Current Status and Future Prospects of Agricultural Mechanization in Sub-Saharan Africa [SSA]

by
G. C. Mrema
Professor of Agricultural Engineering
Sokoine University of Agriculture (SUA)
P.O. Box 3233, Morogoro
TANZANIA

J. Kienzle
Agricultural Engineer
FAO Headquarters, Rome
ITALY

J. Mpagalile
Agricultural Engineer
FAO Regional Office for Africa
Accra
GHANA

Abstract

In this paper, data on the demand for mechanization inputs (and potential for its growth) including availability of tractors in countries in sub-Saharan Africa [SSA]* is presented. Overall, the Southern Africa region has the highest number of tractors in use while the Central Africa region relies on human muscle power for primary land preparation on about 85% of the cultivated land. The annual level of importation of tractors and other agricultural mechanization inputs in many SSA countries is quite low and this raises the issue of the sustainability and viability of the franchises and supply chains for agricultural machinery, implements and spare parts. Due to the small size of the market for mechanization inputs in many countries, it is important to consider sub regional mechanisms and cooperation in order to establish viable agricultural machinery supply chains and manufacturing entities.

Acronyms	
AUC	African Union Commission
CA	Conservation Agriculture
CT	Conventional Tillage
DAP/T	Draft Animal Power/Technology
FARA	Forum for Agricultural Research in Africa
LAC	Latin America and Carribean
LSFs	Large-Scale Farmers
MNCs	Multinational Corporations
MSFs	Medium-Scale Farmers
PSFs	Peasant Subsistence Farmers
RECs	Regional Economic Communities
SAM	Sustainable Agricultural Mechanization
SCFs	Small-scale Commercial Farmers
SME	Small & Medium Scale Enterprises
THS	Tractor Hire Services
2+4WT	2+4 Wheel Tractor

*The *FAO Regional Office for Africa (RAF)* caters for 57 member countries in SSA. Further, there are four FAOs' Offices in SSA: (i) *Office for Central Africa (SFC)* covering Cameroon, Central African Republic, Chad, Republic of the Congo, Democratic, Republic of the Congo, Equatorial Guinea, Gabon and Sao Tome and Principe; (ii) *Office for Eastern Africa (SFE)* for Burundi, Djibouti, Ethiopia, Kenya, Rwanda, Somalia, South Sudan and Uganda; (iii) *Office for Southern Africa (SFS)* for Angola, Botswana, Comoros, Eritrea, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe; and (iv) *Office for Western Africa (SFW)* covering Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo.

Sustainable agricultural mechanization [SAM] is key to the development of the agricultural sector in SSA. A holistic approach is essential, as SAM contributes to environmental sustainability through the adoption of sustainable land preparation and crop husbandry techniques; to commercial sustainability through the use of business models which efficiently and profitably provide mechanization inputs and services to farmers at competitive and affordable prices; and to socio-economic sustainability through improved access to higher levels of mechanization inputs and services by smallholder farmers (including women, youth and the elderly). It is equally important to provide training in basic technical and business skills to farmers and mechanization service providers at all levels on how to safely use improved implements and power units in mechanized crop and livestock production systems on the farms and at homes.

Introduction

Progress in agricultural mechanization in much of sub-Saharan Africa [SSA] stalled for approximately three decades, from1985 to 2015. This resulted in limited visibility in national agricultural development programmes and often dropping off the agenda of international development organizations and donor agencies. The negative trend affecting the pace of agricultural development in SSA during this period included the decline of food production per capita, agricultural value addition and exports, and an increase of agricultural imports (FAO, 2015). The use of agricultural machinery such as tractors declined, and in several areas animal traction shifted back to hand hoeing due to, among other reasons, loss of draught animals to droughts, increased outbreaks of livestock diseases and deteriorating animal health service.

Agricultural mechanization is widely supported in SSA by farmers, local leaders, policy makers and politicians, although it has been subject to controversy in some circles. The SSA region was and is still considered to be a land surplus region with comparatively low population density and in most countries, wages remain low (Binswanger, 1986; IBRD, 1987). However, the factors that drove mechanization in other regions of the world may not be present in many areas of SSA (FAO, 2008 &2014). Africa's experience with oxen and tractor mechanization has, in general, not been very successful (Eicher and Baker, 1982; Pingali *et al.,* 1987; Mrema, 1991). Government investments in tractor support and supply schemes without sound mechanization strategies and policies may worsen the situation at field and farm level (FAO, 2008 & 2016; FAO/UNIDO, 2009).

This paper provides a review of the role of agricultural mechanization in agricultural and economic development of SSA, specifically on the current status and future prospects of agricultural mechanization. It includes an analysis of current and future potential markets for agricultural machinery and implements. This paper will focus on the technical constraints to effective and efficient utilization of agricultural machinery, implements and equipment in SSA including recommendations on the needs to be addressed by research and development institutions.

If agricultural growth and overall development is to occur in SSA, it is important that farming undergoes transformation and is geared towards increasingly competitive local, regional and international markets, with machines and implements in line with the other major inputs—improved seeds, fertilizers, water and pesticides—, all of which play an integral part in increasing agricultural productivity and overall production. In this regard, the role of the public sector should be to facilitate an enabling environment for promoting private sector initiatives which are key in the area of agricultural mechanization. This paper focuses on crop production as the core area of agricultural development—since livestock production and aquaculture are all interlinked with crop production.

This paper covers demand issues, including (1) area under production, types of farmers and major crops; (2) farm power typology; (3) the sta-

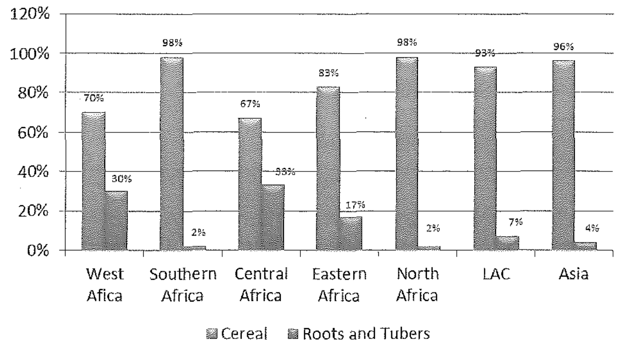


Fig. 1 % of Areas for food crops cultivated in SSA and Other Regions [2000] (Source: FAOSTAT/IFPRI -2014)

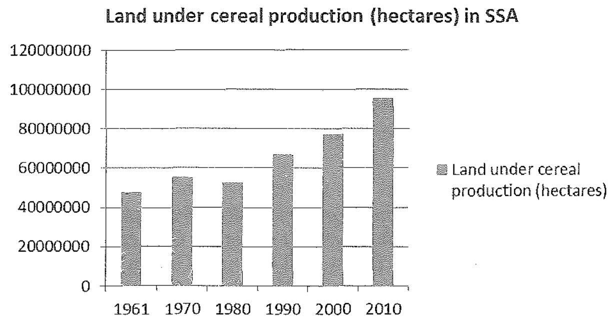


Fig. 2 Land under cereal production (hectares) in SSA (Source: FAOSTAT/IFPRI, 2014)

tus of agricultural implements and equipment; (4) the sustainability of agricultural mechanization systems in SSA; and supply issues, including (5) franchises for distribution of agricultural machinery, implements and equipment; (6) manufacturing of agricultural machinery and implements; and (7) research and development issues.

Types of Crops

In SSA, there are substantial areas where crops, such as roots and tubers are cultivated and dominate the food sector, unlike in Asia or Latin America & Carribean (LAC) where the dominant food crops are cereals. As shown in **Fig. 1**, in 2000 the area cultivating cereals, as a percentage of the total area cultivated, ranged from 67 percent in Central Africa to 98 percent in Southern Africa. On the other hand, roots and tubers ranged from 2 percent in Southern Africa to 33 percent in Central Africa. The data for Southern Africa is comparable to that of North Africa at 98 percent for cereals and 2 percent for roots and tubers, while corresponding figures for Asia and Latin America were respectively 96 percent and 4 percent and 97 percent and 3 percent of total cultivated land. Therefore, it is no wonder that Southern Africa and, to a lesser extent, Eastern Africa (both dominated by cereal-based systems) have much higher intensities of tractor use than either West or Central Africa.

The total area under cereals in SSA increased from 45 million hectares in 1961 to 96 million in 2010 (**Fig. 2**). The potential for further increasing the area under cultivation is high due to the fact that Africa has the highest area of uncultivated arable land (202 million hectares) in the world, about 50 percent of the global total. However, productivity lags far behind other developing regions with yields being only 56 percent of the international average (FAO, 2011; AfDB, 2016). In 2015, the total land area under cereals in SSA was about 68 percent of the 142 million ha under cultivation in India (Singh, 2016). Further, 40% of the cultivated land in India is irrigated compared to only 7 percent in SSA (FARA, 2014; AfDB, 2016). These statistics demonstrate the challenges of mechanizing agriculture in SSA, especially where small holder farmers dominate.

Types of Farmers

The agricultural sector in many countries in SSA has largely been dualistic, with a medium- and large-scale farm (MSF & LSF) sub-sector co-existing with a small-scale farm (SSF) sub-sector. The MSF & LSF sub-sector has been involved in producing cash and/or industrial crops—such as coffee, sisal, tobacco, pyrethrum, flowers and horticultural products, tea, maize, rice, wheat, dairy, beef, sugar cane, etc. (Wood, 1950; Mayne, 1954 & 1956; Eicher & Baker, 1982). At independence in the 1960s, the MSF & LSF sub-sectors were dominated by settler farmers and/or transnational corporations. After independence of numerous African countries during the 1970s and 1980s, a number of government owned state farms were established in many countries even though the private sector remained the dominant force. Also in some countries (such as Kenya, Tanzania, Zambia, Zimbabwe) which had large settler population, some of the large scale farms were acquired by the governments and sub-divided for re-distribution to small-holder farmers. After the economic structural adjustment programmes of the 1990s, most of the state farms were privatized. The LSFs have been highly mechanized and, in most countries, owned and operated a significant proportion of the four-wheel tractor [4WT] fleets in the various countries at any one time.

From a mechanization perspective, the farm power typology [FAO, 2005 & 2008] can be categorized under the following farmer groups:

- Peasant Subsistence Farmers (PSFs) cultivate less than 2 ha and rely on family labour and hand-tool technology for all field land preparation and crop husbandry tasks (e.g. primary tillage/hoeing; planting; weeding; harvesting and post-harvest processing; shelling; threshing). They may hire tractors or draft animal power [DAP] for land preparation—to break the hard pan or facilitate timeliness in field operations—if they have off-farm income and if the hiring cost is affordable.
- Small-scale Commercial Farmers (SCFs) cultivate 2 to 10 ha of land and would normally use DAP where it is available (either owned or for hire) or tractors (either two-wheel tractor [2WT] owned or for hire and/or 4WT for hire) for land preparation. Other tasks may be mechanized, including planting for maize, harvesting for paddy, shelling and threshing for maize and paddy. A few such SCFs may own 4WT bought second hand, in which case, they have to offer tractor hire services [THS] to other SCFs and PSFs to attain effective and commercial annual utilization rates of their machinery.
- Medium-Scale Farmers (MSFs) cultivate more than 10 ha and up to 100 ha. These farmers would normally have their own 2WT bought new and/or 4WT bought new or second hand and an assortment of implements. They may opt not to own their own equipment and instead rely on hired services where these are available, efficient and timely provided. If they own their own 4WT, they are unlikely to attain commercially optimum utilization rates on their farms alone and are in most cases forced to either offer THS to SCFs

or the PSFs, or engage in off-farm hire activities, such as in transportation, etc.

- Large-Scale Farmers (LSFs) cultivate more than 100 ha and up to 2,000 ha and will normally own a complete range of 4WT with their assorted implements. They may have to hire specialized machinery, such as combine harvesters. These LSFs may also offer machinery hire services to the MSFs on a contract farming basis for harvesting and so on. These could be state farms or privately owned commercial farms that grow both food and cash crops and are often linked to downstream agro-processing value chains (e.g. tea and sugar cane processing, seed production).

During the 1960s, and immediately thereafter, nearly all land under cultivation was, in most countries, owned by the small scale farmers [PSFs and SSFs], with the exception of the countries that had large settler populations (e.g. Angola, Kenya; Namibia, Mozambique, Zambia, Zimbabwe). In this regard, South Africa is the special case with MSF and LSF dominating its agriculture and land ownership. A recent survey of several countries shows that since the beginning of the twenty-first century, the ownership pattern of farms is changing and the role of medium scale farmers [MSF] is increasing. This is illustrated in **Fig. 3** where land owned by SSF in 2015 in Ghana, Tanzania and Zambia was respectively 49 percent, 53 percent and 34 percent of total cultivated land.

From a mechanization perspective, the land owned by MSFs in Ghana, Tanzania and Zambia was at 33, 38 and 54 percent respectively. In addition, large-scale farmers respectively owned 18, 9 and 12 percent of total cultivated land in these three countries. Only in Kenya is the situation slightly different, with land owned by the SSFs, MSFs and LSFs at respectively 66, 19 and 15 percent of total cultivated land. This situation reflects the impact of the land settlement programmes in Kenya of the 1950s and 1960s under the Swynnerton Plan, the independence era land reform, and the commercialization of the SSF sector through the growing of high-value cash crops (such as coffee, tea, dairy, horticulture) [Swynnerton, 1954; Clayton, 1973]. There is therefore considerable transformation of the farming system, which will significantly influence the pace of agricultural mechanization as well as demand of agricultural machinery and implements in SSA (FAO, 2008; AASR, 2016).

The Farm Power Typology

Agricultural mechanization in SSA has remained at the first stage of the mechanization process, referred to as the Power Substitution Stage. This is the earliest developmental stage involving the substitution of the use of animate power (either from muscles of humans or draft animals) with mechanical power from internal combustion engines and/or electric motors used in performing energy-intensive and often back-breaking tasks, such as primary land tillage, and grain milling (FAO, 1981; Rijk, 1983; Singh, 2001).

The extent of available farm power plays an inordinate role in defining the level and process of agricultural mechanization in a country and has been a major indicator of progress attained. In this regard, the role of farm power in increasing agricultural productivity globally was first hypothesized in 1965 by Prof. Giles '....farm power with fertilizers, improved seeds [HYVs], irrigation and pesticides are interdependent for growth in agricultural productivity and overall growth....' (Giles, 1966).

Success of the green revolution (GR) of the 1970s in Asia was attributed mostly to the increased use of HYVs, fertilizers and irrigation but the role of farm power was not examined. The mechanization experience of developed countries, such as the United States of America and European countries from 1925 to 1965 demonstrated the criticality of farm power:

- According to White (2000; 2001), the tractor was the "Unsung Hero" of twentieth century economic growth of the United States of America. It replaced 24 million draft animals from 1925 to 1955 and significantly transformed agricultural productivity and land-use patterns.
- Similar developments occurred in Europe between 1945 and 1965, facilitated in large part by Marshall Plan, when millions of draft animals were replaced by tractors (Carillon & Le Moigne, 1975; Promsberger, 1976; Gibb, 1988).

When most countries in Africa,

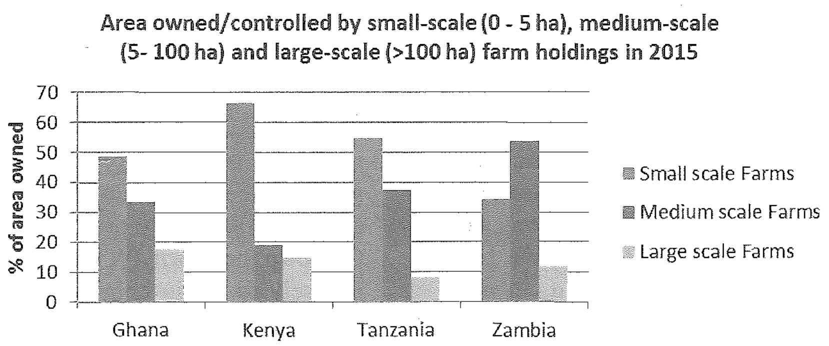


Fig. 3 Areas of different farm sizes in four countries in 2015 (Source: AASR 2016 - Jayne & Amayew)

south of the Sahara gained political independence during the 1960s, the advent of mechanization in developing countries (e.g. Asia, Africa, and LAC) was therefore equated to "tractorization," which became the prevailing development paradigm accepted by most development experts, politicians, and major development organizations which were supporting agricultural development in SSA countries (IBRD, 1960; GoG 1962; FAO, 1966; de Wilde, 1967; Gemmill and Eicher, 1973). The number of tractors in use in any country, therefore, has been the main indicator of levels of mechanization represented in the databases of the major development agencies such as FAO, UNIDO and the World Bank.

The significant role of farm power is even more prominently demonstrated by the situation in Asian countries where significant progress in agricultural mechanization has been achieved over the past fifty years—from a farm power availability level of less the 0.2kW/ha in the 1960s to in 2013 a level of 2.5, 2.02, 1.7 and 1.32 kW/ha for Thailand, India, Viet Nam and Cambodia respectively (Singh and Zhao, 2016). The increased utilization of farm power has been achieved by increased investments in mechanically powered machinery and equipment—tractors, irrigation pumps, harvesters, etc.—and significant reduction in use of animate power from draft animals and human muscles. In India the use of animate power has declined from 90 percent of power available per hectare in 1961 to less than 10 percent by 2014 whereas the mechanical power availability increased from less than 10% to over 90% by 2014 [Singh, 2016].

Hand-tool Technology and Ergonomics of Human Muscle Power

Agriculture in SSA is still carried out using hand-tool technology with almost entire reliance on human muscle power on about 60 to 80 percent of the cultivated land (**Fig. 4**). Ergonomically, primary land preparation by hand-hoeing is the most difficult task, demanding excessive power input from human muscles with the level of energy expenditure being 8 to 10 kilo calories per minute (kcal/min) in the tropics (Passmore & Durnin, 1955; Fluck & Baird, 1979; Nag & Pradhan, 1992). Planting and weeding demand about 25 to 40 percent of the power required for hand hoeing. Although the time taken to perform a task is essentially linked to the energy demanded by that task, the rate at which energy is required is critically important (Boshoff & Minto, 1974; Mrema, 1984; Nwuba & Kaul, 1986). Therefore, the engineering design efforts have been directed at reducing the rate of energy demand. It is particularly desirable, if energy required to operate a piece of equipment is reduced to approach the ergonomically tolerable level of 3 kcal/min. As it has been observed elsewhere this level of energy demand by human powered equipment will be preferable even if there is no dramatic increase in the work output per unit time (Boshoff & Minto, 1974; Mrema, 1984; Nag & Pradham, 1992).

It is no wonder therefore, that many 'appropriate' or 'intermediate' technologies designed during the 1970s & 1980s and powered entirely by human muscles were not adopted by farmers notwithstanding their perceived better work output. As noted in several ergonomic studies, if the equipment does not offer noticeable improvement in the rate of energy demand from the operator it is unlikely to be favorably received by farmers (Boshoff & Minto, 1974; Makhijani, 1979; Stanhill, 1984; Fluck, 1992). It is for this reason, among others, that agricultural mechanization which liberates the African farmer from the drudgery associated with using the hand hoe as a basic tool in agriculture has strongly been supported by African leaders and politicians as well as farmers (Eicher & Baker 1982; FAO, 2008; FAO, 2013).

Unlike in Asia where DAP has been used for centuries, SSA is the only region in the world where the difficult and arduous tasks like primary tillage are being performed with entire reliance on human muscle power on over 60 percent of cultivated land. Hand hoeing has been regarded by the judicial system in most countries of the region as a deserving punishment for the worst crimes, when one is sentenced to serve a term in prison with 'hard labour'. Other regions in the world have long-ago liberated their farmers, through draft animals and/or machines, from this burden of tilling the land by hand hoeing.

Liberation of the African farmer from the drudgery associated with using the hand hoe, as a basic tool

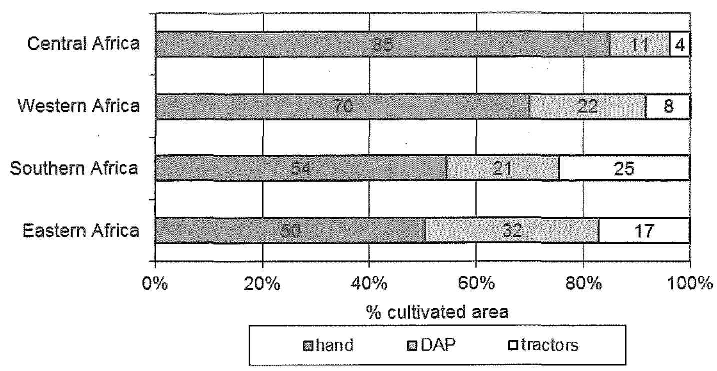


Fig. 4 Source of power for primary land preparation in sub-Saharan Africa (2005) (Source: FAO, 2008)

in agriculture, is therefore a high priority item as enunciated in the Malabo Declaration of 2014 and Vision 2063 of the African Union (AUC, 2016). This is also consistent with the strategies of a number of countries to significantly reduce, by 2035, the area tilled by the hand hoe. One could also argue that the slash and burn system of cultivation was/is a response of the African farmer to tackling the problem of the drudgery associated with primary tillage by reducing the energy required for land preparation, from the 8 to 10 kcal/minute expended using a hand hoe to a more tolerable level of 3 to 5 kcal/min required for slashing (AUC/FAO; 2017). In this regard, ergonomics may be more important in mechanization policy considerations than merely looking at the issue from the perspective of economics of unemployed labor.

Draft Animal Power [DAP] and Associated Technologies

In other regions of the world, agricultural mechanization has evolved through three power stages—the hand-tool technology, draft animal technology (DAT), and mechanical technologies. In most cases, the intermediate stage of DAT lasted for several generations and centuries. Furthermore, farmers had a long tradition of keeping livestock for other products and services (meat and milk; transportation) before using the same for tillage. It has therefore been expected that SSA will evolve through the same three stages in so far as farm power is concerned.

This has not been the case due largely to the fact that in much of SSA those who own much of the livestock that could be used for draft purposes are essentially pastoralists and are traditionally not involved in crop production (e.g. Maasai in Tanzania and Kenya). In addition, almost two-thirds of the land area of SSA is infested with tsetse flies, which makes it difficult to keep livestock. Unfortunately, tsetse infested areas are in the humid tropics of Western, Central, Eastern and Southern Africa with large tracts of uncultivated land which could potentially be used for crop production [**Fig. 4**]. Rendering these areas tsetse fly-free, involves massive land clearing which inevitably leads to severe environmental degradation (Ford, 1971; Tiffen *et al.*, 1994).

With the exception of countries like Ethiopia and Mali, where DAP has been used for centuries and where it has been considered as a possible intermediate stage of mechanization, in other countries its development and dissemination have encountered challenges (Kjoerby, 1983; Ehui & Polson, 1992; Mrema & Mrema, 1993). While DAP has been promoted in such countries for more than a century, its adoption has largely been confined to the drier areas where the farmers have both a livestock and a crop husbandry tradition—in Tanzania this is confined to five regions in the North West out of 26 (Mrema, 2016; Mrema & Kahan, 2017). Consequently, tillage and transport services by draft animals (mostly cattle and donkeys) will remain important only in these regions.

Also, DAT is challenged by the growing demand for livestock products (including donkey skin) and recurrent costs associated with keeping livestock for draft purposes (human resources for herding and shortage of grazing land). Furthermore, heavy soils found especially in the humid zones of SSA makes it necessary to use two to three pairs of oxen, thereby increasing the investment cost and complicating the training required. The demand for livestock products is increasing rapidly throughout SSA due to urbanization—expected to reach more than 50% of total population by 2040 in all SSA countries (UNFPA, 2016)—and improved living standards.

Notwithstanding, the massive dissemination effort of DAP by the public extension services and many NGOs, it is also regarded by some, especially the youth, as a "BC" (Before Christ) technology and not a technology for the twenty-first century. This perception is heightened by the unprecedented pace of technological transformation which has occurred in other sectors like ICT (mobile telephones) and transportation (2- & 3-wheel motorcycles and pickups) in the last 20 years. The ubiquitous expansion of the use of motorcycles and tricycles, as well as second-hand vehicles, has created a vast institutional and physical infrastructure for motorized equipment which was not there in the 1970s and 1980s. This has made DAT look like an obsolete technology and not appealing especially to the youth of the 21st Century

The key question therefore, is whether the agricultural mechanization strategy in some areas of SSA should aim at leapfrogging the DAP stage. For quite some time, this has been an issue of debate, among development experts having in some cases diametrically opposite views (de Wilde, 1967; Kline *et al.*, 1969; FAO, 1975, 2008; Eicher & Baker, 1987; IBRD, 1987; Pingali *et al.*, 1987; Panin, 1994; Starkey, 1998). Since DAT has only been adopted mostly in the drier areas and only by farmers who have a livestock and crop husbandry tradition, it may well be time to consider leapfrogging this stage of mechanization development. There are however a number of experts who advocate the continued promotion of DAT, ostensibly due to the perception that it is a renewable source of power/energy and more environmentally friendly (Dikshit & Birthal, 2010) as well as being more socially sustainable and equitable [Binswanger, 1978]. This should be scientifically and objectively assessed and the issue resolved as some have noted (Fluck & Baird, 1979; Adams, 1988; Stanhill, 1984).

Mechanical Power

Four types of mechanical power technologies are used in agriculture in SSA with varying degrees of success:

i) Tractors including:

- Traditional two-axle, four-wheel tractors (4WT) in either the two-wheel drive (2WD) or four-wheel drive (4WD) versions,
- Specially designed, for the developing world, four-wheel low-horse power tractors developed between the 1960s to 1980s, such as the Kabanyolo, Tinkabi, etc. (Boshoff, 1966),
- The power tiller or two-wheel tractor (2WT), which is a single-axle tractor developed initially for cultivation in irrigated areas in Asia;
- Crawler Tractors for land clearing and construction work.

ii) Motorized pumps and other water lifting devices;

iii) Motorized harvesting, post-harvest handling and on-farm processing equipment (including combine harvesters, threshers, shellers, etc.);

iv) Grain milling equipment (such as hammer mills, disc attrition and roller mills).

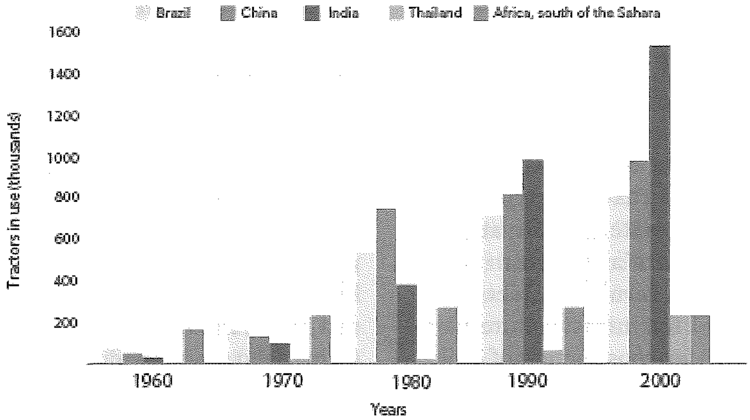
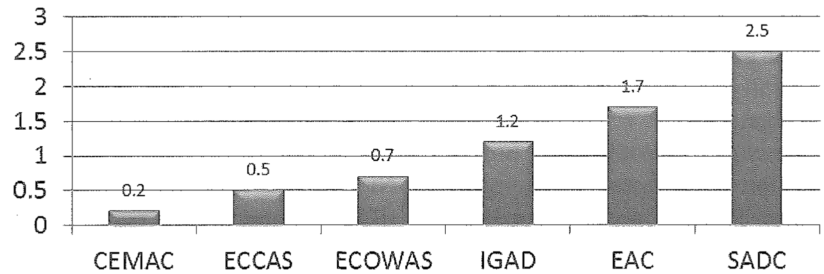


Fig. 5 Tractors in use in SSA cf. Other developing countries (Source: FAOSTAT/AGS, 2004; FAO, 2008)



(i) *Central African Economic and Monetary Community (CEMAC)*: Cameroon, Central African Republic (CAR), Chad, Equatorial Guinea, Gabon and Republic of Congo; (ii) *Economic Community of Central African States (ECCAS)*: Angola, Burundi, Cameroon, Central African Republic, Chad, Republic of Congo, Democratic Republic of Congo, Equatorial Guinea, Gabon, Rwanda and Sao Tome and Principe; (iii) *Economic Community of West African States (ECOWAS)*: Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, The Gambia, Ghana, Guinea, Guinea Bissau, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo; (iv) *Intergovernmental Authority on Development (IGAD)*: Djibouti, Ethiopia, Kenya, Somalia, Sudan, Uganda, Eritrea and South Sudan; (v) *East African Community (EAC)*: Kenya, United Republic of Tanzania, Uganda, Rwanda, Burundi and South Sudan; and (vi) *Southern Africa Development Cooperation (SADC)*: Angola, Botswana, Comoros, Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, United Republic of Tanzania, Zambia and Zimbabwe.

Fig. 6 Number of tractors per 1,000 ha of land in different RECs (Source: FAOSTAT)

From a mechanization perspective, the tractor (mostly 4WT) and hammer mills used for grain milling represent the two main types of agricultural machinery technologies disseminated over the past seven decades on a relatively large scale in SSA, with varying degrees of success. This equipment is expensive and unaffordable for a majority of farmers. Therefore, rental mechanisms are the main route through which farmers, in particular the small-scale ones, have been availed use of such machinery services. In most countries in SSA, services offered under tractor hire services [THS], include primary land preparation and transportation, making the plow (disc, moldboard and chisel), the harrow and the trailer, the most important implements in use (Kolawole, 1974; Seager & Fieldson, 1984).

Recently, from 2005, there has been increasing interest in 2WT as a solution to the mechanization problem of SSA. The success of the 2WT in mechanization of rice-based farming systems in Asia has catalyzed efforts to introduce it to similar systems in SSA. New manufacturers and suppliers—mostly from Asia—have emerged and established supply chains for 2WTs, their accessories and spare parts on the continent. Significant adoption has occurred in a number of districts in different countries, largely in rice-based irrigated farming systems. Over 70 percent of the 2WT in use in SSA in 2010 were in three countries (Madagascar; Tanzania and South Africa) with the remaining 25 percent spread in the rest of the continent (AUC/FAO, 2017).

Specially designed tractors for agriculture in the developing world were tested in several parts of Africa during the 1970s and 1980s. Notable in this respect, were the thousands of Swaziland-designed and manufactured Tinkabi tractors. Thousands of these specially-designed tractors were imported by some countries in Southern Africa in the 1970s & 1980s. However the testing with this type of farm power was not successful and stopped in the mid-1990s (Boshoff, 1966; Holtkamp, 1989 & 1991; Dihenga & Simalenga, 1989).

There has been some experience of using and operating tractor hire services (THS) for both the traditional tractor (4WT) and more recently and to a lesser degree—the power tiller (2WT). Both the public and private sectors have been involved in offering THS. Many public sector THS of the 1960s to 1980s failed and this significantly influenced policy decisions on the use of tractors in Africa during the last two decades of the 20th Century (Kolawole, 1974; Seager & Fieldson 1984; FAO/UNIDO, 2009).

The hammer mill used for grain milling is a case of successful development and dissemination of mechanical technologies in SSA, from which lessons on operating machinery hire services can be learned. The issue of agricultural machinery hire services on a commercially sustainable basis, therefore, has been and will remain high priority in any strategy for sustainable agricultural mechanization in SSA. Mechanization of grain milling has occurred in most SSA countries through the introduction and operation of hammer and disc-attrition mills operated by small and medium scale entrepreneurs [SME] who offer hire services to the farmers and other consumers. This has led to a rapid transformation of the grain milling sector—the shift from traditional tools (such as grinding stones and/or pounding in a mortar and pestle) to milling using hammer mills powered by electric motors or small engines. This transformation has been particularly of relief to women and youth who were the main power sources for the traditional tools. The same model is being applied in dehulling of rice in many rice growing areas.

Other powered machinery includes crawler tractors used in land clearing and road construction—these are operated by private sector contractors although in a few countries government fleets have been used for infrastructure work including for construction of irrigation as well as soil and water conservation infrastructure. Combine harvesters are used especially in those countries with a significant number of medium and large scale farms. There is also an increasing number of farmers using irrigation pumps powered by small engines especially for production of fruits and vegetables.

The changes in the farm power situation (as denoted by the total number of 4WT in use) from 1960 to 2000 in SSA is given in **Fig. 5** where it is also compared to the situation in Brazil, China, India and Thailand. As noted in FAO, 2008, the trend in tractor use in SSA has been quite different as compared to other developing countries during 1960 to 2000. While the number of tractors in use in SSA in 1961 was more than in both Asia and in the Near East regions (at 172,000 versus 120,000 and 126,000 units, respectively), it increased very slowly thereafter, peaking at only 275,000 by 1990 before declining to 221,000 units by 2000. The number of tractors in use in SSA in 2000 was about 3.3 percent, 11 percent and 12 percent of corresponding numbers of tractors in use in Asia, Latin America & Caribbean (LAC) and Near East regions, respectively.

While in 1960, SSA had 2.4, 3.3 and 5.6 times more tractors in use than in Brazil, India and the People's Republic of China respectively, by 2000, the reverse was the case, and India, the People's Republic of China, and Brazil had respectively 6.9, 4.4, and 3.7 more tractors in use than in the entire SSA region (including South Africa) [**Fig. 6**]. Similarly in 1960, SSA had approximately 3.4 times more tractors in use than in Thailand; however, by 2000 Thailand had the same number as in SSA. Furthermore, the tractors in use in SSA in 2000 were concentrated in a few countries, with 70 percent being in South Africa and Nigeria.

The number in use per 1,000 ha of arable land is shown in **Fig. 7** for the different Regional Economic

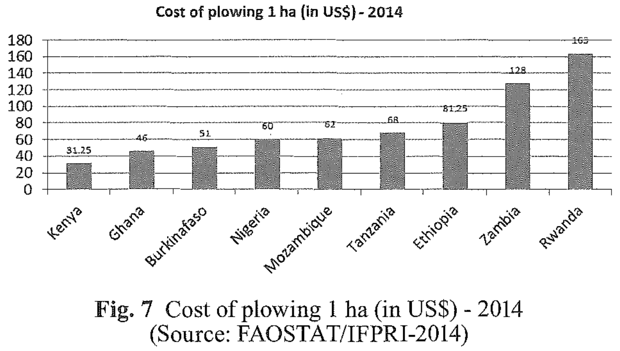


Fig. 7 Cost of plowing 1 ha (in US$) - 2014
(Source: FAOSTAT/IFPRI-2014)

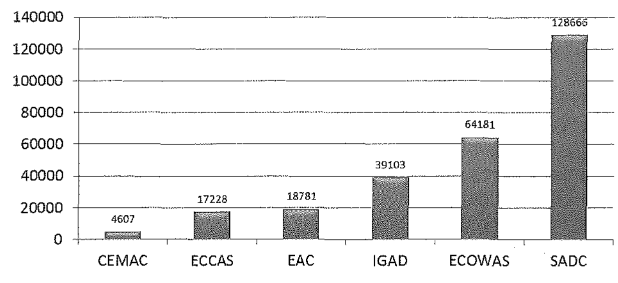


Fig. 8 Number of 4WT imported during 2000-2007 in different RECs
(Source: FAOSTAT, 2000-08)

Communities (RECs) in SSA. The lowest number is 0.2 tractors per 1,000 ha in Central Africa (CEMAC) and the highest is 2.5 in Southern Africa (SADC). These figures compare very unfavorably with the global average of 13 tractors per 1,000 ha. It is no wonder therefore that the cost of ploughing a hectare of land in many countries in SSA is quite high ranging from $31 in Kenya to $163 in Rwanda [**Fig. 8**]. These high costs reflect the scarcity of farm power services in the countries of SSA and need to be reduced if mechanization services are to be affordable to the small-scale farmer and farming is to remain a competitive business.

Agricultural Implements and Equipment

The source of farm power and its use by small-scale farmers was a notable feature of the debate on agricultural mechanization in Asia and Africa during the second half of the twentieth century. Mechanization studies in Asia and in SSA in the 1960s and 1970s were not very concerned about the environmental impacts of tillage implements being hitched to the draft animals and/or tractors until much later. Research on tillage then was more focused on the need to reduce draft power requirements and increase the versatility of the implements for multipurpose use, such as ploughing, harrowing, planting and weeding (Maher, 1950; Willcocks & Twomlow, 1992; Lal, 1998; Starkey, 1988).

On the other hand, mechanized tillage was one of the major contributors to the dust bowls in the United States of America in the mid-1930s. This led to a large long-term research programme focused on better tillage implements and practices. It is in this context that minimum tillage practices and conservation agriculture (CA) gained traction in North and South America (Troeh *et al.*, 1980; Lal, 1998; Friedrich, 2013). CA is an approach to manage agro-ecosystems for improved and sustained productivity, increased profits and food security while preserving and enhancing the resource base and the environment [Friedrich, 2013]. The environmental impact of mechanization, especially of tillage implements and practices, became an issue of concern in Asia and Africa only in the late 1990s and at the beginning of the twenty-first century. This led to the introduction of Conservation Agriculture (CA).

According to the African Conservation Tillage (ACT) Network, the adoption of CA practices in sub-Saharan Africa has occurred more on large scale farms. For example, out of a total of 2.679 million hectares under CA in 2016, about 1.835 million ha were under large farms in South Africa, Zambia, Mozambique, Malawi and Zimbabwe, using technologies similar to those developed for North America and Australia (ACT, 2017). Adoption is highest in South Africa with 65.3 percent of the total area under CA in Africa followed by Zambia at 11.8 percent, Malawi at 7.9 percent, Mozambique at 5.7 percent and Zimbabwe at 3.7 percent. These five countries have 94 percent of the total CA area in Africa. Adoption of CA on small scale farms in these countries has been promoted through donor-funded projects. The percentage of cultivated land where CA has been adopted in Africa, south of the Sahara is still very small compared to where conventional tillage [CT] is used (ACT, 2017; Friedrich, 2013, Houmy *et al.,* 2013). There is also concern on the use of herbicides, increased through the adoption of CA, especially in the smallholder sector where environmental and food safety safeguards are not that well developed.

The major challenge of agricultural mechanization in SSA remains the need to increase the farm power available for, among other reasons, relieving the African small-scale farmer of the drudgery associated with hand hoeing. CA is focused on the second problem, which involves the type of implements and crop husbandry practices to be adopted. It is important these two problems are handled in the right sequence. Today, CT implements (e.g. disc, and/or moldboard plows and harrows) are being used on most of the cultivated land in the region where mechanical technologies have been adopted. Also, most of the land cultivated by small-scale farmers has not been completely de-stumped, thus making use of other types of implements difficult [e.g. CA implements].

Other implements and equipment include:

- Crop protection equipment—both manually operated as well as powered ones.
- On-farm produce handling and processing equipment such as threshers, decorticators, shellers, cream separators and cooling tanks, etc.
- Rural transportation of agricultural produce and input supplies through animal drawn carts where draft animals are available or through wheeled equipment (bicycles, two and three wheel motorcycles and pickup trucks—especially second hand trucks imported from Europe and Japan—and tractor trailers).

These may be owned by the individual farmer although in recent years there are quite a number of entrepreneurs who offer implement/equipment hire services (e.g. maize shelling, threshing of paddy and sorghum, sprayers) to farmers including small-scale farmers.

Sustainability of Agricultural Mechanization Systems in SSA

Successful agricultural mechanization is historically linked to market-oriented enterprises, which generate the necessary cash flow to cover capital costs and facilitate loan repayments. Effective demand for outputs of farming translates into effective demand for equipment and machinery services, only if farming is profitable (FAO, 2008). If farms are not profitable before mechanization, the likelihood of them becoming profitable as a result of mechanization alone is low. In most circumstances, as noted in FAO (2008), it is perhaps more realistic to view farm profitability as a condition that makes mechanization feasible, rather than as an outcome of mechanization.

In SSA, the low profitability of many small farms coupled with the levels of investment required, places medium- and large-scale (5 to 200 ha) commercial farmers to be in the most favorable position to mechanize first, as has happened in Asia (FAO, 2008 & 2014; Singh, 2013; Wang, 2013). Even medium-scale commercial farmers face constraints that limit the profitability of their farming enterprises and may find it difficult to maintain and replace equipment. Furthermore, costs of hiring machinery for plowing are extremely high in Africa (**Fig. 8**). Increasing the profitability of medium-scale commercial farming would undoubtedly boost effective demand for mechanical technologies, augment the supply of machinery hire services to small-scale farmers, and reduce unit costs of hiring machinery (Mpanduji, 2000; Agyei-Holmes, 2014). It is therefore important to identify such farmers and encourage the development of viable commercial farming operations, which also would have the potential of providing mechanization services to smaller-scale farmers (FAO, 2008; 2013).

In order to facilitate the commercial sustainability of agricultural mechanization systems, there is need to adopt a holistic approach and to consider the entire agri-food chain, including financing of capital investments required to support the acquisition of farm machinery and implements, off-farm uses of mechanization inputs, and value addition activities on the produce. Mechanization technologies for agri-food chains can also contribute significantly to programmes for reducing losses along entire food chains and for maintaining rural infrastructure and increasing employment opportunities in rural areas, especially for the youth and women.

Coupled with this is the need to achieve efficient utilization rates of agricultural machinery as well as the timeliness of performing field operations. Studies in several parts of SSA show that delayed planting can lead to reduction in yields in rain fed cereal systems in the semi-arid areas of up to 100 kg/ha for each day planting is delayed beyond the optimum date (Kosura, 1983). Further, the number of days available for field operations in such semi-arid areas is limited to about 30 days and hence timeliness is critical in most farming systems in SSA (Simalenga, 1989; Simalenga & Have, 1992). This limits the effective annual utilization rates, of say tractors [4WT], to 300 to 400 hours as opposed to the recommended 800 to 1,200 hours (Crossley & Kilgour, 1983; Hunt, 1983; Culpin; 1988; Kepner *et al.*, 2005). This will remain a major challenge to the commercial viability and profitability of powered mechanization investments in SSA. This calls for cross border services, for example for bordering countries within the same regional economic community (RECs).

There is also the issue of policies and strategies for agricultural mechanization, including for financing of agricultural mechanization inputs and services and for research and development. This involves, in particular, the roles of the public and private sectors in these areas, including which sector should take a lead, and where joint action is required. The failures which occurred in the 1960s and 1970s were caused by, among other reasons, the lack of clear policies and agreement on the roles of each of the sectors.

While it is agreed that the private sector should take a lead in agricultural mechanization initiatives, it is also important to recognize that the private sector works best if there is a large enough demand for mechanization inputs and services. Some of the past public sector actions were a result of low demand in most countries, which led to the sub-sector being unattractive to the private sector. As shown in **Fig. 8**, the number of 4WT imported annually in the different RECs over the eight years period 2000-2007 is quite low. It is only in Southern Africa [SADC] and West Africa [ECOWAS] where the numbers are substantial to attract significant private sector investments. At the same time, there is also a lack of critical mass on an individual country basis (for R & D, testing and standards, etc.) and this may necessitate some cross country cooperation especially for capacity building to achieve economies of scale and scope.

When adopting a more holistic approach, the sustainability of agricultural mechanization systems in SSA takes into consideration sustainability from a commercial, environmental and socio-economic perspectives. Sustainability includes environmental sustainability, in particular the contribution which agricultural mechanization interventions can reduce soil erosion and compaction by adopting sustainable land preparation and crop husbandry techniques; commercial sustainability through business models which offer mechanization services to farmers not only efficiently and profitably but also at competitive and affordable prices; and socio-economic sustainability that recognizes the dominance of smallholder farmers in SSA agriculture and other groups who may be disadvantaged by higher levels of mechanization (including women, youth and the elderly). Sustainable agricultural mechanization strategies will need to cater for all these issues to ensure that, to the extent possible, the interests of all these groups are addressed and they contribute effectively and efficiently to the national economy (ILO, 1973; FAO/OECD, 1975).

Franchises and Supply Chains for Agricultural Machinery and Implements

Timely availability of machinery, equipment, spare parts and other supplies is essential for successful and sustainable agricultural mechanization. Agricultural mechanization includes the development of local industries for production of machinery and implements. Where production is not feasible, the establishment and development of local franchise holders are needed to import them. Even more important is the need to establish efficient and effective distribution channels for equipment, spare parts and repair services and supplies, such as fuel and lubricants. Mechanization should include the development of supply chains and the associated logistical services in order to ensure a better choice of equipment for particular types of users and uses.

During much of the second half of the 20th century, the manufacture and supply of agricultural machinery was dominated by suppliers from the western world (Kurdle, 1975; Burch, 1987). From the turn of the 21st century, however, new suppliers of agricultural machinery and implements have emerged from Asia. The People's Republic of China and India, in particular, have become important global suppliers of low-cost appropriate equipment (Singh, 2013; Wang, 2013; Renpu, 2014). Further, most of the machinery and implements available from the high-income industrial countries are too expensive and too complicated, with often a high power rating and adapted for extremely large-scale farms. Brazil, India, the People's Republic of China, Pakistan, and other developing countries produce and export agricultural machinery and implements at lower prices than prevailing prices of equipment imported from developed countries.

Elimination/reduction of import duties on agricultural machinery and equipment, except in countries that have a thought-out plan to develop local production capacity, could significantly increase access to agricultural mechanization inputs. Opportunities exist in rural settlements and in urban centers and towns to harness the potential entrepreneurial talent available in SSA for promoting the development of input supply chains and agribusinesses focused on the provision of services to producers and processors. The impact could be considerable and the number of jobs created, indirectly through manufacturing and dealer operations, could be substantial.

The issue of efficiencies of the franchises and supply chains for agricultural machinery and implements is critical. According to the available data 26 countries in SSA have less than 1,000 tractors in use, and 6 had between 1,000 to 2,000 tractors, with 10 having between 2,000 and 10,000 units and only 6 with between 10,000 and 30,000 units. South Africa stands out with over 67,700 tractors in use [**Fig. 9**]. Given that these usually represent several brands and sizes of tractors—this implies that the numbers of a particular brand and size imported each year in most countries is quite small, thus raising the issue of sustainability and viability of the franchises and supply chains for agricultural machinery, implements and their spare parts. This is a critical issue related to sustainability of mechanization in many countries in SSA and requires regional collaboration under the regional economic commissions.

Manufacturing of Agricultural Machinery and Associated Services

Coupled with the viability of franchises and supply chains for agricultural machinery and implements is the issue involving manufacturing and testing of agricultural machinery, implements and equipment in the region. Given the small size of the market for mechanization inputs in most countries this is likely to require cooperation at the sub regional level to attain economies of scale and scope if viable manufacturing entities are to be established. A start could be made by developing sub-regional protocols for setting standards and testing of agricultural machinery and implements under the regional economic commissions. Many of the agricultural machinery manufacturing units established in the 1970-1990 period became uncompetitive as a result of the global trade liberalization agreements implemented since the turn of the century.

Under the RECs, the development of local industry for manufacturing of machinery, implements and equipment is a feasible option in quite a number of countries. It has the advantage of generating alternative employment, reducing dependence on imports, saving foreign exchange and facilitating the supply of parts and services. Some of the machinery and equipment needed (fodderchoppers and threshing machines, as well as a range of implements), whether powered by human or draft animal muscles or engines and motors, could be manufactured and serviced locally in many of the countries of Africa, south of the Sahara.

Implements specific to the local

circumstances (agricultural conditions, soil types, etc.) can best be made by small-scale industries, thereby reducing manufacturing and transportation costs and generating employment. To the extent possible, most hand tools and animal drawn implements should be manufactured in the country where they are to be used. It is unlikely that the agricultural machinery for medium and large-scale commercial farmers could be manufactured locally in many countries, it is conceivable that some countries could start by assembling them from Semi Knocked-Down [SKD] parts and Completely Knocked-Down [CKD]

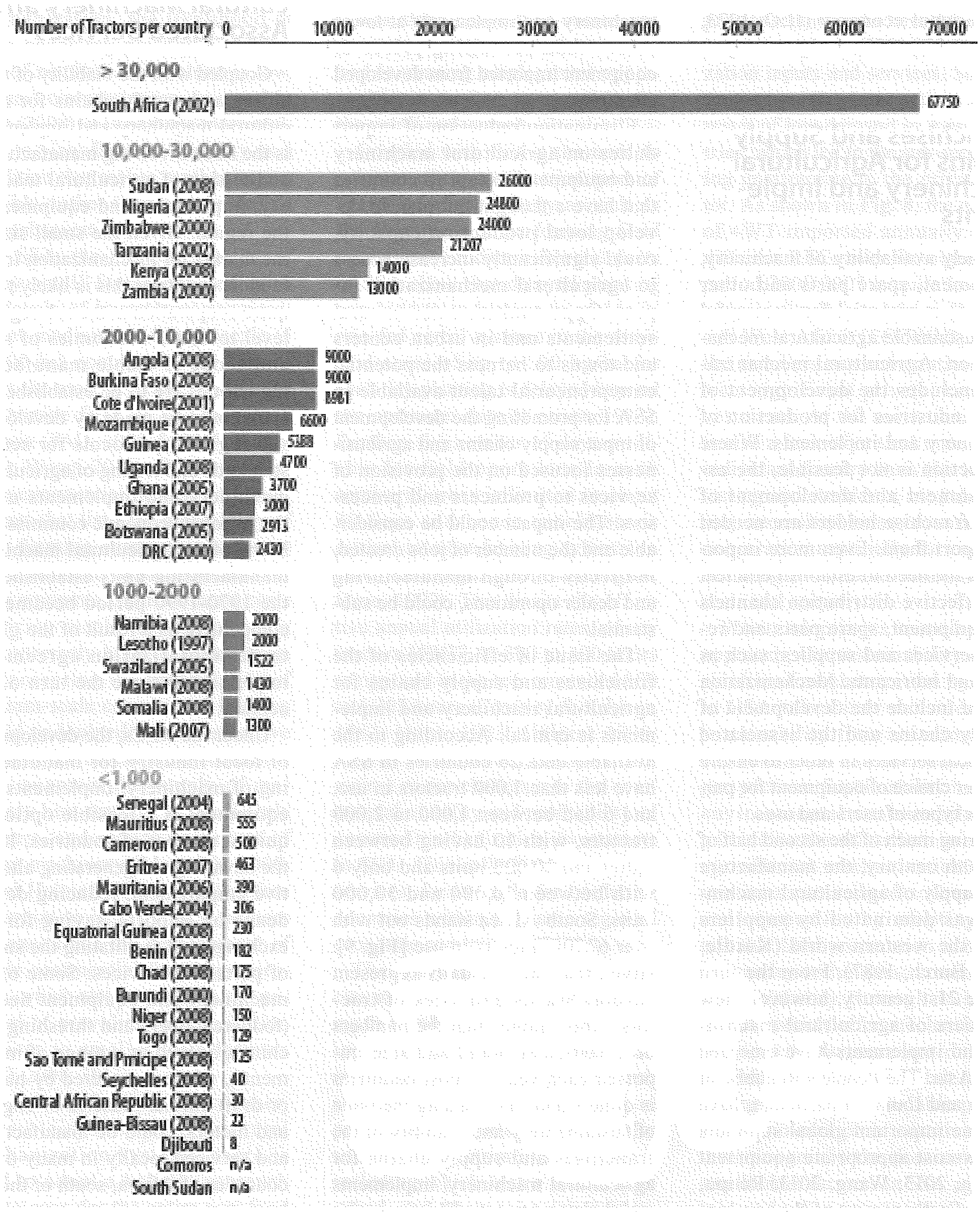


Fig. 9 Number of tractors [4WT] per country – Viability of agricultural machinery franchises (Source: FAO-STAT; World Bank Stat -; AUC/FAO, 2017)

parts.

Such arrangements should be facilitated through the RECs, as the demand in most countries is small and a sub-regional market should be considered (**Figs. 8 & 9**). Also, testing and certification of agricultural machinery and implements, to the extent possible, should be considered at the regional/REC level. Most countries in Africa, south of the Sahara will not likely be able to establish and finance adequately equipped and resourced testing centers at the national level. The RECs should consider facilitating the establishment of regional centers of excellence and networks for standard setting and testing of agricultural machinery and implements.

Research and Development

Public sector research and development activities on agricultural machinery and implements, including sustainable mechanization, are normally handled, in most countries, by several government departments, often lacking coordination between them. These include: Agriculture (mechanization research, soils, post-harvest, irrigation, etc.); Trade and Industries (industrial research; manufacturing; patenting; standards; trade licensing, etc.); Energy (energy generation and distribution, alternative fuels, etc.) and Higher Education (research and education on all aspects of mechanization in schools of agriculture and engineering). Globally, the private sector has undertaken much of the research and development work as well as technology transfer for agricultural machinery and implements in the developing countries.

The private sector is also responsible for the manufacture and distribution of agricultural machinery, implements and equipment to farmers. Some of these private sector entities are branches of multinational Corporations (MNCs), while others are local companies that have established themselves over the past one to two decades. Coordinating and regulating the activities of all these entities, and those of the public sector research and development centres, is an issue of concern for most countries in the developing world. This applies both to activities at the national and regional levels.

In a majority of SSA countries, the strongest in-country capacity for R & D resides in the agricultural engineering departments in the schools of agriculture and/or engineering of the universities. These departments are responsible for training human resources in three critical disciplines: agricultural engineering and mechanization; irrigation and water resources engineering; and post-harvest process engineering. The departments also are the main units responsible for post-graduate training and research in these areas. Together with the departments of agribusiness and farm management, they form the critical mass for effective action within a country, if properly enabled.

The centres for research in agricultural mechanization and rural technologies, in countries where they exist, constitute the important country node for any regional networking in agricultural mechanization. If there is going to be any regional mechanism for agricultural mechanization, then its primary role should be to facilitate the coordination of efforts of the national centres to work together in a structured regional network to achieve economies of scale and scope.

Training and Capacity Building

Smallholder farmers including small scale commercial farmers do not have the necessary capital, either as savings or via access to financial credit, to invest in the expensive farm power and machinery that is essential for increasing land and labor productivity. Moreover, poorly selected or misapplied agricultural machinery can damage, rather than enhance, environmental resources, especially soils. Smallholder farmers require specialized mechanization services that are both environmentally friendly and productivity-enhancing: mechanization service providers who are well trained and appropriately equipped can meet this demand (FAO/CIMMYT, 2018).

FAO, research organizations, private sector and NGOs are working jointly to develop training and capacity building materials for farmers to enhance their business skills in offering mechanization services. Training materials are designed to help train actual and potential farm mechanization service providers, with the aim of increasing access to sustainable farm power and raising the productivity of smallholder farmers. In this regard, the focus is on two crucial aspects: the provision of farm mechanization services as a viable business opportunity for entrepreneurs, and the essential criterion of raising productivity in an environmentally sensitive and responsible way. Increased agricultural production combined with environmental conservation—conservation agriculture—is a viable way forward (FAO/CIMMYT, 2018).

Moreover, agricultural mechanization can be integrated at field level into farmer field schools (FFS) and farmer business schools (FBS). This provides a sound basis for peasant subsistence farmers' competency development in agricultural mechanization and acts as a source of data and information to feed into bigger programmes.

In order to implement short and longer term training for mechanization services providers, commercial farmers, mechanics, dealers and extension services, longer term and broader training programs are required. It is therefore important to encourage and support SSA's existing centers of expertise in agricultural mechanization and engineering to offer such programs. Yet there may also be the need of a new type of regional centers of agricultural mechanization that would rather focus on delivering the new private sector and business esteem that is required to get sustainable agricultural mechanization initiatives going and grounded in many areas of SSA (FAO, 2016).

Conclusions

Given its potential role in agricultural development, mechanization needs to be given higher priority by African governments and development agencies. At the local level, agricultural mechanization can help improve rural livelihoods by breaking labor bottlenecks that constrain productivity and rural income growth while reducing the drudgery associated with hand-tool land preparation and other household tasks (Bishop-Sambrook Clare, 2003). At a larger level, mechanization can be viewed as a necessary dimension of development strategies that promote the commercialization and modernization of small-, medium- and large-scale farms and entrepreneurs in order to accelerate agricultural development and initiate sustained poverty-reducing economic growth. While the benefits of mechanization generally depend on the availability of complementary, improved biochemical inputs as well as water availability and control, the intensification of agriculture requires an adequate supply of power during peak periods, for which a high degree of mechanization is essential.

At a level of extreme generality, history suggests that mechanization should be viewed and supported within the context of a transformation approach to agricultural development. In part, the transformation focuses on larger-scale enterprises with lower unit costs and effective management, viewed within the supply chain. Thus the focus of attention for mechanization would initially be placed on medium-scale farmers and agribusinesses. These farmers and entrepreneurs can provide mechanization services to small-scale farmers and processors. They are the ones who spearheaded the mechanization revolution in Asia over the past 50 years. There is an immediate need to develop the managerial and entrepreneurial capacity of such farmers and managers in SSA, and to provide the necessary planning and logistical support (FAO, 2008; Collier and Deacon, 2009).

While mechanization strategies might initially focus on medium- to large-scale farms and firms, there is clearly not a single pattern or pace of mechanization. There are mechanization options and opportunities suitable for smaller-scale farmers, although realistic consideration needs to be given to the key success factors identified above, namely, effective demand, economic use rates, efficient machinery and equipment supply chains and services. In many cases, the most promising mechanization options for small-scale farms and entrepreneurs may be agro-processing, transport or related non-farm tasks. The preoccupation in SSA with promoting animal traction and tractors for land preparation should give way to flexible strategies for promoting diverse types of mechanical technologies along the value chain that are compatible with local economic, social and developmental conditions.

Also the historical record indicates that successful and sustainable mechanization cannot be established by direct public sector provision of mechanical technologies and services. There are signs that this lesson has not yet been learned, with the corresponding risk that the failures of the 1960s may be repeated. The public sector can nevertheless effectively promote mechanization processes, by, among other things, establishing of enabling environments, training and human resources development, the strengthening of local organizations, and research and development. Particularly important will be targeted efforts to provide public goods and services that create incentives to ensure that large areas and segments of the population are not left behind as agricultural sectors become more modern, commercial and mechanized.

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