in Tanzania (Anthony, 1988).

In Ghana, demand for mechanized farming operations, particularly plowing, has emerged even among smallholders, suggesting that supply issues may now be the main constraint to successful mechanization (Diao *et al*., 2014). However, the agricultural mechanization service centers that the government promotes fail to use tractors services with sufficient intensity, and direct importation of agricultural machinery by the government inhibits the importation of more appropriate and affordable machinery by the private sector for its use in a hiring-out services. The government's service centers are not a profitable business model attractive to private investors, even with the current level of subsidy (Houssou *et al*., 2013).

Not all mechanization schemes in Africa failed; some were successful, particularly in combination with irrigation. The Gezira Scheme in Sudan dates back to 1924 and by the 1970s, 100,000 tenant farmers were cropping 760,000 ha with the assistance of mechanized cultivation services (FAO & UNIDO, 2008). In Tanzania, tractors were successfully introduced in the Morogoro region and single axe tractors in the Mbarali district (Shetto, 2007). In West Africa, animal traction was successfully introduced in the cotton production areas, and spread rapidly in the 1980s and 1990s (Blench, 2015; Tefft, 2010). In Burkina Faso, animal traction was found to greatly improved labor productivity, but also land productivity, in particular for cash crops (maize and cotton) (Savadogo *et al*., 1998).

Still, mechanization on smallholder farms in SSA remains limited, and grain milling is often the only fully mechanized operation (Kienzle, Ashburner, & Sims, 2013). Examples of areas where animal power is used for milling are Somalia and Chad (Starkey, 2000), but in most countries diesel-powered mills are common. Mechanization is also increasingly adopted for irrigation, mostly with relatively low-cost small motor pumps (Kienzle *et al*., 2013) and sometimes with animals, as in Egypt (Starkey, 2000). The success of mills and pumps is their relatively low cost and easy maintenance (Kienzle *et al*., 2013). Smallholders also use animal power for threshing cereals, as in Tunisia and in Ethiopia (Starkey, 2000).

Large scale farming, in contrast,

has seen higher levels of mechanization at all stages of production. For example, irrigation schemes in Sudan (the Gezira scheme) are highly mechanized. Similarly, in sugar cane production Kenya and Tanzania, land preparation, cane loading, and cane transport to the factory are largely mechanized (Kienzle *et al*., 2013). Another example is wheat farming in Kenya, with tractors for cultivation and planting, spraying equipment, and combine harvesters, mostly by large-scale farmers with their own machinery (Longmire & Lugogo, 1989). Small-scale wheat farmers do not own machinery and have to hire contractors or use manual labor (van Eijnatten, 1976).

**Recommendations from the literature**

This literature review indicates that both the government and the private sectors have clear, but distinct, roles to play in sustainable mechanization. The role of the government lies in education and training, in the creation and funding of relevant research institutions, and the dissemination of information on mechanization (FAO & UNIDO, 2008; Mrema, Baker, & Kahan, 2008; Zewdie, Wallace, & Kic, 2015). Further, governments should facilitate trade relationships with new suppliers of technology and equipment and help in maintaining standards (FAO & UNIDO, 2008).

The private sector, on the other hand, is better equipped to regularly provide farm inputs including farm machinery and its support services. Once economic conditions have evolved to create an effective demand for machinery, private firms respond rapidly (Binswanger, 1986). Decisions on which operations to be performed, which prices to be charged, and so on, are better made by the private sector than by the government. The private sector has clear incentives for the mechanization of agriculture: more mechanization implies a higher demand for their services and result in higher revenues (Pingali *et al*., 1987). Government can help the private sector by developing and supporting the market for hiring-out, for example by the development of mechanized service hiring market through medium and large scale tractor-owning farmers as in Ghana, but the direct importation of agricultural machinery by the government inhibits imports of appropriate and affordable machinery (Diao *et al*., 2014).

The economic costs of using tractors, animals or human labor is determined by the relative costs of labor and capital, the interest rate, the utilization of capacity, the farm size, the availability of fodder, the comparative maintenance costs of animals and tractors, and the difficulty of obtaining spare parts, fuel, and repair services for the tractors or veterinary services for the animals (Pingali *et al*., 1987). Therefore, farmers need to calculate and compare the costs and benefits of alternative options and find those best suited to their needs. However, draught animal power, tractor power and human power should be taken as complimentary sources of power for agriculture production and not as mutually exclusive ones. In Burkina Faso, for example, of-farm income was a major factor that allowed farmers to invest in animal traction (Savadogo *et al*., 1998).

The development and modernization of Africa's agriculture needs appropriate agricultural policies, and agricultural mechanization policy needs to be placed within an overall agricultural growth strategy (Pingali, 2007). It is imperative for African leaders and policy makers to understand the importance of mechanization for Africa's future. There should be concerted efforts by all stakeholders to accelerate the rate of adoption of mechanization by farmers in sub-Saharan Africa, whether through drought animals or tractors. These efforts to accelerate mechanization will require substantial long-term political and financial commitments, which ought to address the biting problems in the agriculture sector and help to improve the prospects for African agriculture and farmers (Mrema *et al*., 2008). In the meantime, it is important to look at available information to guide policies, as we do in the next section.

## Results

**Farm Implements Currently Used**

The proportion of farmers who used different implements in 2012 reveals the very limited extent of agricultural mechanization in Kenya (**Fig. 2**). Most farm implements used were hand tools, and most households owned at least some pangas (machetes), hoes, axes, spades or shovels. More than half of the households owned a fork hoe or a slasher. The most popular mechanical device was the bicycle, owned by almost half of the households (48%). The most popular modern farm implements were the knapsack sprayer (owned by 46% of respondents) and the wheelbarrow (45%). As to mechanization, more than a quarter of farmers owned an ox-plow (28%), but few had an oxen or donkey cart (8%), and even fewer had a push cart (2%). Tractors were rare, owned by 2% of the farmers in the survey owning them.

Devices to generate electricity were more popular than tractors: 17% of respondents had solar panels and 6% had a generator. For transport, apart from the bicycle, only a few farmers owned vehicles and a few households had a motorbike (10%) or a car (5%).

**Evolution of Agricultural Mechanization**

Plotting the evolution of agricultural mechanization in Kenya over the last 20 years shows how the levels of adoption were never high (**Fig. 3**). Oxen were introduced by European and South African settlers in the early 20th century, who switched to tractors over time. After independence, the large settler farms and their equipment were purchased by African farmers and the upcoming elite (Jones, 1965). The latter, however, never had many tractors, and tractor use has been decreasing. In 1992, only 4% of farmers owned tractors, and in 2012 less than 2%. During this period, there were many more farmers with plows than with tractors, and their number has been steadily increasing, from 12% to 28%. Similarly, the proportion of farmers owning oxen increased steadily from 17% to 33%. There was a dip in oxen ownership in the third survey, in 2010, likely because of a serious drought just before the year of the survey.

Plotting the results separately for each year and by zone shows the large differences in mechanization levels, both for tractors and animal traction, between the agroecological zones (**Fig. 4**). The relative importance of tractors and animal traction over the different zones did not change over the years. Tractors have always been most important in the highlands, while oxen and oxen plows were more popular in the dry mid-altitudes and, to a lesser extent, the moist mid-altitudes. Most tractors were found in the highlands, with only a few in other zones, likely influenced by its colonial his-

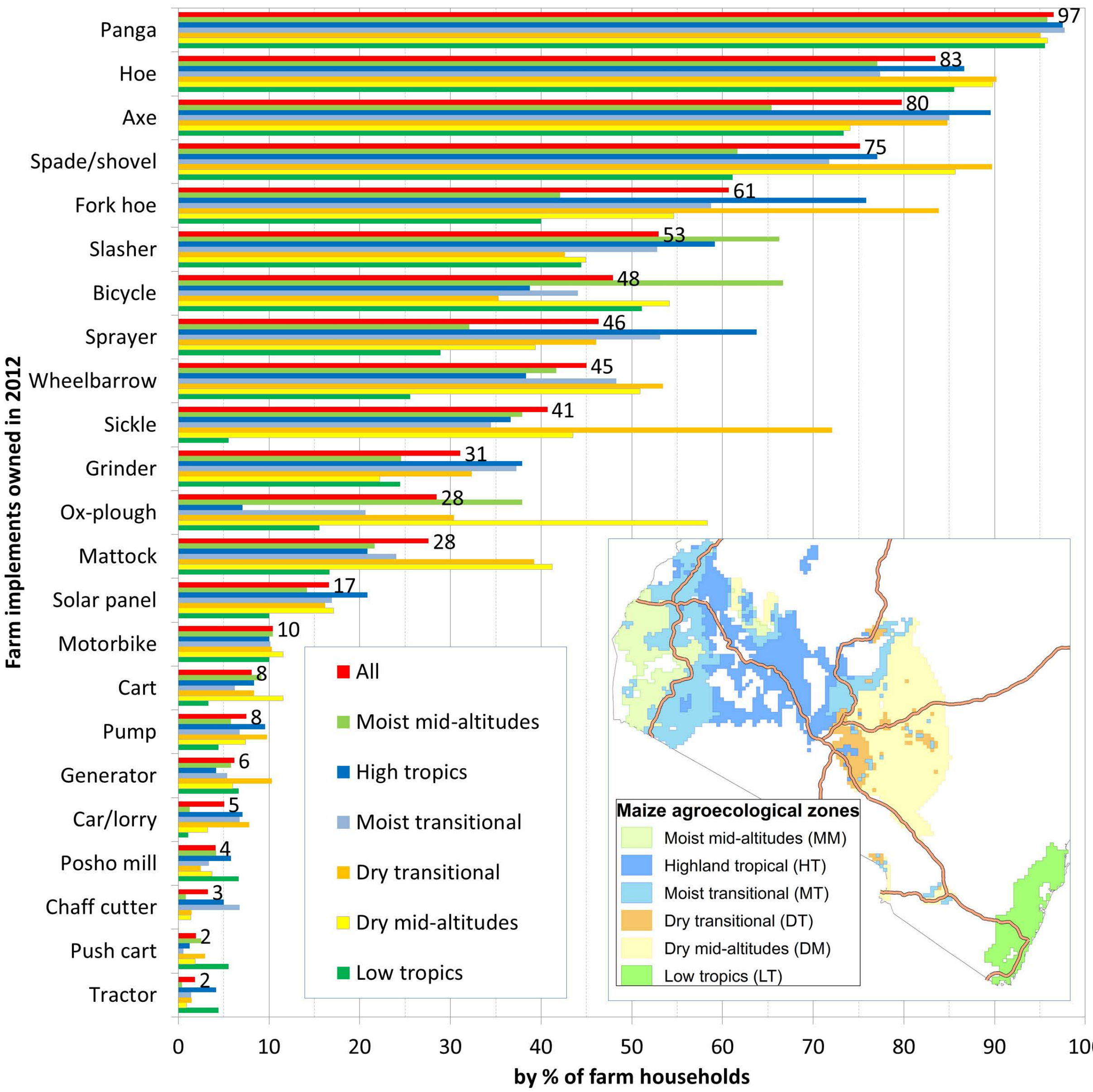


**Fig. 2** Farm implements used, by agro-ecological zone (farm households of 2014)

tory of large-scale, capital intensive farms. Only in the last survey did tractors show up in the coastal lowlands. Likely, the presence of tractors in the highlands is influenced by colonial history, which favored large-scale, capital intensive and commercial farming. Ownership of plows is, understandably, strongly correlated to ownership of oxen. Especially in the dry zones, many farmers have oxen and plows. The popularity of oxen in the dry areas likely is affected by the lower population density, so farms have larger land areas for both farming and pasture and have more cattle from which to draw oxen. Similarly, farmers in the moist mid-altitudes tend to have more cattle, which affect the adoption of animal traction. The high tropics, on the other hand, have the lowest levels of animal traction, despite its high potential and large available land areas. This might be affected by its history tractors and the resulting presence of tractors for hire. Also, the highlands tend to have only one long rainy season, so plowing is only needed once a year, as compared to the other zones which tend to have two rainy seasons and therefore, need to prepare land and plow twice a year.

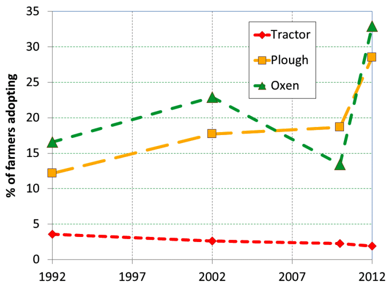


**Fig. 3** Evolution of farm mechanization from 1992 to 2012

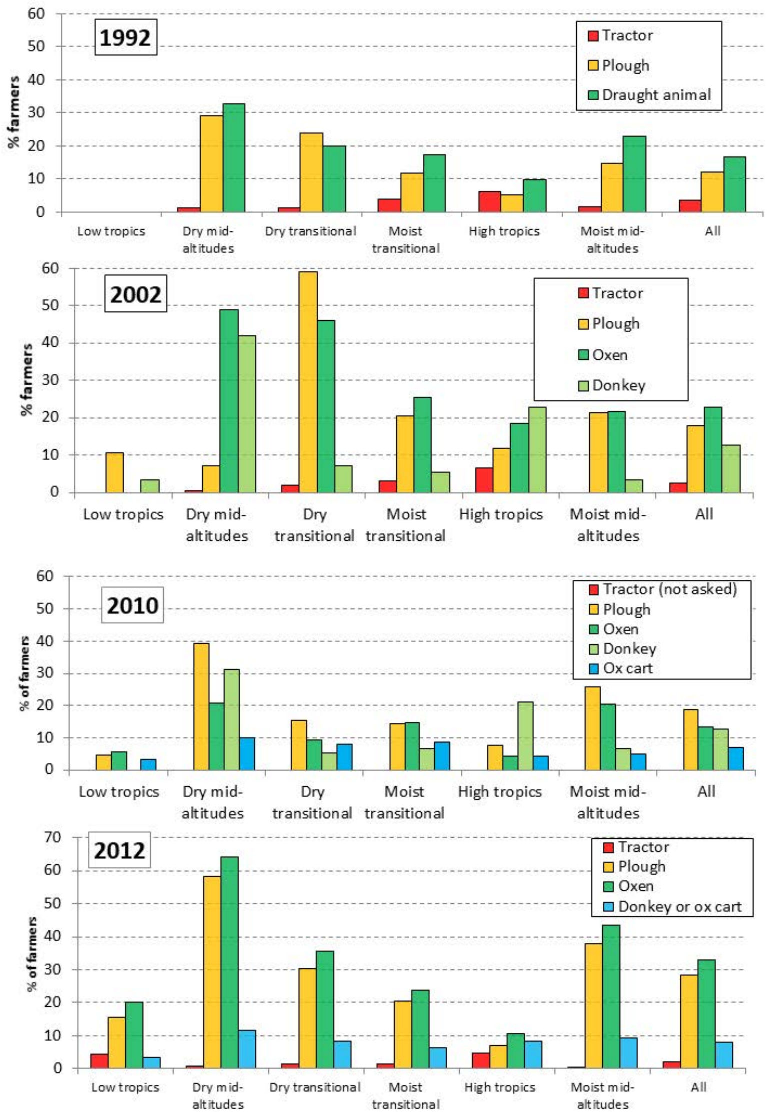


**Fig. 4** Evolution of farm mechanization from 1992 to 2012, by agro-ecological zone and year

The analysis shows that few farmers owned carts, for donkeys or oxen: 12% in the dry mid-altitudes and less than 10% in all other zones. The proportion of farmers with carts did not increase much over the years.

Plotting the evolution for the different implements for each zone shows the similarity of the trajectories in the different zones (**Fig. 5**). With few exceptions, the proportion of farmers who own tractors has been declining, while the proportion of those with oxen and plows has been increasing. One exception is the coast, where several farmers obtained tractors between the last two surveys. Another exception is the reduction in the proportion of farmers with oxen or plows in the dry transitional zone: there was a strong increase in 2001, but was followed by a decrease in 2010, and then finally an increase up to the last survey.

### Factors Affecting the Adoption of Farm Mechanization

A logistic model was estimated to analyze which factors affection the adoption of agricultural mechanization. Three different dependent variables were used for the analysis: ownership of tractors, trained oxen or plow (for either tractor or oxen), all expressed as binary variables (yes = 1, no = 0). The results show that the model for tractors was very different from that for oxen and plows, which had similar results. Only two factors significantly affected both the tractor and the oxen/

plow models: ownership of both implements increased with the age of the household head and with household income. Total available land per household affected ownership of both tractor and oxen but in different ways: it increased the likelihood of owning tractors, but decreased ownership of trained oxen. Similarly, the agroecological zones mattered, but where farmers in the highlands had more tractors and fewer oxen, those in the dry and moist transitional zones had more oxen and fewer tractors.

Clearly, the adoption of tractors and of oxen and plows follows different mechanisms. The adoption of tractors is affected by age: older farmers are more likely to have tractors. This is consistent with a decline in tractor ownership over time. Further, tractor ownership increased with available land and capital, which is also understandable: tractors need sufficient land to justify their use and require a substantial amount of capital. After taking into account those factors, there are still regional differences: the high tropics, as well as the low tropics, have significantly higher proportions of farmers with tractors than the other zones. The higher adoption of tractors in the highlands clearly originates in its colonial history

Ownership of oxen was affected by household composition. Households with absentee- husbands were more likely to have oxen. This might be because of remittances from the husband or because the household is short of labor, although both arguments are problematic: income does not increase the probability of owning oxen, while available labor reduces this probability. The latter indicates that oxen power compliments labor rather than substitutes for it. Further, the number of tropical livestock units owned increased the probability of adopting oxen and plows. Likely it helps to own more cattle, from which oxen can be pulled. More land, on the other hand, decreases the probability of having oxen, but does not affect plows. This is counterintuitive; we would have expected larger farms to be more likely to own oxen.

The number of extension contacts is an important factor in the adoption of mechanization: an increase in one extension contact over the last year increases the probability of owning oxen or plows by 1%. Land ownership (in % of land owned) does not seem to make a difference. The use of fertilizer, or at least top dressing, is negatively correlated with the adoption of animal traction: likely when a household has oxen there is less need for fertilizer. Marketing of maize, on the other hand, increases the adoption of animal traction, indicating commercially-oriented farmers are more likely to invest in animal traction. After taking into account the above factors, the zones are still important factors in the adoption of animal traction.

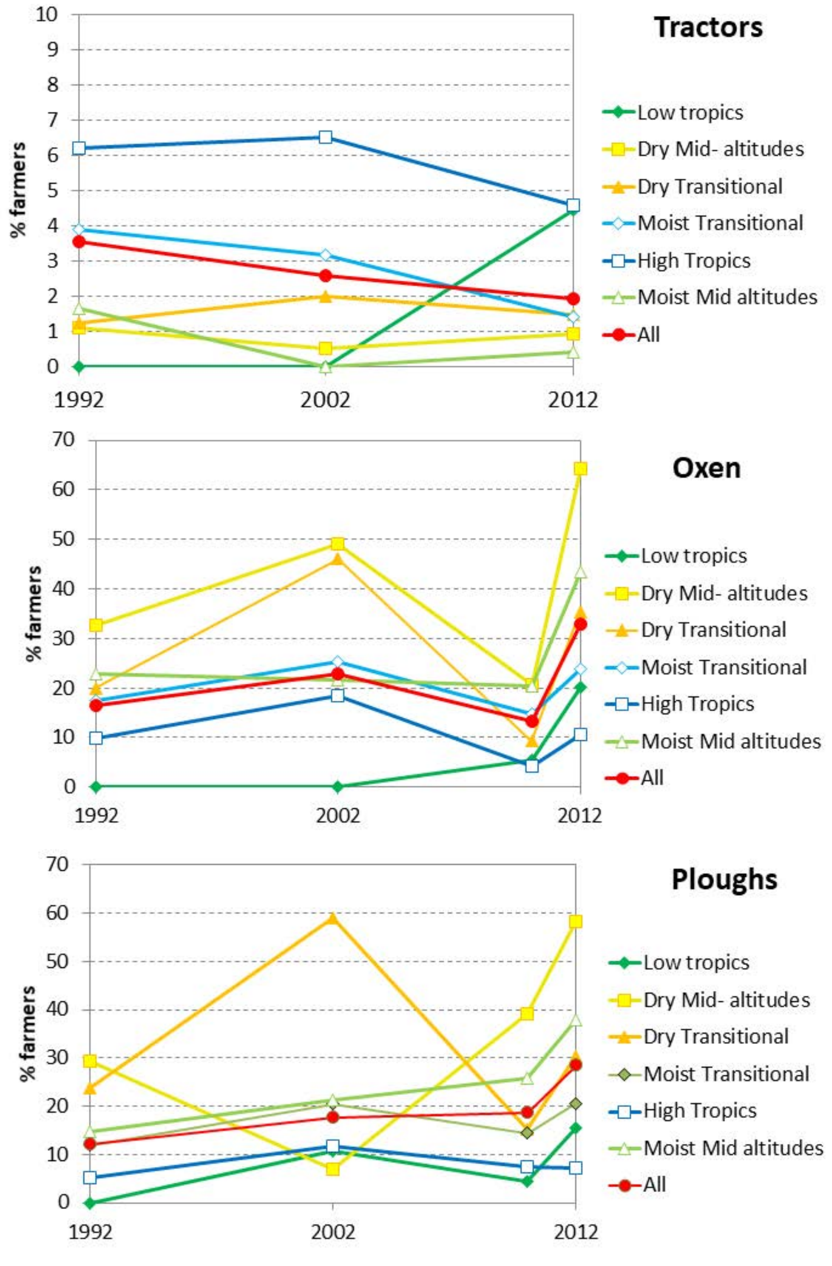


**Fig. 5** Evolution of farm mechanization from 1992 to 2012, by year and by agro-ecological zone

The drylands and the moist mid-altitudes have higher adoption levels than the low tropics (the base), likely because they have more cattle and less people. The high tropics have lower levels of animal traction, likely because of its historic use of tractors (**Table 2**).

## Conclusions

This study documents the low levels of agricultural mechanization in Kenya. In 2012, most farmers used only hand tools, and slightly less than half owned a bicycle, a knapsack sprayer or a wheelbarrow. Slightly more than a quarter of farmers (28%) owned a plow, and very few (2%) owned a tractor. None of the interviewed farmers owned two-wheel tractors. From 1992 to 2012, the proportion of farmers with trained oxen increased from 17% to 33%, while the proportion of those with tractors decreased from 5% to 2%. Tractors were most important in the highlands, while animal traction was more popular in the dry areas and moist mid-altitudes (around Lake Victoria). Relative differences between zones have remained over the years, and all zones have followed the same trend of increased animal traction and decreased adoption of tractors. Adoption of tractors and animal traction follow distinctly different models, as expressed by the different factors affecting them. Adoption of tractors increased with household income, acreage and age of the household head. The adoption of animal traction, on the other hand, increases with income and age of the household head, but decreases with land area. Further, adoption of animal traction is higher in households where the husband is away, and increases with sales of maize, livestock, family size, and access to extension. Finally, adoption of animal traction is negatively correlated with the top dressing of fertilizer.

The four different household surveys over the last 20 years offered good insights into the evolution of agricultural mechanization in the different zones, despite the first three surveys having independent cross-sectional designs. It remained a problem that different surveys use different tools and definitions for

**Table 2** Factors affecting the adoption of farm mechanization (farm household survey of 2012)

| | | Tractor | | Trained oxen | | Ox plow | |
|---|---|---|---|---|---|---|---|
| Dependent variables | | Coef. | Std. Err. P > z | Coef. | Std. Err. P > z | Coef. | Std. Err. P > z |
| Head | Constant | -7.29 | 1.98 *** | -4.55 | 0.83 *** | -4.21 | 0.74 *** |
| | Age of household head (years) | 0.04 | 0.02 * | 0.00 | 0.01 | 0.02 | 0.01 *** |
| | Household head is male | -0.37 | 1.05 | 0.54 | 0.45 | -0.25 | 0.39 |
| | Head education (years) | 0.04 | 0.04 | 0.01 | 0.02 | 0.03 | 0.02 * |
| Marital status | Married but spouse away | 0.59 | 0.91 | 0.88 | 0.32 *** | 0.45 | 0.30 |
| | Divorced/separated | 0.00 | (empty) | 0.18 | 0.80 | -1.00 | 0.78 |
| | Widow/widower | 0.38 | 1.06 | 0.50 | 0.46 | -0.34 | 0.41 |
| Household | Adult equivalent | 0.14 | 0.09 | 0.15 | 0.04 *** | 0.15 | 0.04 *** |
| | Tropical livestock units | 0.00 | 0.02 | 0.16 | 0.02 *** | 0.11 | 0.02 *** |
| | Total land (acres) | 0.03 | 0.01 ** | -0.02 | 0.01 *** | 0.00 | 0.01 |
| | Number of extension contacts | 0.00 | 0.01 | 0.01 | 0.00 *** | 0.01 | 0.00 *** |
| | Total income (KES) | 0.81 | 0.33 ** | -2.18 | 0.48 *** | -1.41 | -2.18 *** |
| | % land owned | 0.56 | 1.01 | 0.34 | 0.40 | 0.53 | 0.35 |
| | planting fertilizer (1 = Yes; 0 = No) | 0.16 | 0.73 | 0.10 | 0.25 | 0.10 | 0.22 |
| | Topdressing fertilizer (0 = No; 1 = Yes) | 0.98 | 0.68 | -0.70 | 0.24 *** | -0.56 | 0.21 *** |
| Agro-ecological | Dry mid-altitude | -1.95 | 0.97 ** | 1.58 | 0.46 *** | 2.19 | 0.39 *** |
| | Dry transitional | -2.25 | 1.01 ** | 0.80 | 0.49 | 1.11 | 0.41 *** |
| | Moist transitional | -2.51 | 0.89 *** | 0.34 | 0.47 | 0.40 | 0.40 |
| | High tropics | -1.07 | 0.76 | -1.69 | 0.58 *** | -1.75 | 0.51 *** |
| | Moist mid-altitudes | -2.54 | 1.17 ** | 1.07 | 0.46 ** | 0.90 | 0.39 ** |
| Marketing | Distance to main market (km) | 0.02 | 0.02 | 0.00 | 0.01 | -0.01 | 0.01 |
| | Percent of own maize sold | 1.03 | 0.80 | 1.64 | 0.32 *** | 1.51 | 0.29 *** |
| Model | Number of observations | 1,111.00 | | 1,128.00 | | 1,128.00 | |
| | Pseudo R2 | 0.26 | | 0.26 | | 0.24 | |
| | Log likelihood | -80.48 | | -427.58 | | -512.80 | |

data collections. The experience gained with this analysis, however, shows how future surveys can be improved by harmonizing the variables. In particular, a distinction should be made between ownership of, access to and use (through ownership or rental services) of the different farm implements and draught animals involved in agricultural mechanization. Further, within the different implements a distinction should be made between oxen and tractor plows, and between different cart types (oxen, donkey or hand carts). Ownership and use of weeding implements, to be used with draught animals, and shelling equipment should be included. A distinction should be made between oxen for fattening and oxen trained for draught, and ownership of donkeys should be included.

Further, household surveys typically ask about farm implements and draught animals, which ignores other types of mechanization. For example, most households have moved from manual to mechanical milling, but mills are typically owned by a few small businesses located in towns and market places, but do not frequently show up in rural household surveys (only 4% of those owned mills in 2012). The presence of such services (and also electricity and irrigation) would be easier to observe through community surveys, while their use would be best observed through household surveys.

Our results show that agricultural mechanization is only slowly making progress in Kenya, but through animal traction rather than tractors, and this trend is likely to continue. Promoting tractors does not seem advisable, at least not ownership by maize farmers. Tractors are expensive and fuel prices are steadily increasing. Further, the population in Kenya is growing rapidly and most of the population is still living in rural areas, reducing the availability of agricultural land per person and therefore farm size, and suppressing rural wages. As a result, the proportion of farmers owning tractors is decreasing and is likely to decrease further. Tractor rental services, on the other hand, might provide access to mechanization without requiring tractor purchase, but our data did not include information on this. While two-wheel tractors are substantially cheaper than four-wheel tractors, no farmers in the survey owned or used any. The arguments against them are similar to those against four-wheel tractors, so their profitability needs to be carefully assessed and compared to animal traction and manual labor. Again, hiring services might provide a solution and should be considered for further study.

These results from Kenya align with the conclusions of earlier studies (Pingali *et al.*, 1987) that the farming systems in Africa have not yet reached the intensification levels suitable for investment in tractors. Similarly, they conform the results from West Africa (Blench, 2015) that the farming systems, or at least some of them, are more suited for animal traction. Despite the increased interest by farmers, animal traction has been receiving little attention from rural development projects and extension agencies. In our analysis, animal traction is not linked to farm size; it does not reduce labor but rather complements it; it helps reduce the use of chemical fertilizer and helps to engage in commercial maize production. Moreover, there is still a large potential for expanding animal traction, particularly in the highlands. While tractors were popular in this zone, likely for historical reasons, animal traction should be given more attention: large land areas are still available, for both crop production and pasture, the population density is low and commercial maize production is important. Contact with extension increases the probability of adoption, so continued training of trainers, and research and dissemination of locally adapted implements should be encouraged. Animal traction is not indicated, however, in areas with high population density, low land areas per household and low availability of pasture, which would include most of the moist transitional zone.

It was concluded that despite the seemingly more advanced nature and attractiveness of tractors for rural development, the future of agricultural mechanization in Kenya lies in the promotion of animal traction, at least in the short- to medium-term, and in areas with sufficient land area.

## Acknowledgments

The authors acknowledge the sponsors of the surveys: USAID, the Syngenta Foundation of Sustainable Agriculture, and the Bill and Melinda Gates Foundation. We thank the enumerators for their effort in data collection, the farmers for answering our questions, Frédéric Baudron for his useful suggestions, and Kathleen Sinclair for editing the manuscript.

## REFERENCES

Anthony, C. G. 1988. Mechanization and maize: Agriculture and the politics of technology transfer in East Africa. New York: Columbia University Press.

Baudron, F., B. Sims, S. Justice, D. Kahan, R. Rose, S. Mkomwa. B. Gérard. 2015. Re-examining appropriate mechanization in Eastern and Southern Africa: two-wheel tractors, conservation agriculture, and private sector involvement. Food Security, 7(4), 889-904. doi: 10.1007/s12571-015-0476-3

Beddington, J. 2010. Food security: contributions from science to a new and greener revolution.

Philosophical Transactions of the Royal Society B: Biological Sciences, 365(1537), 61-71. doi: 10.1098/rstb.2009.0201
Binswanger-Mkhize, H. P., and S. Savastano. 2017. Agricultural intensification: the status in six African countries. Food Policy, 67, 26-40.
Binswanger, H. 1986. Agricultural Mechanization. A Comparative Historical Perspective. The World Bank Research Observer, 1(1), 27-56.
Bishop-Sambrook, C. (2005). Contribution of farm power to smallholder livelihoods in sub-Saharan Africa. Agricultural and Food Engineering Technical Report No. 2. Rome: FAO.
Blench, R. 2015. A history of animal traction in Africa: origins and modern trends. Cambridge: Kay Williamson Educational Foundation.
Boserup, E. 1965. The conditions of agricultural growth: The economics of agrarian change under population pressure: Transaction Publishers.
Brussaard, L., P. Caron, B. Campbell, L. Lipper, S. Mainka, R. Rabbinge, and M. Pulleman. 2010. Reconciling biodiversity conservation and food security: scientific challenges for a new agriculture. Current Opinion in Environmental Sustainability, 2(1-2), 34-42. doi: http://dx.doi.org/10.1016/j.cosust.2010.03.007
CBS. 2001. 1999 Population and Housing Census. Volume 1. Population Distribution by Administrative Areas and Urban Centres. Nairobi, Kenya: Central Bureau of Statistics (CBS), Ministry of Planning and National Development.
Christiaensen, L. 2017. Agriculture in Africa—Telling myths from facts: A synthesis: Elsevier.
Diao, X., F. Cossar, N. Houssou, and S. Kolavalli. 2014. Mechanization in Ghana: Emerging demand, and the search for alternative supply models. Food Policy, 48, 168-181. doi: http://dx.doi.org/10.1016/j.foodpol.2014.05.013
Doss, C., W. Mwangi, H. Verkuijl, and H. De Groote. 2003. Adoption of Maize and Wheat technologies in East Africa: Synthesis of the Findings of 22 Case Studies. Mexico, D.F.: CIMMYT.
Evenson, R. E., and D. Gollin. 2003. Assessing the Impact of the Green Revolution, 1960 to 2000. Science, 300(5620), 758-762. doi: 10.1126/science.1078710
FAO, and UNIDO. 2008. Agricultural mechanization in Africa - Time for action. Planning Investments for Enhanced Agricultural Productivity. Report of an Expert Group Meeting. January 2008, Vienna, Austria. Rome, Vienna: UNIDO, FAO.
Guthiga, P., J. Karugia, and R. Nyikal. 2007. Does use of draft animal power increase economic efficiency of smallholder farms in Kenya? Renewable Agriculture and Food Systems, 22(04), 290-296.
Hassan, R. M., J. Lynam, and P. Okoth. 1998. The Spatial Sampling Frame and Design for Farmer and Village Surveys. In R. M. Hassan (Ed.), Maize Technology Development and Transfer. A GIS Application for Research Planning in Kenya (pp. 27-41). Oxon, UK: CAB International.
Houssou, N., X. Diao, F. Cossar, S. Kolavalli, K. Jimah, and P. O. Aboagye. 2013. Agricultural Mechanization in Ghana: Is Specialized Agricultural Mechanization Service Provision a Viable Business Model? American Journal of Agricultural Economics, 95(5), 1237-1244. doi: 10.1093/ajae/aat026
Jayne, T. S., J. Govereh, M. Wanzala, and M. Demeke. 2003. Fertilizer market development: a comparative analysis of Ethiopia, Kenya, and Zambia. Food Policy, 28(4), 293-316.
Jones, N. S. C. 1965. The Decolonization of the White Highlands of Kenya. The Geographical Journal, 131(2), 186-201. doi: 10.2307/1793793
Joubert, B. 1995. An historical perspective on animal power use in South Africa. In P. Starkey (Ed.), Animal power in South Africa: empowering rural communities (pp. 125-138). Gauteng, South Africa: Development Bank of Southern Africa.
Kienzle, J., J. E. Ashburner, and B. Sims. 2013. Mechanization for rural development: A review of patterns and progress from around the world. Integrated Crop Management, 20.
Kislev, Y., and W. Peterson. 1981. Induced Innovations and Farm Mechanization. American Journal of Agricultural Economics, 63(3), 562-565. doi: 10.2307/1240549
Lamidi, W. A., and L. O. Akande. 2013. A Study of Status, Challenges and Prospects of Agricultural Mechanization in Osun State, Nigeria. Education, Arts and Humanities.
Lawrence, P. R., and R. A. Pearson. 2002. Use of draught animal power on small mixed farms in Asia. Agricultural Systems, 71(1-2), 99-110. doi: http://dx.doi.org/10.1016/S0308-521X(01)00038-5
Longmire, J., and J. Lugogo. 1989. The economics of small-scale wheat production technologies for Kenya: CIMMYT.
Mrema, G. C., D. Baker, and D. Kahan. 2008. Agricultural mechanization in sub-Saharan Africa: time for a new look. Agricultural Management, Marketing and Finance Occasional Paper (FAO).
O'Neill, D. H., and D. C. Kemp. 1989. A comparison of work outputs of draught oxen. Journal of Agricultural Engineering Research, 43, 33-44. doi: http://dx.doi.org/10.1016/S0021-8634-(89)80004-6
Onyango, S. O. 1990. Reducing present constraints to the use of animal power in Kenya. In P. H. Starkey & A. Faye (Eds.), Animal

traction for agricultural development. Proceedings of the Third Workshop of the West Africa Animal Traction Network held 7-12 July 1988, Saly, Senegal (pp. 479). Ede-Wageningen, The Netherlands: Published on behalf of the West Africa Animal Traction Network by the Technical Centre for Agricultural and Rural Cooperation (CTA).

Pingali, P. 2007. Chapter 54 Agricultural Mechanization: Adoption Patterns and Economic Impact. In R. Evenson & P. Pingali (Eds.), Handbook of agricultural economics (Vol. Volume 3, pp. 2779-2805): Elsevier.

Pingali, P., Y. Bigot, and H. P. Binswanger. 1987. Agricultural mechanisation and the evolution of farming systems in sub-Saharan Africa. Baltimore, MD: The John Hopkins University Press, for the World Bank.

Rijk, A. G. 1989. Agricultural mechanization policy and strategy: the case of Thailand: Asian Productivity Organization.

Ruttan, V. W., and Y. Hayami. 1984. Toward a theory of induced institutional innovation. The Journal of Development Studies, 20(4), 203-223. doi: 10.1080/00220388408421914

Savadogo, K., T. Reardon, and K. Pietola. 1998. Adoption of improved land use technologies to increase food security in Burkina Faso: relating animal traction, productivity, and non-farm income. Agricultural Systems, 58(3), 441-464. doi: http://dx.doi.org/10.1016/S0308-521X(98)00040-7

Shetto, R. M. 2007. The Challenges of Mechanizing Agriculture in Sub-Saharan Africa. Paper presented at the Addressing the Challenges Facing Agricultural Mechanization Input Supply and Farm Product Processing: Proceedings of an FAO Workshop Held at the CIGR World Congress on Agricultural Engineering.

Sims, B. G., and J. Kienzle. 2006. Farm power and mechanization for small farms in sub-saharan Africa. Agricultural and Food Engineering Technical Report No. 3. Rome: FAO.

Smale, M., and T. Jayne. 2003. Maize in Eastern and Southern Africa: "Seeds" of Success in Retrospect. EPTD Discussion Paper No. 97. Washington, D.C.: IFPRI.

Starkey, P. 2000. The history of working animals in Africa. In R. M. Blench & K. C. MacDonald (Eds.), The origins and development of African livestock: Archaeology, genetics, linguistics and ethnography (pp. 478-502). London, New York: Routledge.

Takeshima, H., A. N. Pratt, and X. Diao. 2013. Mechanization and Agricultural Technology Evolution, Agricultural Intensification in Sub-Saharan Africa: Typology of Agricultural Mechanization in Nigeria. American Journal of Agricultural Economics. doi: 10.1093/ajae/aat045

Tefft, J. 2010. Mali's White Revolution: Smallholder cotton from 1960 to 2006. In S. Haggblade & P. B. Hazell (Eds.), Successes in African agriculture: Lessons for the future (pp. 113-162). Washington, DC: IFPRI.

van Eijnatten, C. 197. A Study of The Production of Wheat in the Naro-Moru and Waraza Settlement Schemes In Kieni East, Central Province, Kenya: University of Nairobi.

Xu, Z., W. J. Burke, T. S. Jayne, and Govereh, J. 2009. Do input subsidy programs "crowd in" or "crowd out" commercial market development? Modeling fertilizer demand in a two-channel marketing system. Agricultural Economics, 40(1), 79-94.

Zewdie, R., E. Wallace, & P. Kic 2015. Developing countries in Africa and priorities towards implementation of agricultural mechanization. AMA, Agricultural Mechanization in Asia, Africa and Latin America, 46(2), 35-40.