Chapter 7

INTENSIFICATION OF MAIZE-BASED FARMING: WHAT HAPPENED TO THE MAIZE GREEN REVOLUTION?

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Maize is the major food crop in eastern and southern Africa, including Kenya. Maize-based farming systems make up the largest proportion of agricultural land, and maize is central to the food system, in both rural and urban areas. Because of its importance, maize has received wide attention from the government, including in policy and research. As a result, Kenya has been at the forefront of the "maize green revolution" in Africa (Hassan and Karanja 1997; Hassan, Njoroge et al. 1998c). It was one of the first countries in Africa (with South Africa and Zimbabwe) to develop its own maize hybrids and combine them with fertilizer in demonstration trials, demonstrations, and dissemination (Hassan and Karanja 1997). In both South Africa and Zimbabwe, the settler communities continued to dominate commercial maize production (Eicher 1995), but in Kenya, indigenous African farmers took over most of the maize production right after independence.

The new government supported research and dissemination of improved maize varieties, initially focusing on large-scale farmers in the highlands but quickly expanding to small-scale farmers and to other maize areas (Harrison 1970; Gerhart 1975). The government also continued the colonial policies of controlled input and output markets, with pan-territorial prices (Wangia, Wangia, and De Groote 2004). These efforts were successful and resulted in high adoption rates for the new improved maize varieties and increased yields and production, especially in the highlands (Lynam and Hassan 1998b).

Unfortunately, since the 1980s, maize yields have stagnated (De Groote et al. 2005). A range of policies, projects, and other measures have been put in place to boost yields and production, to keep up with population growth, but with little success. The government, facing inefficient markets and high intervention costs, and under pressure from the donor community, liberalized agricultural input and output markets in the 1990s (Wangia, Wangia, and De Groote 2004). The resulting privatization of the maize sector brought new actors from the private sector, including maize seed companies, which increased the number of maize varieties and agrodealers to distribute them, with accompanying fertilizers and pesticides (Ariga and Jayne 2009). However, privatization had limited impact on maize yields (De Groote and Omondi 2023).

Other efforts were undertaken, including the United States Agency for International Development (USAID)-funded Maize Development Program (Smale et al. 2012), a second-generation input subsidy program (Jayne et al. 2018), and continuing control of maize prices by the National Cereals and Produce Board (NCPB) in combination with import and export control by the government. At the same time, maize research continued at high levels with, among other initiatives, the Stress Tolerant Maize for Africa, the Improved Maize for African Soils, and the Accelerated Genetic Gains projects, mostly focusing on the breeding of improved maize varieties.

Despite all these different efforts, statistics show an increase in maize production but not in yields, as the next section describes in detail. As production cannot keep up with population growth, substantial maize imports are required most years. This chapter first provides some historical background, needed to understand the Kenyan maize sector and the food system it dominates. Next, we study the trends in the adoption of improved maize technologies, in particular improved maize varieties and fertilizer. Finally, we analyze the effect of research, policies, and other factors on maize yields and production, identify weaknesses in current approaches, and try to formulate alternatives.

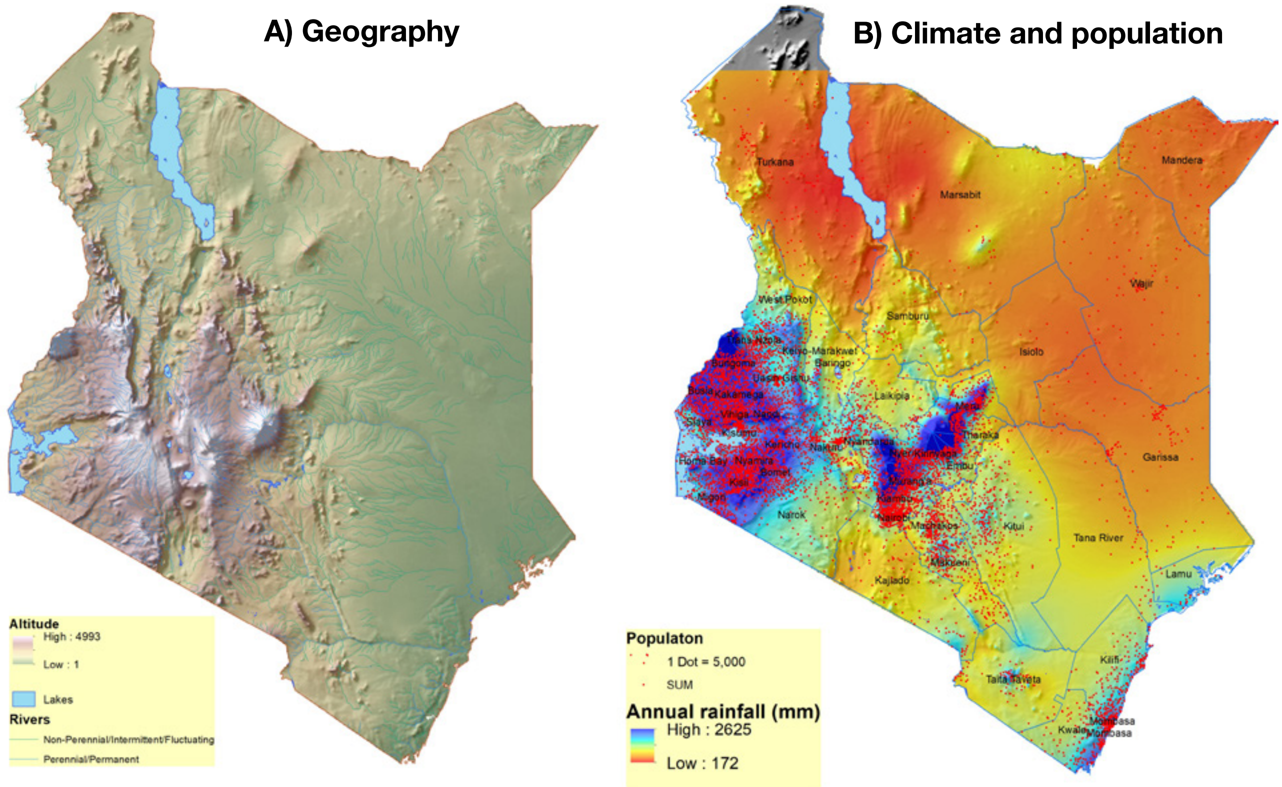
A good understanding of historic trends in the intensification of maize production systems is essential to understanding the food system in Kenya. Maize is grown by almost all rural households, which constitute two-thirds of the population. Moreover, maize constitutes the major food staple of the rural as well as the urban population, especially the poor. Therefore, it plays a central role in the food system in Kenya, as in the rest of eastern and southern Africa.

Background on maize in Kenya

Geography, climate, and demography

Maize production in Kenya is closely linked to geography and climate. Kenya's climate is largely a result of its position on the equator and its geography, dominated by the Great Rift Valley (GRV), which was shaped by tectonic drift and related volcanic activity (see map in Figure 7.1, panel A). The rims on the sides of the GRV were pushed up to form the highlands, with a valley in

FIGURE 7.1 Geography, climate, and population in Kenya



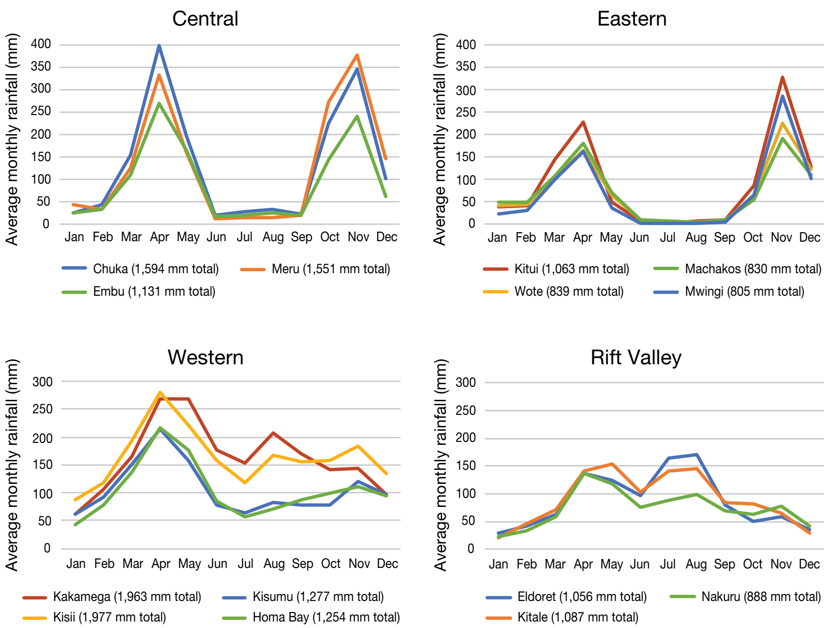
Source: https://datasets.wri.org/dataset/kenya-digital-elevation-model-dem-250m-resolution; www.worldclim.org/; www.worldpop.org/

between. The center of the valley has a relatively high elevation and is therefore also classified as highlands. On the eastern side of the GRV, the highlands range from the Ngong Hills to the Aberdares, and are extended by Mount Kenya, after which the elevation descends into the lower plains all the way to the coast. The western rim forms the Mau Mau escarpment, and the highlands extend to Mount Elgon in the north; westward, the altitude gradually descends into the Lake Victoria basin.

Rains originate from the Indian Ocean in the east and are transported by the trade winds, and orographic rain falls where moist air is lifted by the geography, in particular on the eastern side of Mount Kenya and on both rims of the GRV. The lee sides, however, form rain shadows, in particular after the coastal hills, in the lower parts of the GRV and on the shores of Lake Victoria (Figure 7.1, panel B). Most of the country does not have enough rainfall for agriculture, so most of the population is concentrated in areas with high rainfall, suited to agriculture. Most of the population is still rural—69 percent as per the 2019 Census (KNBS 2019), and their livelihood largely depends on rainfed agriculture.

Because of its location on the equator, Kenya has two rainy seasons as a result of the trade winds, which shift from northeast to southeast following a seasonal pattern. Most agricultural areas are in the northern hemisphere, to which the southeast trade winds bring the major rains between March and June. The second rainy season, from October to January, is driven by the northeast trade winds; it is usually called the minor season, although it is more important in the southeast, except for at the coast. The seasonality of rainfall can easily be seen in the patterns of average monthly rainfall in the different regions (Figure 7.2). Central Kenya, close to the equator and located on the windward side of Mount Kenya, receives ample rains, in two distinct but roughly equal seasons, and almost no rain in between. Eastern Kenya, on the other hand, is located in the low and mid-altitudes, far from the mountains, and receives little rainfall; most of what falls is in the second season (October to December). Most of western Kenya, located between Lake Victoria and the western ridges of the GRV, also receives ample rain, concentrated in the main season but without much seasonality: there is hardly a dry period and the months from June to November all receive similar amounts of rain. In the North Rift Valley, often called "the breadbasket of Kenya," there is hardly any seasonality: apart from a small dip in June, the region basically has one long rainy season, from March until September.

FIGURE 7.2 **Seasonal rainfall patterns in the different regions of Kenya**



Source: https://en.climate-data.org/africa/kenya

Maize arrival and distribution

Maize is a relatively recent introduction in Africa. The first maize varieties that came to East Africa were Caribbean flints, most likely introduced by Portuguese traders at the end of the 15th century (Miracle 1965; McCann 2001). These varieties were mostly used as a garden crop, and spread only slowly. Maize became the major food staple relatively recently, with the establishment of European settlers, who imported white dent varieties from South Africa that had originated in North America (Smale and Jayne 2003). Maize gradually replaced local cereals such as millet and sorghum because of its wide adaptability, better yields, and good resistance to birds and other pests (McCann 2005). At the beginning of the 20th century, maize covered only an estimated 20 percent of Kenya's crop area; by 1960, this area had risen to 44 percent (Hassan and Karanja 1997), boosted by the interest of the European settlers in the crop, which was grown on large-scale settler farms. The colonial government strongly supported these farmers, and a successful maize breeding program was started in 1955.

After independence in 1963, land ownership was transferred to African farmers (often members of the new political elite), under the "willing buyer, willing seller" principle, with programs providing credit to the buyers (Jones 1965; Boone, Lukalo, and Joireman 2021). At the same time, the breeding program was continued, and the original program in Kitale, for the highlands, was expanded to four other regions. Many popular hybrid varieties and open pollinated varieties (OPVs) were released in the 1960s and 1970s (Hassan and Karanja 1997). The hybrid varieties for the highlands took off very fast (Gerhart 1975), and they still form the base of the most popular varieties decades later. The improved OPVs were also popular, especially those for the dry areas, such as the Katumani variety, and to a lesser degree those for the coast (Hassan, Njoroge et al. 1998c).

Evolving agricultural policies

The colonial government controlled the maize sector tightly, mainly to protect the settler farmers in the highlands (Wangia, Wangia, and De Groote 2004). After independence in 1963, this control was maintained for another three decades, to (1) enable efficient marketing with a reasonable balancing and stabilizing of producer and consumer prices, (2) provide food security through strategic reserves, and (3) ensure regulated domestic movement of maize with strict management of imports and exports (DAI 1989). Implicitly, the state had a "social contract" with the majority of citizens to ensure the supply of maize, which had now become the basic food staple, at low and stable prices (Jayne et al. 1999).

State control of the maize sector (and the wider agricultural economy) included research, seed production, extension and dissemination of seed and fertilizer, and marketing of the grain, all through different specialized parastatals. New maize varieties were developed by public research institutes, initially within the East African Community and from 1977 incorporated in the Kenya Agriculture Research Institute (KARI), with different programs for the different agroecological zones (AEZs) (Karanja 1996). The Kenya Seed Company (KSC), initially a private seed company founded by European settler farmers, was asked to produce the seed of the first improved maize varieties (IMVs), and over time parastatals acquired a majority of shares in the company. A seed unit within KARI managed quality control, and the Ministry of Agriculture was charged with the extension of new technologies. Distribution of seed, and the accompanying fertilizers and other inputs, was carried out through the retail network of the Kenyan Farmers Association (Hassan, Karanja, and Mulamula 1998a).

From the late 1960s to the early 1980s, this system was remarkably effective at producing and disseminating many popular varieties, which, in combination with improved agricultural practices such as use of chemical fertilizers, led to rapidly increasing maize yield and production (Gerhart 1975; Karanja 1996). While government intervention is essential in areas without established markets, such as hybrid seed in the 1960s, in the long run it tends to be costly and inefficient, as it does not take advantage of the flexibility and efficiency of private sector initiatives (Gisselquist and Grether 2000). Liberalization of input and output markets in developing countries has therefore been advocated since the 1980s as part of structural adjustment programs (Gisselquist, Nash, and Pray 2002), including in Kenya. The liberalization has aimed at three major changes: (1) lifting of the controls in the maize market, (2) restructuring the NCPB, and (3) market development (Lewa and Hubbard 1995). The European Community sponsored the Cereal Sector Reform Programme (CSRP) from 1988, with the main goals of decontrolling the maize grain market and restructuring the NCPB (Jayne, Robert, and James 2008). The private sector was supported through the USAID-sponsored Kenya Market Development Project, specifically targeting maize and beans (DAI 1989).

The evolution of the parastatal-based system to an open input and output market system with increased private sector participation has been a long and hard process because of the existence of many entrenched interests (Lewa and Hubbard 1995). The reforms were only firmly established in 1995, after an extended period of uncertainty. The seed sector was opened up to include the private sector, with national, regional, and multinational companies competing. New national and regional companies benefited from publicly owned varieties, while multinationals could tap into new markets with their own germplasm (Tripp and Rohrbach 2001). The Kenya Plant Health Inspectorate Service was established as a regulatory agency in 2012. However, efforts to privatize KSC, as with national seed companies in other African countries, failed and its parastatal status was re-established.

In the fertilizer market, the monopoly of distribution of the Kenyan Farmers Association was cancelled in 1985, fertilizer prices were decontrolled in 1990, and foreign exchange and import licensing controls were removed in 1993, leading to a fully liberalized fertilizer market (Mwangi, Lynam, and Hassan 1998). Fertilizer subsidies were reintroduced in 2007–2009, albeit with limited results (Mather and Jayne 2018). Deregulation in the seed and fertilizer market led to a proliferation of small agrodealers throughout the country. In the grain markets, finally, control of prices and movement was removed, and NCPB was established as a buyer of last resort, to buy maize at floor prices (Jayne, Robert, and James 2008).

The December 2002 election created a window of opportunity for issue- and performance-based politics in Kenya (Poulton and Kanyinga 2014).

In March 2004, the new government set out its Strategy for Revitalizing Agriculture (SRA). However, the government coalition began to unravel soon after attaining power, and the return to ethnically based patronage politics undermined the SRA's chances of success. After the 2008 elections, the new government launched the 2010 Agricultural Sector Development Strategy (Kenya, Government of Kenya 2010), with clearly assigned roles for the private and public sectors—divesting from all state corporations production, processing, and marketing that could be better done by the private sector while reforming and streamlining agricultural services such as in research, extension, training, and regulatory institutions, to make them more effective and efficient. Nevertheless, the KSC's status as parastatal was confirmed.

Historic trends in maize production

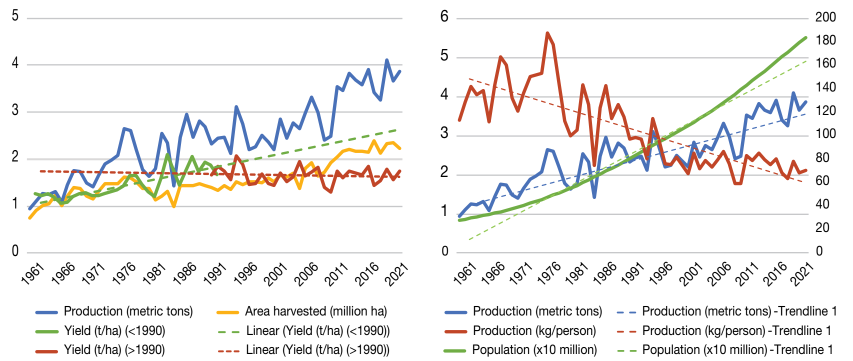
Maize production trends are shown in Food and Agriculture Organization of the United Nations (FAO) statistics of the past 60 years, which illustrate the importance of maize in the farming system and the initial success and later stagnation of the sector (Figure 7.3). Currently, it covers 37 percent of crop area. The success of the maize sector is shown in the substantial yield increase, from 1.2 metric tons/ha[1] to 1.5 tons/ha in the 1990s. In the 1960s and 1970s, there was also a substantial increase in maize production per person, from 110 kg/person to 180 kg/person (FAOSTAT 2022). However, since the 1990s, yields have stagnated at around 1.5 tons/ha. Maize production continues to increase but this can be attributed largely to an increase in area, which has doubled from about 1 million ha in the 1960s to about 2 million ha now. Further, the increase in production has not kept up with population growth: per capita production decreased to 90 kg/person in the 1990s and further to 70 kg/person in the 2000, where it has remained.

The 2019 Census counted a population of 45.6 million, still growing at a rate of 2.2 percent (down from 2.9 percent since the prior census) (KNBS 2019). The rural population remains very large, at 69 percent of the total, and most rural people live in maize production areas. Agriculture remains the mainstay of the economy and an important source of employment and income for Kenyans (see Chapter 2).

Currently, of a 5.7 million ha cropping area, more than half is covered by two crops: maize (37 percent) and beans (21 percent) (FAOSTAT 2022). Other

1 Tons refers to metric tons throughout this volume.

FIGURE 7.3 **Maize production trends, 1961–2021**



Source: FAOSTAT (2022).

cereals are much less important, including sorghum (3 percent) and millet and wheat (2 percent each). Similarly, area shares of tuber crops are particularly small, with the most popular tubers being potatoes (3 percent), cassava (2 percent), and sweet potatoes (1 percent). Maize to date retains its prime role in the economy, not only as food but also as a source of cash. Maize is not a major cash crop, except for a decreasing number of large-scale farmers, but many smallholder farmers do sell maize when there is a surplus or when there are immediate cash needs in the household (Jena et al. 2020). The Kenyan government estimates that 12.5 percent of maize production is used for animal feed, especially for poultry and dairy cattle.

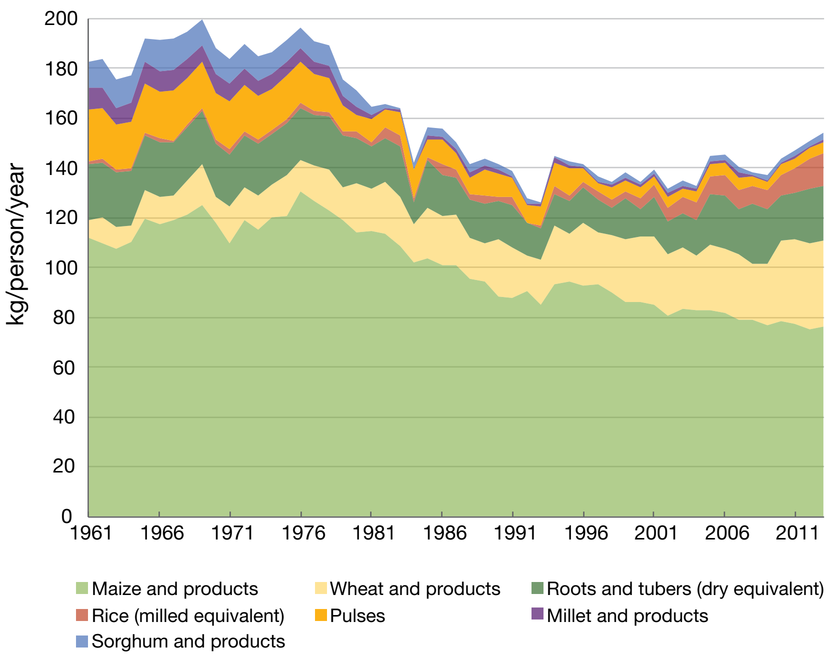
Several cash crops are grown in the various AEZs: tea is most common in the upper highlands (at 1,500–2,700 meters) whereas coffee is grown in the lower highlands (at 1,400–2,000 meters) and sugarcane in the low and mid-altitudes. Several other cash crops have been introduced in the past, including cotton, sisal, pyrethrum, and others, but all have largely been abandoned because of marketing difficulties after the collapse of the specific marketing parastatals. The remaining cash crops still have marketing issues, and interested farmers typically need a certain minimum size to make their work worthwhile. Smallholder farmers therefore tend to sell vegetables and fruits, products that enjoy a steady market and entail no minimum size requirement. Finally, in many maize areas, dairy cattle have become an important source of cash. In the mid- and high altitudes, even small farms can maintain a dairy cow, with zero grazing, based on Napier grass (Odero-Waitituh 2017).

Shift in consumption patterns

Food consumption patterns in Kenya closely follow agricultural production patterns, as most of the population still live in rural areas and consume local produce. Maize is by far the most important food source, with an annual consumption of 62 kg per person, followed by wheat products (including bread, chapatis, and *mandazis*) (34 kg), roots and tuber crops (21 kg), and rice (13 kg) (FAOSTAT 2020). Consumption of other cereals is very limited, and includes pulses (4.5 kg), sorghum (3 kg), and millet (1 kg). The other main sources of plant foods are tubers (22 kg) and pulses (4.5 kg).

Substantial changes have occurred in the consumption of plant-sourced food over the past 60 years (Figure 7.4). Overall, annual consumption of plant-sourced food has declined from more than 180 kg in the 1960s to about 140 kg now, although this reduction took place mostly in the late 1970s and 1980s, with the situation remaining stable since then. Another major change over time has been the reduction of maize consumption, from more than 100 kg per

FIGURE 7.4 Trends in the consumption of food from plant sources over time



Source: FAOSTAT (2020).

person per year from the 1960s through the mid-1980s, but down to less than 70 kg now. In addition, consumption of coarse grains has fallen dramatically to the point of becoming negligible: sorghum has decreased from 10 kg to 3 kg/person/year, and millet from 9 kg to 1 kg/person/year. Similarly, consumption of pulses has decreased by three-quarters, from 21 kg per person to 4.5 kg. Finally, the decrease in the consumption of locally produced maize and coarse grains has been compensated by an uptake in the consumption of the new cereals: wheat (from 8 kg to 34 kg) and rice (from 1 to 13 kg), most of which is imported.

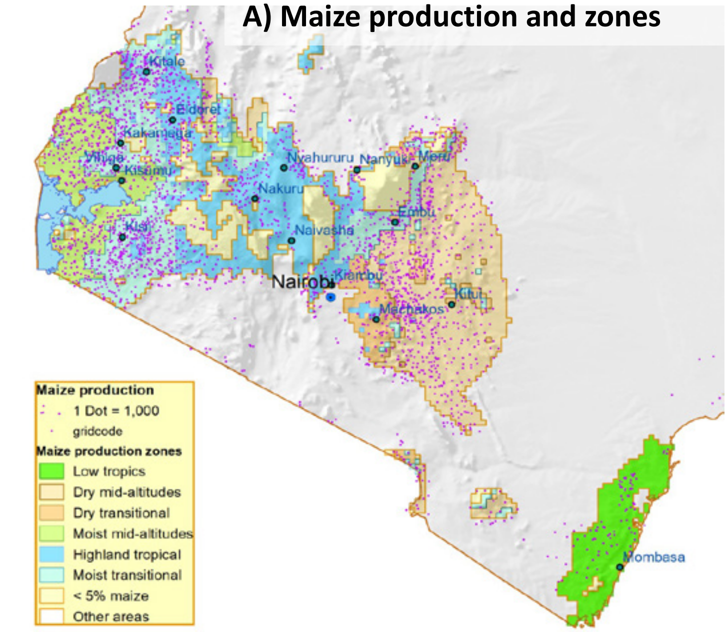
Household surveys on the use and impact of improved agricultural inputs

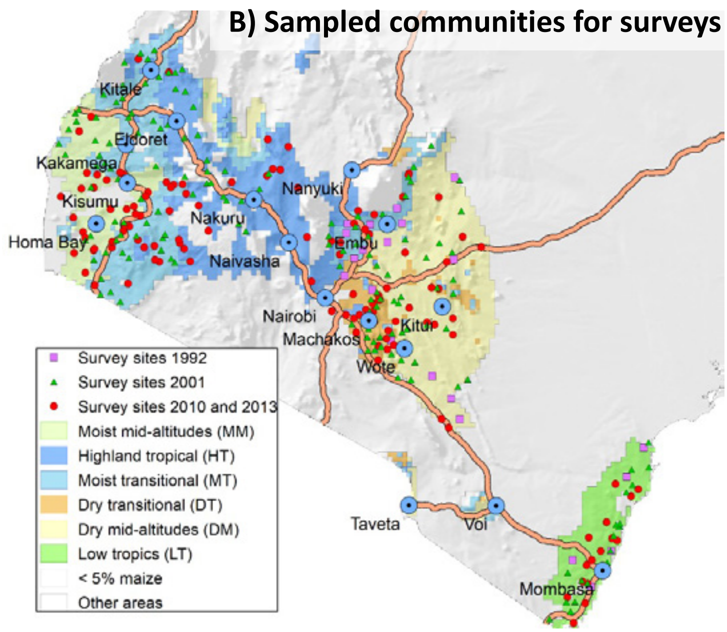
Farm household surveys, the Kenya Maize Data Base, and the establishment of maize production zones

Farm household surveys are important to gauge farmers' appreciation and adoption of new technologies, and the suitability of technologies in the pipeline. Over the years, many such surveys have been conducted in Kenya, including four nationally representative surveys by the International Maize and Wheat Improvement Centre (CIMMYT) and KARI, now the Kenya Agriculture and Livestock Research Organization (KALRO), as well as four panel surveys by the Tegemeo Institute. This chapter uses the data from the former and compares the results to the latter in the discussion.

The first national household survey in Kenya was conducted in 1992, by CIMMYT and KARI, and resulted in the Kenya Maize Data Base (KMDB) (Hassan, Lynam, and Okoth 1998b). This survey covered the adoption of maize technologies such as improved varieties and fertilizer. The households were georeferenced, and the data were used to adapt the standard agroecological classification into six major AEZs for maize production in Kenya, important to guide the maize breeding programs (Corbett 1998) (Figure 7.5). The major adjustment was the creation of a transitional zone between the mid-altitude AEZ and the highlands. When moving from east to west, the first zone is the lowland tropics at the coast; this is followed by the dry mid-altitude and the dry transitional zones around Machakos. These three zones are characterized by low yields (less than 1.5 tons/ha); although they cover 29 percent of maize area in Kenya, they produce 11 percent of the country's maize (Table 7.1). In Central and Western Kenya, we find the highland tropics, bordered to the west and east by the moist transitional zone (transitional between the mid-altitude AEZ and the highlands). These zones have high yields (more than 2.5 tons/ha)

FIGURE 7.5 Agroecological zones and the communities of different household surveys over time





Source: www.mapspam.info/; De Groote, Marangu, and Gitonga (2018).

and produce 80 percent of the maize in Kenya on 30 percent of the area. Finally, around Lake Victoria is the moist mid-altitude zone, which has moderate yields (1.44 tons/ha): it covers 22 percent of the area and produces 9 percent of maize in the country.

While Kenya in general has two maize-growing seasons, these differ in importance between zones (Figure 7.2). In the highlands, for example, almost all of maize production takes place in the main season (March–July) (Figure 7.2, panel D). In the moist transitional zone, on the other hand, more than half of the maize is produced in the minor season (October–February) (Figure 7.2, panel B).

Consecutive national surveys by CIMMYT and KARI

Apart from the KMDB, CIMMYT, in collaboration with ARI, has conducted three nationally representative household surveys in the major maize growing areas over the past 30 years. We will use the data from these four surveys to analyze and synthesize trends in the adoption of new technologies. The data and the surveys have been described in more detail elsewhere, as the same data were used to analyze the trends in mechanization (De Groote, Marangu, and Gitonga 2018), fertilizer use (Jena et al. 2021), and varieties (De Groote and Omondi 2023).

All surveys used the same two-stage stratified design, with maize AEZs as strata, census clusters or sublocations as primary sampling units, and maize-growing households as secondary sampling units (see map in Figure 7.5, panel B). The first survey, for the KMDB, was conducted in 1992 by CIMMYT and KARI and covered 79 clusters totalling 1,397 farmers (Hassan, Lynam, and Okoth 1998). This survey also defined the six AEZs as described above, and these were subsequently used to stratify the next three surveys. The second survey was conducted in 2002 as a baseline for the Insect Resistant Maize for Africa project, and covered 185 sublocations based on the 1999 Census, with 1,652 households (De Groote et al. 2005). The third survey was conducted in 2010 as a baseline for the AflaControl project, and covered 120 sublocations with 1,341 households (De Groote et al. 2016). The fourth and last survey, in 2012, interviewed the same farmers with a replacement of 20 percent of randomly sampled households (Wainaina, Tongruksawattana, and Qaim 2016).

Micro adoption studies

CIMMYT also helped build capacity for social science research in East Africa by supporting a series of small local adoption surveys (Doss et al. 2003). Four of these studies took place in Kenya, covering two districts in Western Kenya (Salasya et al. 2007), one district in Central Kenya (Makokha et al. 2001), one district in Eastern Kenya (Ouma et al. 2002), and two districts at the coast (Wekesa et al. 2003).

Tegemeo adoption studies

The Tegemeo Institute, in collaboration with Michigan State University, has conducted panel household surveys in 5 rounds over 13 years (Mathenge, Smale, and Olwande 2014; Smale and Olwande 2014). These households represent the major maize AEZs of Kenya, although they do not fully overlap with Hassan's zones and also do not cover all maize production areas (Hassan, Lynam, and Okoth 1998). Further issues with these panel data are that no partial replacement over time was used, causing the whole panel to age over time, and that the sampling strategy of the first round (including the sampling stages and the sampling frames) is not clearly defined and the proceedings were not well recorded. We will compare our results to those of the Tegemeo surveys in the discussion.

Combining household surveys with SPAM data

Kenya does not, unfortunately, produce regional maize statistics. To estimate maize production by AEZ, we therefore used the map of the zones as developed by Hassan et al. (1998) and overlayed this with the 2017 SPAM (IFPRI 2020) and calculated the maize area and production for 2017 for the different AEZs (Table 7.1). To estimate the population in each AEZ, we used the 2015

TABLE 7.1 Maize agroecological zones in Kenya, with estimated maize area and production in 1992 and 2017

AEZ	Elevation (masl)	Maize 1992				Maize 2017			Population 2020 ('000s)
		Area ('000 ha)	Production ('000 metric tons)	% long rains	Yield (t/ha)	Area ('000 ha)	Production ('000 metric tons)	Yield (t/ha)	
Lowland tropics	0–700	33	45	0.62	1.36	58	37	0.65	2,857
Dry mid-altitude	700–1,400	118	122	0.41	1.03	401	196	0.49	3,825
Dry transitional	1,100–1,700	37	45	0.51	1.21	588	486	0.83	5,403
Moist transitional	1,200–2,000	424	1170	0.74	2.76	386	524	1.36	7,931
Highlands	1,600–2,900	307	893	0.99	2.91	248	586	2.36	1,801
Moist mid-altitude	1,110–1,500	118	170	0.61	1.44	103	109	1.06	12,137
<5%						91	119	1.30	1,858
Other						210	326	1.55	10,076
Total		1,037	2,445	0.70	2.31	2,086	3,186	1.53	45,890

Source: Author's calculations based on Hassan (1998); IFPRI (2020); Stevens et al. (2015); and Wainaina, Tongruksawattana, and Qaim (2016).

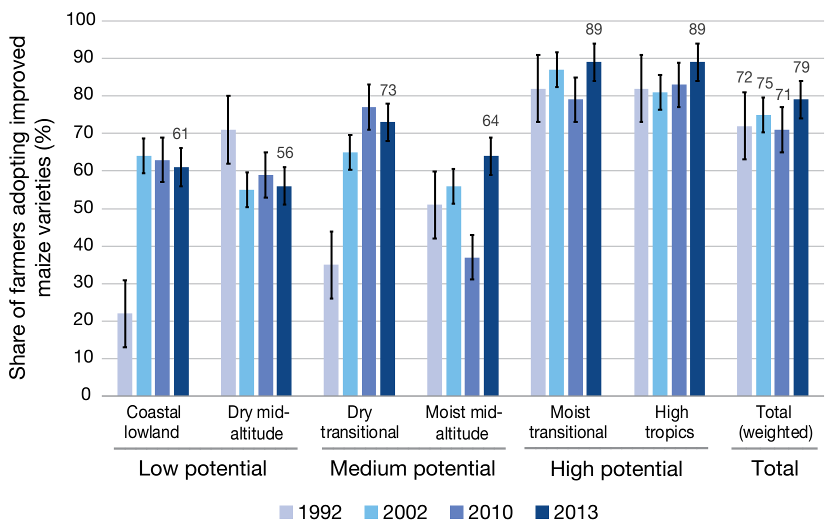
population density dataset from WorldPop (www.worldpop.org) (Stevens et al. 2015). Finally, we allocated the annual production data for each zone to the two seasons, proportionate to the distribution found in the 2013 household survey (Wainaina, Tongruksawattana, and Qaim 2016).

Results on the adoption of improved maize varieties and fertilizer, by agroecological zone

Improved maize varieties

Over time, as pictured by the four consecutive national surveys, the average adoption rate of IMVs (weighted by AEZ) did increase, but only slightly, from 72 to 79 percent (Figure 7.6). However, adoption rates over the first three surveys were nearly the same: the small increase was realized only between the last two surveys, between 2010 and 2013. Adoption rates also differed substantially between AEZs, and the graph shows a clear increase in adoption rates from low- to high-potential zones. The highest adoption rates are found

FIGURE 7.6 Trends in adoption of improved maize varieties, by survey and agroecological zone



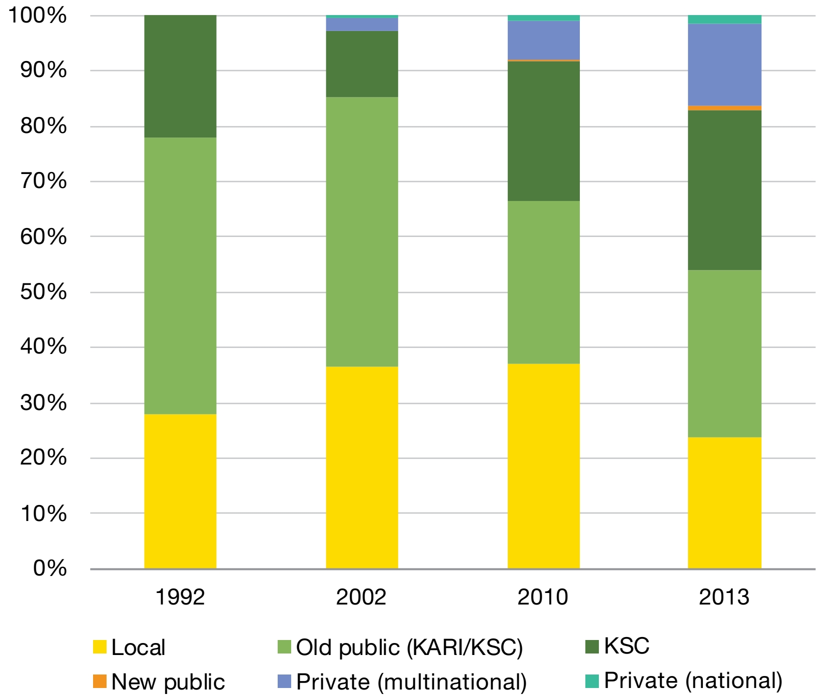
Source: De Groote and Omondi (2023).
Note: Error bars are standard errors.

in the high-potential areas (moist transitional and high tropics), where almost all farmers (89 percent) had adopted IMVs by 2013. In the medium-potential areas, the results vary between the moist mid-altitude (64 percent) and the dry transitional (73 percent) zones. In the low-potential areas, finally, adoption rates were the lowest, but IMVs had still been adopted by more than half the farmers in both the coast (61 percent) and the dry mid-altitude (56 percent) zones.

Using regression analysis (with a random effects probit model), the factors affecting the adoption of IMVs can be analyzed over the four surveys (De Groote and Omondi 2023). The household characteristics that significantly and positively affected adoption of IMVs were education of household head, household size, if the household sold maize, and access to extension services. Gender and age of household head, on the other hand, did not have a significant effect on adoption rates. A major factor was market participation: households selling maize were much more likely to grow IMVs. Market participation increased from 20 to 49 percent over the study period, although that latter level remains low, reflecting the importance of production for home consumption. Among institutional factors, access to extension services increased the adoption rate but access to credit or distance to market did not have significant effects. There were also substantial differences between AEZs, as seen in the graph, with farmers in the high-potential zones more likely to adopt IMVs than their colleagues in low-potential areas.

Liberalization of the seed sector aimed to increase the participation of the private sector. We therefore analyze how the private seed sector's market share evolved over time, based on farmers' adoption trends (Figure 7.7). In 1992, before privatization, the old public KARI/KSC varieties covered half of the maize area, while the new (parastatal) KSC varieties covered 22 percent. This left 28 percent of maize area under local varieties, while the private sector had not yet come in. Because of the liberalization in the late 1990s, KARI started developing varieties independently of KSC, and the private sector entered the market. KSC, on the other hand, obtained the legal property rights to the varieties it had been producing, while also continuing to develop more varieties on its own. Despite the liberalization, but perhaps negatively affected by the disturbances in the market, the proportion of area under IMVs dropped to 66 percent in 2002 and 62 percent in 2010, and increased only later (in 2013) to 77 percent. Even after the liberalization, KSC remained the dominant seed company in Kenya, retaining more than half of the market. Private sector participation evolved slowly: varieties owned by the private sector (mostly multinationals and companies from southern Africa) made up only 2 percent in 2002 and increased their share to 15 percent by 2013. Varieties owned by the

FIGURE 7.7 Market share of maize varieties, by source and over time



Source: De Groote and Omondi (2023).

public sector (KARI, its successor KALRO, and CIMMYT), with seed mostly produced and disseminated by local seed companies, had a share of 6 percent in 2002 but increased it to only 9 percent in 2013.

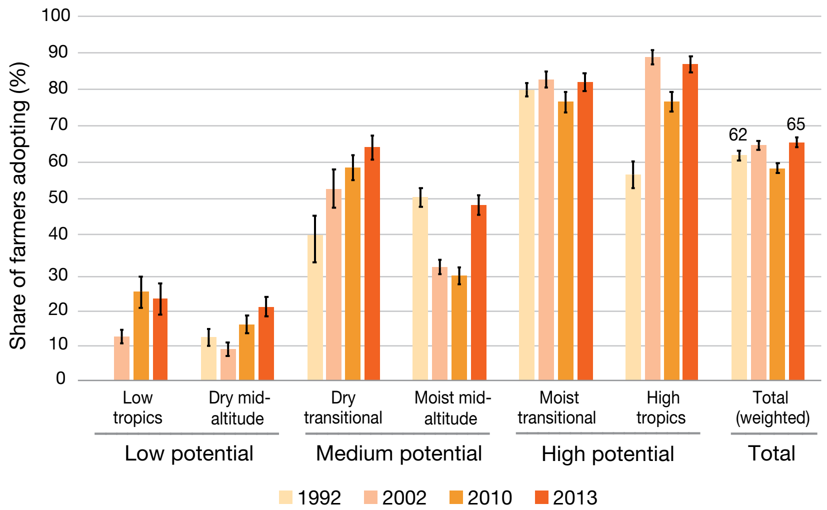
We did not include OPVs as a separate class in the analysis as they were important only in the lowlands (going from 18 percent in 1992 to 14 percent in 2013) and the dry midlands (from 49 to 8 percent); in the other regions they never covered more than 2 percent. Moreover, as KSC is phasing out its OPVs and replacing them with popular hybrids, they are also decreasing rapidly in those two areas (for details on OPVs, see Supplementary Material 3 in De Groote and Omondi 2023).

Adoption of fertilizer

The data from the four household surveys allow us to map the trends in the adoption of fertilizer over time (Figure 7.8). In 1992, the first year, 62 percent of farmers used fertilizer, but with a strong variation between the different maize production zones. By 2002, the average proportion of fertilizer users had increased only slightly, to 65 percent. The next survey, in 2010, showed a substantial reduction of fertilizer adoption rates, to 58 percent. Finally, the 2013 survey, which was a follow-up to the 2010 survey, showed average fertilizer adoption of 65 percent, a significant increase over 2010 yet not significantly higher than the 1992 and 2002 levels. So, overall, there is no significant increase in adoption of fertilizer over time.

Fertilizer adoption rates differ highly between the different maize AEZs. In the high-potential areas, most farmers—generally 80 percent or more—have adopted fertilizer, with little or no change over time (except for the jump from 57 to 89 percent in the highlands between the first two surveys). About half of farmers in the medium-potential zones have adopted fertilizer, but with a clear increase in the dry transitional zone (from 40 to 64 percent) but not in the moist mid-altitude zone (where it remained around 50 percent), which is also the zone furthest away from the main fertilizer markets. The low-potential areas, finally, also saw a modest increase—in the low tropics from no adoption to about a quarter of farmers (24 percent) and in the dry mid-altitude zone

FIGURE 7.8 Trends in the adoption of fertilizer over time, by agroecological zone



Source: De Groote and Omondi (2023).

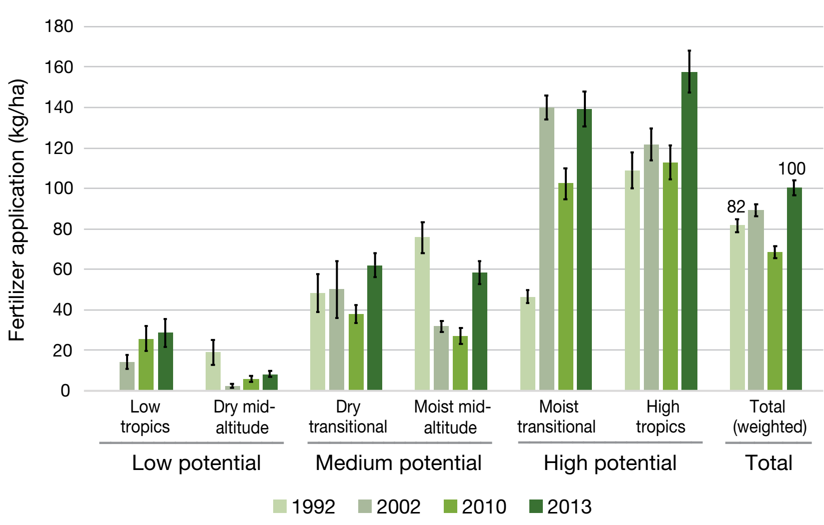
Note: Error bars are standard errors.

from 12 to 21 percent of farmers. However, the three zones with an increase in adoption are rather small maize producers compared with the high-potential areas, so their increase in adoption did not affect the overall trend of stagnation in fertilizer adoption.

Next, we calculate the average dose of fertilizer used per hectare; again, we calculate weighted average using the maize areas in the different AEZs as weights to ensure representativeness at a national level. The seasonally weighted averages for the four years indicate a modest increase over the study period, from 82 kg/ha in 1992 to 100 kg/ha in 2002 but with a dip in 2010 (to 68 kg/ha). These doses are still substantially below the recommended dose for fertilizer application. Again, application rates vary among AEZs: the high-potential zones have high rates (between 140 and 160 kg/ha in the last year) while the low-potential zones have particularly low rates (between 8 and 30 kg/ha). The high standard deviations for the average figures also indicate a high variability in fertilizer application rates between farmers, with a standard deviation higher than the mean in all years.

Analyzing the change in application rates by zone, however, shows that the overall increase stems mostly from the increase in the high-potential areas (again

FIGURE 7.9 Trends in the fertilizer application rate by agroecological zone



Source: Jena et al. (2020).

Note: Error bars are standard errors.

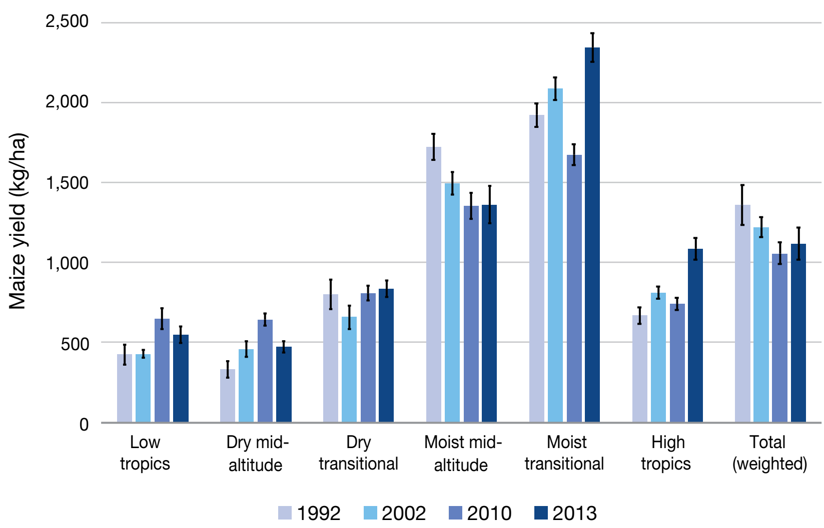
with the dip in 2010). In the low- and medium-potential zones, no increase in application rates was observed, except for in the dry transitional zone.

Effect of improved maize varieties and fertilizer on yields

Analyzing maize yield trends in Kenya over the same four surveys shows no increase, rather a slight decrease from 1,360 to 1,116 kg/ha (Figure 7.10). The yield estimates from our surveys follow the trend of the FAO statistics but are actually systematically lower (see Jena et al. 2020 for details of the comparison). Yields differ strongly between AEZs, and these differences remained high over the 30 years of the study period. Yields are understandably higher in the high-potential zones, at around 1,500 kg/ha in the moist transitional zone and 2,000 kg/ha in the high tropics. In the low-potential areas, however, they barely reach 500 kg/ha (500–1,000 kg/ha in the mid-potential zones). Trends also differ by zone but without a clear overall trend: while the high tropics and the moist mid-altitude zone show an increase, in the moist transitional zone yields decreased, and in the other zones they just stayed stagnant.

The question remains: What are the major drivers of maize yields? A previous analysis, using endogenous switching regression coefficients, showed

FIGURE 7.10 Average maize yields, by agroecological zone and year of survey



Source: Jena et al. (2020).
Note: Error bars are standard errors.

the factors that affect maize yields for fertilizer adopters and non-adopters (Jena et al. 2020). The use of hybrid maize also positively affects the yield for both groups, with an increase of 291 kg/ha for adopters and 174 kg/ha for non-adopters, indicating the synergistic effect of combining both technologies. Maize area per household, in contrast, has a negative and significant coefficient for non-adopters, indicating that a larger maize area leads to a yield reduction for this group. Among institutional variables, access to extension service has a positive and significant impact, increasing maize yield by 240 kg/ha for fertilizer adopters and 184 kg/ha for non-adopters, indicating a synergy between extension and fertilizer use. Household size has a positive impact on yield for both adopters and non-adopters. Among weather variables, an increase in minimum temperature has a positive effect on yield, while an increase in annual rainfall has a positive effect on yields for adopters. Finally, the AEZ are a major driver of yields, with the high-potential areas easily reaching 2.5 tons/ha and the low-potential areas having difficulties reaching 1.5 tons/ha.

Another analysis shows yields to increase for younger varieties, with about 4 kg/ha for each reduction of a year (De Groote and Omondi 2023). Fertilizer also increased yields, by 5 kg/ha for each 1 kg, with a significant, negative cross-effect, indicating that younger varieties are more responsive to fertilizer. At the average fertilizer rate by fertilizer users of 132 kg, the effect of a year is an additional 2.5 kg/ha.

Discussion

This analysis, based on data from four household surveys conducted over 30 years, shows a very slow process of intensification in the maize production sector. Adoption rates for IMVs show a slight increase (from 72 to 79 percent), and poor progress in varietal turnover, with a continuous domination of the parastatal KSC in the seed market. Similarly, adoption rates of fertilizer increased slightly (from 62 to 65 percent), with a modest increase in application rates (from 82 to 100 kg/ha). However, maize yields did not increase during the study period. This is confirmed by the FAO data (FAOSTAT 2022), which show a stagnation in yields since 1990, in contrast with a steady increase from the 1960s till then. Stagnating yields for a major food crop are particularly problematic given the rapidly increasing population. This was partly upset by an increase in maize area, but maize production per person has been reducing steadily over time. This shortage is being countered with increasing imports of maize, but also wheat and rice, reflecting a change in consumer preferences. However, continually increasing imports of the major food staple is likely to create political problems in the long run, especially in times of increasing food prices.

The adoption rates of IMVs in the CIMMYT surveys are similar to those in the Tegemeo panel survey: between 38 to 82 percent of hybrid adopters, depending on AEZ (Mathenge, Smale, and Olwande 2014), with an overall level of hybrid adoption by more than 80 percent of farmers (Smale and Olwande 2014). Our results on fertilizer, however, stand in contrast with those from the Tegemeo panel data, which show an increase of fertilizer use and maize yields from 1997 to 2007 (Olwande, Sikei, and Mathenge 2009; Ariga and Jayne 2011). The FAO yield data for this period also show an increase in maize yields. However, our analysis, both based on our survey and the FAOSTAT data, indicate that this short-period increase is not part of a larger trend (Jena et al. 2020). Further, our results indicated yields reduce with maize area, while other studies find a U-shaped relationship, including an older study (Carter and Wiebe 1990) and one based on the Tegemeo data (Muyanga and Jayne 2019). However, the yield increase of the latter study was only found in the 5–70 ha farm size range. Our data, based on representative household surveys, do not include enough households in that range to test that relationship. Other factors not included in our analysis were climate and economic data. Important climate variables are volatility and timing of rainfall, which would be good to include when better data become available. Also, output and output prices, in particular grain, seed, and fertilizer prices, would be good to include in future surveys; the Tegemeo data showed a strong positive effect of the grain/price ratio on adoption of hybrids (Smale and Olwande 2014).

Our results do confirm that intensification of maize production, in particular the use of fertilizers and improved varieties, has a positive effect on yield, income, and food security. This has, of course, been reported before (Mathenge, Smale, and Olwande 2014). What remains puzzling, though, is the low rate of intensification. The slow rate of intensification and the stagnation of maize yields are major concerns for a country that relies heavily on maize for its food security. Some of the factors that affect the adoption of improved maize technologies can be influenced by policy, in particular availability of affordable inputs, education, and extension. Others, in particular the commercialization of maize production, are more difficult.

On the provision of inputs, the liberalization of the maize seed sector was not particularly effective. While many private seed companies have entered the market and many varieties are now available, farmers seem to prefer their old varieties, and are risk-averse in trying new ones. This has led to a low varietal turnover and a continued domination by the parastatal KSC. The combination of public research and local seed companies does not, however, seem very successful as compared with international private seed companies and, especially, KSC.

In the fertilizer market, liberalization was initially successful, leading to the entry of the private sector and the development of an efficient distribution system. However, the liberalization was later countered by new subsidy programs, which did increase input use for some time, with, for example, a 34 percent increase in smallholder fertilizer use over 1997–2007 (Ariga and Jayne 2011). Unfortunately, government subsidies and intervention in distribution do crowd out private investment in the sector (Makau et al. 2016), and do not necessarily reach targeted households. Moreover, distribution of subsidized fertilizer by NCPB is contrary to the earlier liberalization policy and expands its role from buyer of last resort. What is particularly lacking in Kenya is systematic research on soil fertility management to counter the continuous cultivation without nutrient replenishment.

Agricultural extension was also found to affect adoption of technologies, but the interaction of the public and private sectors remains problematic. New apps hold some promise but, while our surveys confirm that most farmers now have access to phones, these are not usually smartphones, hindering access to the new developments in apps for pest management, variety selection, and soil fertility management.

Finally, the major factor not yet included in the analysis is the low level of urbanization in the country, linked to relatively low population density, low prices for agricultural land, and high levels of home consumption of maize. Less than 30 percent of the Kenyan population lives in urban areas (KNBS 2019), and more than half of the farmers produce maize only for home consumption. Kenya may therefore not have reached the conditions that will lead to the intensification of the major food crop, in particular population density (Boserup 1965), especially as related to arable land (De Groote 1999). In this case, the stagnation of the intensification may be worrisome but not much can be done to speed it up. What would be very useful, however, is a regular farm household survey, like the living standard measurement surveys (LSMS) or the household survey in Ethiopia (CSA 2014), to follow and understand the trend. It is therefore unfortunate that no new rounds for either the CIMMYT or the Tegemeo surveys have been conducted in the past 10 years.

Conclusion and policy recommendations

Based on the results of our review, several policy recommendations can made. First, it is important to create an enabling environment for the private sector to compete on a level playing field with the parastatal KSC. Second, at this stage in agricultural intensification, soil fertility is the major factor in maize yields, so it should receive the appropriate level of attention from research, extension, and policy.

Finally, to improve the adoption of IMVs, our results indicate several recommendations. More participatory variety evaluation would ensure varieties fit farmers' needs and reduce the number of varieties released that do not get adopted. Access to extension also needs to be promoted, both through the public extension service and the private sector, which now dominates seed dissemination, to ensure farmers choose the right varieties for their situation. Policies should also promote universal education, especially in rural areas. And, given its important effect on the adoption of IMVs, market participation of farmers needs to be encouraged and supported, by promoting good drying and storage practices and increasing access to markets, in particular through the provision of market information and infrastructure and a reduction in transaction costs.

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