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OCCASIONAL PAPER

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Preface

In February 1975, the Food and Agriculture Organization of the United Nations (FAO) and the Organisation for Economic Co-operation and Development (OECD) convened an expert consultation meeting entitled "Effects of agricultural mechanization on production and employment". The meeting was attended by agricultural economists and engineers as well as sociologists and government planners from the developing and developed countries. The meeting concluded that there was a need for greater interdisciplinary effort to dispel some of the myths and confusion on agricultural mechanization in order to put it in a proper perspective as an input in agricultural development. As a follow up to this meeting, the Committee on Agriculture (COAG) of the FAO Council designated "agricultural mechanization and its effects on employment and income distribution" as a selected development issue for discussion at its fifth session held in April 1979 (COAG/79/8). During discussions on this issue, most COAG members from the developing countries agreed that mechanization was an indispensable input to rural development. COAG concluded that lack of clearly defined strategies on agricultural mechanization was an important constraint to increased agricultural production and efficiency.

In 1981, the Rural Infrastructure and Agro-industries Division (AGS), then known as the Agricultural Services Division, published FAO Agricultural Services Bulletin No. 45 entitled *Agricultural mechanization in development: guidelines for strategy formulation*. The main objective of this bulletin was to define and put in proper perspective the relationship between agricultural mechanization and overall national development objectives in the developing countries and to provide guidelines for appropriate mechanization strategy formulation. While this publication was not meant to provide a "cookbook" recipe that could be applied to each and every development situation pertaining to agricultural mechanization, it nevertheless remained a main reference source for technical guidance in mechanization strategy formulation over the past two decades. As part of the planning process for the organization's Medium Term Plan (MTP) for 2006–2011, the AGS division has, since January 2004, embarked on a review of its involvement in different disciplinary areas of its mandate including agricultural mechanization. The review on agricultural mechanization included an analysis of progress achieved over the past three decades in this area in the different regions of the developing world.

This review concluded that while considerable progress had been made in agricultural mechanization in Asia; Latin America and the Caribbean (LAC); and the Middle East and North Africa regions, the situation in sub-Saharan Africa (SSA) was different. Agricultural mechanization has in many countries of SSA either stagnated or retrogressed. This has occurred despite of the strong support for mechanization from African political leaders and heavy investments that have been made in both animal traction projects as well as those for mechanically powered mechanization, such as in tractors, pumps and post-harvest processing equipment. Given this scenario, it was therefore decided to undertake a critical analysis of agricultural mechanization in SSA, by reviewing performance over the last three decades with an eye to the future while at the same time taking cognizance of the experience of other regions of the world. This paper is geared towards provoking dialogue and debate on what

should be the options for appropriate mechanization policies and strategies in SSA given the experience of the past three decades. It is intended to encourage increased attention on agricultural mechanization in SSA and raises some of the technical and institutional factors that need to be taken into account.

Contents

LIST OF FIGURES

LIST OF TABLES

Acknowledgements

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Geoffrey C. Mrema/Doyle Baker/David Kahan

Acronyms

ADB	Asian Development Bank
AGS	Rural Infrastructure and Agro-industries Division (FAO)
AMTU	Agricultural Machinery Testing Unit
APCAEM	Asian and Pacific Centre for Agricultural Engineering and Machinery (United Nations)
APO	Asian Productivity Organization
ASARECA	Association for Strengthening Agricultural Research in Eastern and Central Africa
CAR	Caribbean region
COAG	Committee on Agriculture (FAO)
DAT	draught animal technology
ECAPAPA	Eastern and Central Africa Programme for Agricultural Policy Analysis
ECOWAS	Economic Community of West African States
ESA	Eastern and Southeast Asia – including the People's Republic of China
FAO	Food and Agriculture Organization of the United Nations
GoI	Government of India
GTZ	German Technical Cooperation
HIV/AIDS	human immunodeficiency virus/acquired immune deficiency syndrome
HYV	High-Yielding Variety
IARC	International Agricultural Research Centre
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IDA	International Development Association (World Bank)
IFAD	International Fund for Agricultural Development (United Nations)
ILO	International Labour Organization (United Nations)
IITA	International Institute of Tropical Agriculture
LAC	Latin America and the Caribbean
MTP	Medium Term Plan
NARO	National Agricultural Research Organisation (Uganda)
NARS	National Agricultural Research System
NGO	non-governmental organization
ODI	Overseas Development Institute (United Kingdom)
OECD	Organisation for Economic Co-operation and Development
PPP	Public-Private Partnership
RNAM	Regional Network for Agricultural Mechanization
SA	South Asia – including India
SACU	Southern African Customs Union
SADC	Southern African Development Community
SAP	structural adjustment programme
SSA	sub-Saharan Africa
SWMnet	Soil and Water Management Network (Kenya)
USAID	United States Agency for International Development

Executive summary

Over the past three decades, not only has progress stalled in agricultural mechanization in much of SSA, but also there is accumulating evidence that progress attained in the earlier years is being lost in many parts of the continent. Tractor hire services have declined; further, because of decimation of livestock herds by outbreaks of diseases, deteriorating animal health services and recurring droughts, some areas where animal traction had indeed established a foothold have reverted back to hand hoeing. Further, mechanization has dropped off the agenda of international development organizations and donor agencies, resulting in its low profile in national development programmes. Many African leaders and a growing number of experts in the development community, however, believe that mechanization should again be a policy priority in SSA.

A key question posed is whether long-term sustainable growth of the agricultural sector is possible with farmers who rely on hand tool technology (powered entirely by human muscle, and in many cases, women's muscle). Further, can these farmers compete with those in other parts of the world who have mechanized not only the land preparation tasks, but also many harvesting and post-harvest operations? Other concerns are demographic trends affecting the agricultural sector and productivity, including increasing urban populations (in some countries, such as Zambia, there are already more urban than rural dwellers), an ageing rural population including ageing farmers (the young and educated migrate to urban areas to escape arduous and back-breaking hand tool agriculture), and the HIV/AIDS pandemic, which is affecting labour availability.

In the 1960s the advent of mechanization was taken for granted by most development practitioners. It was assumed then that it was only a matter of time before agriculture would be transformed and developed to the extent that use of tractors by farmers – who either owned by them or hired them through services provided by governments and/or private operators – would become ubiquitous in most of the developing world. Indeed, from 1925 to 1940 in the United States, almost all draught animals in use in agricultural production had been replaced by tractors. The same occurred in Western Europe after the Second World War, from 1945 to 1960. While most politicians and many experts in the developing countries viewed agricultural mechanization as inevitable, there were heated debates among influential experts in the development community on the consequences of mechanization on, among other things, production and employment of farm workers. The two main groups of experts involved in these debates were socio-economists and agricultural engineers. At times, they tended to have diametrically opposed views, which in many cases caused confusion among policy-makers in developing countries.

Proponents of mechanization (often equated then to tractorization) advanced several reasons to justify the replacement of the cutlass and hoe and/or animal traction with tractors. Mechanization not only allows previously unutilized land to be brought under cultivation, but also

results in timelier field operations. This is critical for land preparation where there is sequential cropping, especially in irrigated agriculture or in areas of bimodal rainfall and in unimodal rainfall conditions to optimally exploit the short rainy season Other reasons included the reduction of the drudgery associated with farm work, especially for the power-intensive tasks – particularly important in tropical areas where high temperatures and humidity render fieldwork relying on human muscle power quite difficult and arduous ergonomically. Finally, in addition to relieving seasonal labour constraints, tractors and animal traction can also be used for other tasks on and off the farm (transportation, driving pumps and grain-milling equipment; maintenance of farm and rural infrastructure). Proponents of mechanization also argue that farm power together with other farm inputs such as fertilizers, improved seeds and pesticides, interact and are inter-dependent for growth in agricultural productivity and overall production.

There were, however, arguments in the 1970s in favour of caution on the whole issue of agricultural mechanization in the developing world because of, among other reasons, its unemployment effects (e.g. farm workers were reported to be burning tractors in parts of Asia); its perceived high energy costs especially following the energy crisis of the 1970s, which led many experts to advocate against tractorization in developing countries; the small size of farm holdings, especially in Asia, which led many to believe that mechanization would not be possible without farm consolidation, with its perceived undesirable social consequences. Further, studies by many leading agricultural economists concluded that there was no evidence, empirical or otherwise, to show that the use of tractors was responsible for substantial increases in yields, intensity of farming, timeliness and gross returns on farms in Asia.

The socio-economic field studies from the 1960s and 1970s particularly influenced policy on mechanization in many parts of the world. It is therefore worthwhile to recall some of the limitations of those studies for policy advice. Four problems should be noted because of their continuing relevance today:

- Essentially all studies were based on cross-sectional data to the exclusion of time series, and presented static *ex post* financial and technical comparisons of alternative technologies. Consequently, the studies failed to adequately project the impacts of mechanization over a longer time horizon. As noted by some experts, however, changes in intensity of production are best evaluated over time and at locations where machine use and density have established a mature equilibrium.

- There was a failure to separate out the effect of different types of mechanization, in combination and in sequence, e.g. a series of studies on the Punjab conducted in the early 1970s largely failed to differentiate between irrigation and tractorization.

- Many studies carried out in Asia and most of those carried out in Africa did not quantify the benefits from non-agricultural use of equipment or even the supplementary income from machinery hiring services. Non-agricultural use of equipment is essential in order to ensure utilization rates that justify the required capital investments.

- Little attention was given to institutional research needed to understand and develop strategies for addressing the organizational, logistical and managerial problems to be tackled in the transition to mechanized agricultural systems. Mechanization is not merely technology

substitution – powered machines for hand- or oxen-powered equipment – but also includes the setting up and maintenance of machinery supply, repair and hire services, as well as related financial, marketing, and farm management advisory and support services.

Regardless of the robustness and validity of the conclusions of these socio-economic field studies, they were a critical factor leading to reduced attention to mechanization in SSA since the early 1980s. The momentum for mechanization in Asia and to a lesser extent Latin America, however, had reached a level where it was unstoppable by this change in priority by the major banks and donor agencies. The situation unfortunately was not the case in SSA.

If the number of tractors (with four wheels and two axles) in use is taken as an indicator of how far a country has advanced in mechanizing its agriculture, then there have been significant changes and differences in different regions over the past four decades:

- In Asia, the number of tractors in use increased phenomenally – by five times between 1961 and 1970 – from 120 000 to 600 000 units, and thereafter increased by 10 times to 6 million units by 2000.

- In the LAC, the number of tractors in use increased by 1.7 times between 1961 and 1970 – from 383 000 to 637 000 units, and thereafter almost tripled to 1.8 million units by 2000.

- In the Near East region, the number of tractors in use increased similarly in LAC – doubling between 1961 and 1970 – from 126 000 to 260 000, and thereafter increasing by 6.5 times to 1.7 million units by 2000.

- In SSA the trend has been quite different. While the number of tractors in use in 1961 was more than in both Asia and in the Near East regions (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 (i.e. about 3.3 percent, 11 percent and 12 percent of numbers of tractors in use in 2000 in Asia, LAC and Near East regions, respectively).

A poignant point in this respect is that while in 1961, 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). Similarly in 1961, SSA had approximately 3.4 times more tractors in use than in Thailand; however, by 2000 Thailand had the same number as in SSA. Further, the tractors in use in SSA in 2000 were concentrated in a few countries, 70 percent being in South Africa and Nigeria. Also, primary land preparation in SSA is estimated in 2000 to rely completely on human muscle power on about 80 percent of the cultivated land, with draught animals and tractors being used on only 15 percent and 5 percent, respectively (compared to Asia where land preparation on over 60 percent of the cultivated land is done by tractors).

The stagnation and in some countries decline of agricultural mechanization in SSA occurred during the 1980s and 1990s. The focus on tractor hire schemes of the 1960s and 1970s was replaced in the 1980s with increased emphasis on draught animal technology

(DAT) and intermediate types of tractors specifically designed for African conditions/farming systems (e.g. *Tinkabi, Kabanyolo* and *Centaur*). The intermediate type of tractor failed to take off and was abandoned by the late 1980s, while modest increase in the use of DAT occurred in the drier areas and by farmers who had animal husbandry tradition, especially in West Africa. It should also be noted that of the 11 million draught oxen in use in SSA in the late 1980s, about 53 percent were in Ethiopia, 25 percent in parts of four other countries (Zimbabwe, Kenya, Tanzania and Uganda), and the remaining 22 percent scattered in the semi-arid parts of West Africa, Sudan and Madagascar. A decline in use of DAT has occurred from the late 1990s, especially in eastern and southern Africa because of epidemics of livestock diseases and recurring droughts.

In general, some of the key driving factors responsible for uptake of mechanization in Asia in the 1970s and 1980s are the following:

- the presence of a sizeable number of medium-size farms able to invest in machinery and to provide mechanization services to the numerous small-scale farmers; availability of registered land that could be purchased/leased by individual farmers, thus creating more viable farm sizes as well as affording farmers an opportunity to use the title deeds as collateral for credit to buy machinery;

- farmers' entrepreneurial and adaptive management capacity and versatility in adapting to changing markets, technologies and policies, including opportunities to use agricultural machinery in off- farm and non-agricultural activities, such as in transportation and in rural infrastructure maintenance;

- policies encouraging industrialization, resulting in rising real wages, and complementary policies contributing to the private profitability of farming and to high levels of effective demand for mechanized equipment, leading to the development of suitable low-cost equipment (power tillers, diesel engines) as an alternative to purchasing high-cost and often unsuitable imported machinery;

- the presence of local entrepreneurs involved in machinery manufacturing as well as operating efficient machinery supply and servicing chains facilitated by business- and enterprise-friendly policies, laws and regulations, together with physical and institutional infrastructures that encouraged commercial activities and entrepreneurship in farming, input supply, and in produce processing and marketing.

Mechanization of power-intensive processing and pumping operation, profitable at low-wage rates, have tended to precede the mechanization of crop husbandry and harvesting operations. However, the mechanization of difficult and arduous tasks such as land preparation did not lead to increased unemployment as earlier feared.

Four main policy lessons for mechanization in SSA can be gleaned from the Asian and African experiences of over the past three decades. First, attention should be placed on increasing the profitability of investments in mechanization by encouraging commercial agriculture and focusing investments and support necessary to increase the profitability of farm and non-farm enterprises. A critical question in this respect is whether there are entrepreneurs/

farmers ready to invest in machinery and implements for use on their farms as well as for providing mechanization services to the small-scale farmers who are unable to marshal such levels of capital investments. Second, mechanization should be viewed strategically within a longer-term time frame. Despite the array of studies demonstrating that mechanization is often not profitable, larger-scale farmers in South Asia pushed ahead with their change to tractors. Also in Asia, policy-makers in general regarded the short-term impact of mechanization as less relevant and important, and took a more strategic longer-term perspective viewing mechanization as part of a broad-based economic development strategy aimed at economic growth and agro-industrialization. Short-term social costs were at times ignored in favour of probable increases in labour demands following intensification. The result was a dramatic transformation of agriculture in Asia over a 40-year period. Third, mechanization is a complex and dynamic process that cannot be appraised only from the standpoint of factor substitution or net contribution to production. Where mechanization has taken place worldwide, there have been fundamental and interlinked changes in the structure of agricultural sectors, in the nature and performance of agricultural support services, and in the livelihood strategies of farmers and agroprocessors. These changes do not necessarily take place simultaneously nor impact on all people in the same way. Fourth, while mechanization has been actively promoted by political leaders and governments in Africa and Asia, its successful development has not depended on governments being directly involved in offering mechanization services. Instead, where mechanization has been successfully implemented, essential mechanization supply systems and support services have developed in response to economic demand – in most cases, starting with support services targeting medium- and larger-scale farmers.

Considering the above trends of the past three decades and the increasing globalization of the world agricultural economy, a key question that arises is whether SSA countries can realistically achieve a significant turnaround, development and growth with agricultural sectors that rely to the extent they currently do on human muscle power and hand tools. Trends in mechanization worldwide clearly show that there are strong correlations between economic growth and mechanization – those countries that have achieved unprecedented economic growth over the past three decades and have succeeded in solving their food problems have also advanced to higher levels of mechanization in their agriculture. Countries that have stagnated economically with significant numbers of their citizens steeped deeper in poverty, have also lagged behind in agricultural mechanization. This is quite apparent to many African experts and policy-makers, especially given the impetus of globalization and information flows.

There is a need therefore to re-examine the role of agricultural mechanization in the agricultural and economic development of SSA. The initial focus would be on those power-intensive field operations, such as land preparation, which make agriculture unattractive and difficult. There is evident need for transforming the agricultural systems in Africa through a combined and synchronized approach to promote biochemical technologies with mechanization, abandoning the controversial low input systems and the incremental approach to agricultural development. A dual agricultural system needs to emerge through encouraging more commercial farming by medium-scale farmers (10–200 ha). Such medium-scale farmers are likely to be the ones who will be able to provide mechanization services to the majority of small-scale farmers. They are also likely to create large enough demand for inputs and produce large volumes of outputs to enable viable and sustainable input supply and output recovery enterprises to be established, which can also serve the small-scale farmers at competitive rates/prices.

Some of the essential factors for successful and sustainable agricultural mechanization in SSA are: First is the need for effective demand for the outputs of agricultural production in national, regional and international markets that can be met through profitable farming enterprises. These profitable farming enterprises will in turn lead to an effective demand for agricultural inputs including mechanization services. The second factor is the need to ensure effective utilization rates for machinery and implements through policies and other support services that facilitate multifarm use, development of sustainable machinery rental markets, and freer movement of machinery across district and national boundaries to exploit the rainfall isohyets and peak land preparation seasons. The third factor is the need to establish efficient agricultural machinery supply chains and service enterprises, including linkages to new suppliers/manufacturers, as well as local equipment manufacturing, nationally or regionally where this is feasible.

Other essential and priority factors for the public sector include, among others: (a) the creation of enabling environments for private enterprises to thrive, including appropriate macro-economic policies; legal and regulatory frameworks, including policies for land tenure; availability of credit at reasonable interest rates; (b) training of human resources for mechanization including artisans, technicians and engineers as well as commercial farmers and agribusiness managers; (c) research and development in both hardware (e.g. development and testing of equipment) and in software (e.g. appropriate mechanization systems and support services for different farm sizes and the business skills to operate them). Training may be provided and research could be carried out subregionally.

African leaders understand the importance of mechanization in the future vision of the region; efforts to accelerate mechanization will require substantial long-term political and financial commitments while grappling with new problems. However, unless commitments are made to address these problems, the prospects for African agriculture and farmers remain bleak. The process may at times be turbulent, but governments and leaders in the agricultural sector in SSA must remain steadfast and take a longer-term perspective of mechanization, as Asian governments and leaders did in the 1960s and 1970s. Otherwise, African agriculture will be doomed to continue using seventeenth century tools and implements in the twenty-first century to the detriment not only of food security, but also agricultural development and overall economic growth. Now is the time for a new look at agricultural mechanization in this region!

Introduction

Julius Nyerere, then President of Tanzania, is reported to have told a Western journalist in 1970: "We are using hoes. If two million farmers in Tanzania could jump from the hoe to the oxen plough it would be a revolution. It would double our living standard and triple our product. This is the kind of thing China is doing". Thirty years later in Tanzania, as in most countries of SSA, the hand hoe is still used for land preparation on 80 percent of the cultivated land, with only 15 percent being prepared with DAT and the remaining 5 percent using tractors. Meanwhile, other regions of the world that had the same mechanization level as SSA in the 1960s recorded phenomenal progress in agricultural mechanization over the past three decades.

Progress in mechanization in much of SSA has stalled over the past three decades, resulting in its low profile in national agricultural development strategies and largely dropping off the agenda of international development organizations as well as donor agencies. This is a matter of concern because of disturbing trends that show that agriculture in SSA has fallen behind in many respects, including the reduction of food production per capita, of agricultural value addition and of agricultural imports relative to exports, as well as increased undernourished populations (FAO, 2004). Moreover, there is accumulating evidence that earlier progress made in mechanization is being lost in many areas: tractor hire services have declined following structural adjustment, and some areas where animal traction had established a foothold have shifted back to hand hoeing because of loss of draught animals from droughts, increased outbreaks of livestock diseases and deteriorating animal health services.

There are a growing number of African leaders as well as experts in the development community who believe that mechanization should again be a policy priority in SSA. One of the key questions being posed is whether long-term sustainable agricultural growth can occur with agricultural systems dominated by farmers who rely on hand tool technology powered entirely by human muscle power. A further concern is whether such farmers will be able to produce and compete with those from the other regions of the world who have increasingly mechanized not only the power-intensive tasks, such as land preparation and threshing, but also weeding, harvesting, grading and cleaning. African leaders also worry about the demographic trends affecting agricultural systems and productivity, including increasingly urban populations, ageing rural populations, and in particular, ageing farmers, as well as the effects of the HIV/AIDS pandemic on both rural and urban populations. In the light of their concerns, some African governments, such as in Ghana, Mali, Tanzania and Zambia, have responded by re-launching tractor import and distribution schemes, while many other African governments are actively considering launching such schemes.

While agricultural mechanization is widely supported in SSA by farmers, local leaders and senior level politicians, the revival of mechanization as a key component of agricultural development programmes will almost certainly invoke controversy. Even though Africa

was and is still considered land surplus with comparatively low population densities in most countries, wages remain low and many of the factors that drove mechanization in other regions (Binswanger, 1986) may not be present in many areas of SSA. Moreover, Africa's experience with oxen and tractor mechanization has generally not been very successful (Eicher and Baker, 1982; Pingali *et al.*, 1987; Mrema, 1991). In brief, there is a risk that the absence of sound mechanization strategies and policies at this time may worsen the field and farm level situation while earlier mistakes of investing in government tractor support and supply schemes are repeated.

The purpose of this paper is to re-examine the role of agricultural mechanization in the agricultural and economic development of SSA. Long lingering debates on agricultural mechanization will be summarized while taking cognizance of the experience of other regions and proposing some ideas for the future. This paper is expected to provoke dialogue and debate on what should be the options for appropriate mechanization policies in SSA in the future. It encourages renewed attention on agricultural mechanization in Africa and raises some of the technical and institutional factors that should be taken into account. It makes a case for agricultural growth through farming geared towards increasingly competitive local, regional and international markets, with machines and implements interacting with the other major inputs – improved seeds, fertilizers, water and pesticides – all playing an integral part in increasing agricultural productivity and overall production. The role of the public sector in promoting private sector initiatives in the area of agricultural mechanization will also be examined.

The paper is divided into six parts: First, we shall review policy debates in the development community on the issue of agricultural mechanization, and related studies on its economics. Second, we shall then provide an overview of how different parts of the developing world have fared in agricultural mechanization over the past 40 years. Third, we follow this with a section identifying reasons why it appears it is time to rethink the importance of mechanization in Africa. Fourth, we then highlight some of the critical factors that need to be addressed if mechanization is to be successful and sustainable in SSA. Fifth, we shall provide our views on public sector priorities for supporting mechanization in this region. And then we lead into conclusions.

Mechanization policy debates

None of the modern technologies for increasing agricultural production and productivity in the developing world have attracted as much controversy as agricultural mechanization technologies. In this section, we shall characterize policy debates on agricultural mechanization from the 1960s and 1970s, and then briefly summarize results of field studies undertaken mainly in the 1970s and 1980s that tried to empirically address some of the still continuing debates on mechanization.

Perspectives in the 1960s and 1970s

The diverging opinions on mechanization dating back to the 1960s related to the anticipated effects of farm mechanization on agricultural production, equity and employment. Much of this divergence of opinion stemmed from a different understanding of what is meant by "farm mechanization" and preoccupation with what were then perceived as the ill effects of significant increases in the use of mechanically powered equipment and machinery in traditional agricultural systems. In many cases this stemmed from the then-common perception that mechanization was synonymous with tractorization. Agricultural mechanization was perceived in many developing countries as the replacement of hand hoe, other hand tools, and draught animals with tractors and other mechanically powered machinery and implements.

In the 1960s the advent of mechanization (or tractorization) was taken for granted by most development practitioners. It was then assumed that it was only a matter of time before agriculture would be transformed and developed to the extent that use of tractors by farmers – either owned by them or through tractor hire services provided by governments and/or private operators – would become ubiquitous in most of the developing world. Indeed, this was not then an unreasonable comparison, as in the experience of the United States, where from 1925 to 1940 almost all draught animals in use in agricultural production had been replaced by tractors. The same occurred in Western Europe from 1945 to 1960 (Kurdle, 1975; Promsberger, 1976; Burch, 1987; Gibb, 1988).

While most politicians and many experts in developing countries viewed agricultural mechanization as inevitable, there were heated debates among influential experts in the development community on the consequences of mechanization, especially its effect on production and the employment of farm workers. The two main groups of experts involved in these debates were socio-economists (agricultural economists and sociologists) and agricultural engineers. They tended at times to have diametrically opposite views, causing confusion among the policy-makers in developing countries. As Gemmill and Eicher (1973) noted, economists and engineers were "talking past each other" on the mechanization issue. Most of the debate emanated from results of the empirical studies on the mechanization projects implemented

in the 1960s in many parts of the developing world with varying degrees of success – and in many cases failures.

In Asia the debate was largely about replacing of draught animals with tractors in land preparation, as well as using diesel or electric pumps for irrigation and mechanically powered threshers in post-harvest processing. Farmers in most of Asia had a long tradition, spanning several centuries, of using draught animals (bullocks, buffaloes, elephants, camels, horses and mules) in agriculture. Partly because of the fact that a large part of Africa was infested with tsetse flies – thus making it difficult to raise livestock – most of the land preparation in this region was undertaken by cutlass and hoe cultivation. The debate in Africa then was whether these areas could leapfrog the draught animal stage and move directly to tractor cultivation.

Agricultural engineers, in particular, argued that alternatives to mechanical technologies did not exist as a practical matter, or if they were available, they were inefficient and could not be compared to mechanical technologies in terms of economics and productivity. They characterized the agricultural production process as a thermodynamic process (advocating a minimum level of power availability per hectare) and argued that food and crop production has to be achieved in the most efficient way, maximizing the productivity of land and labour as well as other inputs.

Agricultural engineers and other proponents of mechanization (often equated then to tractorization), advanced five main reasons to justify the replacement of the cutlass and hoe and/or draught animals with tractors:

- Mechanization allows previously unutilized land to be brought under cultivation. This may be the result of the ability of tractors to perform deep tillage of hard soils as well as reclaim wasteland. It could also come about by bringing additional land under cultivation.

- Mechanization should result in timelier field operations and as a result increase in productivity. Timeliness is essential for multiple cropping because of the need for rapid land preparation between sequential crops, especially in irrigated agriculture or in areas with bimodal rainfall and in unimodal rainfall conditions for breaking the hardpan and exploiting the short rainy season.

- Tractors and animal traction are not only useful for land preparation, but can also be used to power implements and equipment used in improving and maintaining farm and rural infrastructure in general (e.g. drainage, irrigation, fencing, rural roads). The same equipment also can be used for transport, carrying inputs, transporting produce to the market, as well as driving pumps and grain milling equipment.

- Mechanization can overcome seasonal shortages of labour and/or release labour in critical periods for other productive tasks. If labour is released for the production of other crops, total farm output should increase; for non-farm activities, overall household income should increase.

- Mechanization reduces the drudgery associated with farm work, especially for power intensive tasks such as tilling the land with a hand hoe. This is particularly important in

tropical areas where high temperatures and humidity render farm work relying on human muscle power to be ergonomically quite difficult and arduous.

In 1967, Professor G. W. Giles of North Carolina State University – a leading agricultural engineer – published a seminal paper that was a highly influential paper in mechanization policy debates. He used worldwide data to show that farm power together with other major farm inputs – fertilizers, improved seeds, water and pesticides – interact and are interdependent for growth in agricultural productivity and overall production. This was the first study where an attempt was made to systematically relate farm power with increased yields (Giles, 1967).

Reflecting widespread acceptance that mechanization is desirable, the agricultural development plans of many governments in the emerging independent African nations in the 1950s and 1960s emphasized transforming the agriculture sector through mechanization, among other things. These plans included, for example, the Swynnerton plan in Kenya of 1954 as well as plans developed by the World Bank in Tanzania ([then known as Tanganyika] IBRD, 1960), FAO in Nigeria (FAO, 1966) and national experts in Ghana (Ghana, 1962).

A number of experts in the development community opposed the above views of agricultural engineers and other proponents of rapid mechanization, arguing for a cautious approach to tractorization. Those who opposed the widespread adoption of tractors argued that mechanically powered agricultural mechanization often leads to displacement of labour and other socio-economic problems, including unemployment, landlessness, rural-urban migration, inequitable distribution of wealth and increases in absolute poverty. They also pointed to balance of payments problems because of the need to import the machinery, fuel and possible technical assistance. They further argued that land holdings are often small and fragmented, making it difficult to use tractors efficiently, that adoption of mechanical technologies does not necessarily lead to increased yields, and that productivity could be achieved by the use of the biochemical inputs alone.

Many of the development specialists that opposed mechanization policies aimed at tractorization did support the use of improved hand tools and animal-powered technology by small- and medium-scale farmers. They viewed these technologies as a transitional step between total reliance on human muscle power and long-term reliance on tractors and other machinery. It was argued that care should be taken to ensure that technological, cultural, economical and social development all move forward in tandem in order to reduce some of the feared socio-economic consequences of mechanization and to ensure well-balanced development.

In 1970–1973, the International Labour Organization (ILO) undertook a number of case studies on mechanization in the developing world that had a major impact on policy debates. The ILO studies supported the serious concerns expressed about the unemployment effects of agricultural mechanization (ILO, 1973). These studies coincided with a number of seminal papers/books by leading academics questioning the rationale of development strategies that emphasized mechanization and advanced mechanical technologies, including the influential book, *False Start in Africa*, by the French political scientist Professor René Dumont (1966). Dumont was particularly critical of the emphasis on tractor hire schemes by many African governments. The book *Small is Beautiful* by renowned economist E.F. Schumacher, which advocated for intermediate technologies, was also highly influential with policy-makers, especially in developed countries.

The arguments against tractorization in the reports by ILO and other organizations were enhanced by the first global oil price hikes of 1973, which made tractorization appear even more uneconomical for the developing world, especially for the smallholder sector. Strong arguments were raised in support of the use of improved hand tools, DTA and other renewable forms of energy. The poor performance of government-sponsored and operated tractor hire schemes in many developing countries strengthened the arguments against tractorization.

In response to the growing criticism of mechanization, supporters of mechanization scorned the opponents who feared unemployment creation and compared them to the Luddites in England in the nineteenth century, who smashed textile machinery for fear it would create unemployment. They argued that as long as agriculture in developing countries is perceived as a "gigantic programme" for relieving unemployment, then these countries would continuously face hunger and massive starvation. On the issue of the high amount of energy required for operating these tractors, the proponents of mechanization argued that the fossil fuels used in agricultural machinery, even in the most advanced countries, accounted for less than 5 percent of the energy used in agricultural production. In fact, biochemical inputs (fertilizers, herbicides, pesticides, etc.), which do not seem to have been questioned as far as energy use is concerned, are even more energy-intensive than the fuel required to run agricultural machinery and implements (Kline *et al.,* 1969; Esmay and Faidley, 1972; Khan, 1972). Studies by the Asian Development Bank (ADB) carried out in the 1970s showed that the manufacture and operation of farm machinery used only 8 percent of the commercial energy used in agriculture, while chemical fertilizers accounted for 84 percent (Rijk, 1983). Advocates of mechanization also argued that when mechanical technologies had failed in developing countries, it was generally as a consequence of poor planning, management and supervision.

In order to bridge the gap between the two viewpoints among policy-makers and development specialists, FAO and the OECD convened an "Expert Consultation on Agricultural Mechanization and its Effect on Production and Employment" in February 1975 in Rome (Italy) to discuss the effects of farm mechanization on production and employment in the developing regions of the world (FAO, 1975). The experts at the consultation agreed that farm mechanization should lead to increased production while reducing the drudgery associated with performing agricultural tasks using hand tool technology. With respect to its unemployment effects, however, the experts noted that there were so many variables that could affect employment in agriculture that it was extremely difficult to isolate the effects of farm mechanization. They concluded that urgent action was required to determine whether or not continued growth in farm mechanization was "socially desirable", which could only be done by conducting field studies in the countries concerned.

The consultation then recommended appropriate mechanization, which combines hand tool, animal and mechanically powered agricultural implements and equipment suited to the physical, cultural, economic and technological environment of the country concerned. Further, the need to train manpower for all aspects of agricultural mechanization programmes was highlighted, noting specifically that "manpower training requirements for extension in the use, or introduction of farm mechanization based on animal power were considerable, particularly if attempts are made to introduce draught animals in areas where there was no tradition of animal husbandry and use of draught animals." There were also recommendations for developing countries to formulate agricultural policies and develop strategies for their

implementation, and for carrying out research in agricultural mechanization within the national agricultural research systems. Finally, there were specific recommendations to FAO, particularly in developing guidelines for determining and evaluating appropriate forms and levels of farm mechanization to suit different ecological, social and economic conditions of the developing countries. It was suggested that FAO provide support to governments in setting up advisory services in this field, strengthening its information services to provide multidisciplinary information on agricultural mechanization.

EARLY SOCIO-ECONOMIC FIELD STUDIES

Many field studies were in fact undertaken from the 1960s to the early 1980s in an effort to generate an empirical basis for resolving the ongoing debates on mechanization. These included studies by Inukai (1970), Ahmed (1972), McInerney and Donaldson (1975), Sargent *et al.* (1981), and many other studies in Asia as summarized by Binswanger (1978 and 1986), Farrington *et al.,* (1984) and Burch (1980), among others.

The results of the socio-economic field studies remain to some degree contentious, but the weight of evidence indicated that the net productivity contributions of tractors were low or non-existent in many developing countries. The accumulating evidence, reinforced by synthesis appraisals for Asia (Binswanger, 1978) and Africa (Pingali *et al.,* 1987), clearly tempered the enthusiasm of international, donor and financial agencies for mechanization and led to increased support for "appropriate technologies" in the form of DATs in the late 1970s and early 1980s, and specially designed small tractors such as the *Kabanyolo, Tinkabi* and *Snail.* Success with these technologies, however, was elusive, leading to reduced support for mechanization during the 1980s. Throughout the 1990s, mechanization was nowhere near the top-level policy priority in developing regions, especially in Africa as it had been in the 1960s and 1970s.

Because of the influence of the socio-economic field studies from the 1960s and 1970s, it is worthwhile to recall some of their key limitations in providing policy advice. Many of the limitations were noted at the time by Gemmill and Eicher (1973) and later by Eicher and Baker (1982), but were largely overlooked by governments and donor agencies. Four problems in particular should be noted because of their continuing relevance today:

1. Essentially, all studies were based on cross-sectional data to the exclusion of time series, and presented static *ex-post* financial and technical comparisons of alternative technologies. Consequently, the studies failed to adequately project the impacts of mechanization over a longer time horizon. However, as noted by Duff and Kaiser (1984), examination of changes in intensity in production are best evaluated over time and at locations where machine use and density have established a mature equilibrium.

2. There was a failure to separate out the effect of different types of mechanization, in combination and sequence. For example, a series of studies on the Punjab conducted in the early 1970s largely failed to differentiate between irrigation and tractorization.

3. Many studies carried out in Asia and most in Africa did not quantify benefits from non-agricultural uses or even the supplementary income from hiring services (Gemmill and

Eicher, 1973; Mrema, 1991; Singh, 2001). Non-agricultural use of equipment is essential in order to ensure utilization rates that justify the required capital investments, and no farm manager or entrepreneur would even think of buying a tractor to use only for one or two field operations on a single small- or even medium-scale farm.

4. Little attention was given to institutional research needed to understand and develop strategies for addressing the organizational, logistical and managerial problems in the transition to mechanized agricultural systems. However, mechanization is not a simple technology substitution – powered machines for hand- or oxen-powered equipment. Mechanization includes the setting up and maintenance of machinery supply, repair and hire services as well as related financial, marketing, and farm management advisory and support services.

Regardless of the robustness and validity of the socio-economic field studies, they were a critical factor leading to reduced attention to mechanization in SSA since the early 1980s. As shown in the next section, however, the momentum for mechanization in Asia, and to a lesser extent, in Latin America, had reached a level where it was unstoppable by this change in priority by the major banks and donor agencies. The same unfortunately was not the case in SSA.

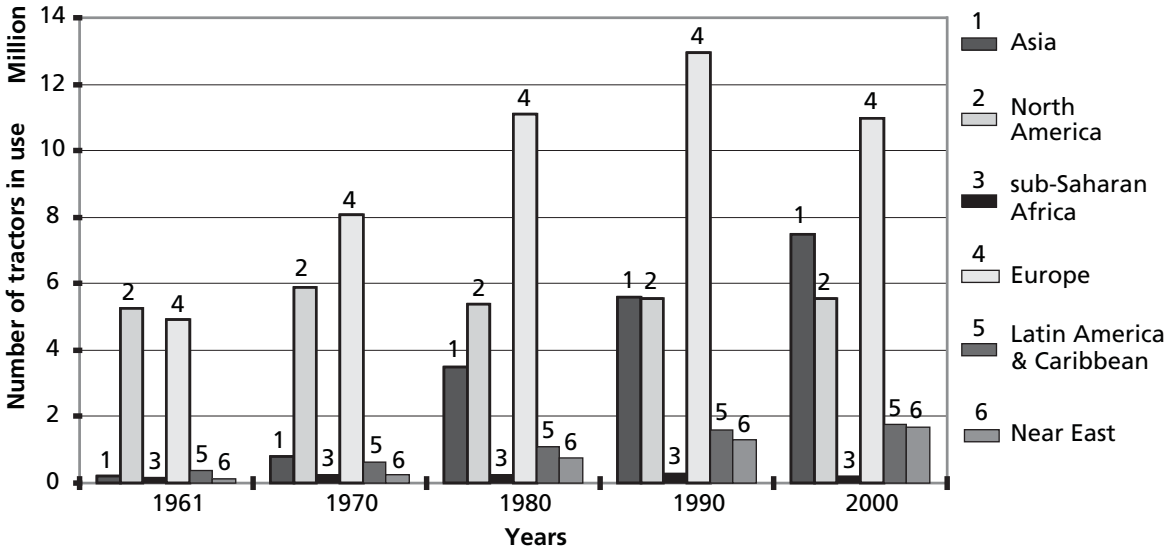
Mechanization trends since the 1960s

This section presents developments in agricultural mechanization over the past three decades in different regions of the world. The number of tractors (with four wheels and two axles) in use is taken as an indication of how far a country has advanced in mechanizing its agriculture. Such indicators are used mainly because the number of tractors in use is one area where most countries have kept records over the past five decades, which are in FAO databases. Because mechanization has proceeded rapidly in Asia, some Asian experiences will be summarized following an overview of SSA. A review of findings and lessons learned will then be presented.

TRACTOR USE BY REGION

Figure 1 gives information on the growth in numbers of tractors in use in different continents (both developed and developing) from 1961 to 2000. The numbers here are for four-wheeled two-axle farm tractors and exclude two or four-wheel garden tractors.

Figure 1 Tractor use by region, 1961–2000



1-Asia includes the People's Republic of China, Japan and India as well as Oceania and Pacific countries.
2-North America includes United States, Canada, Bermuda and Greenland.
3-sub-Saharan Africa includes all countries on the continent except North African Arab countries (Algeria, Morocco, Tunisia, Libya, Egypt and Sudan).
4-Europe includes ex-USSR up to 1990, thereafter including the Russian Federation and Ukraine and the Baltic States. ex-Asian Soviet Republics are excluded.
5-LAC includes Latin America and the Caribbean.
6-Near East includes all mid-Eastern countries and North African Arab countries.
Source: FAOSTAT/AGS (2004).

In Europe, the number of tractors in use increased from 5 million in 1961, more than doubling by 1980 to 11 million and peaking at 13 million tractors by 1990. Thereafter, there was a decline to 11 million by 2000, as a result of the increased shift to higher horsepower tractors in Western Europe (hence a need for fewer tractors) and developments in the former Soviet Union and Communist Eastern European countries after the collapse of the socialist system, where the number of tractors in use declined. In North America the number of tractors in use peaked by 1970 at 5.9 million, and thereafter registered a marginal decline, stabilizing at around 5.5 million from 1980 to 2000.

There have been significant changes in the number of tractors in use in developing countries, and dramatic differences among regions:

- In Asia, the number of tractors in use increased phenomenally – by five times between 1961 and 1970 (from 120 000 to 600 000 units), and thereafter increased by 10 times from 1970 to 2000 (from about 600 000 to 6 million units).

- In the LAC region, the number of tractors in use increased by 1.7 times between 1961 and 1970 (from 383 000 to 637 000 units), and almost tripled between 1970 and 2000 (from 0.64 to 1.8 million units).

- In the North Africa and the Middle East the numbers of tractors in use increased similarly to that in the LAC region – doubling between 1961 and 1970 (126 000 to 260 000), and increased by 6.5 times between 1970 and 2000 (0.26 to 1.7 million).

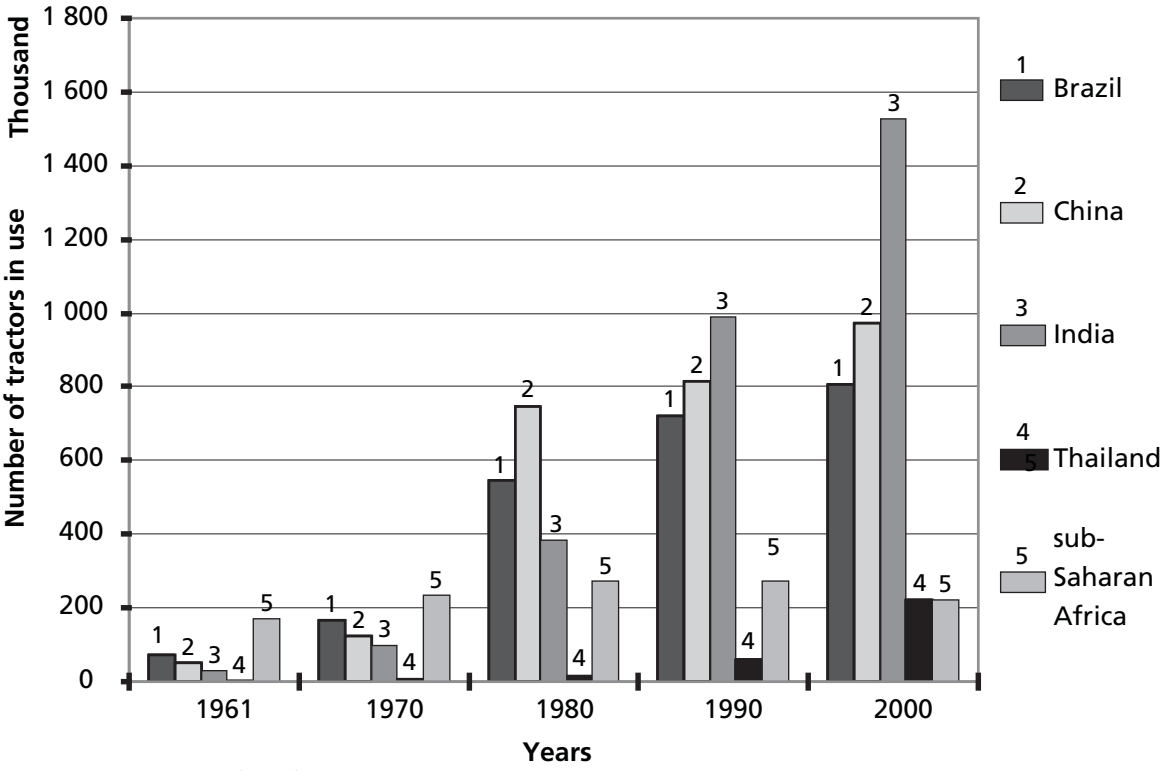
- In SSA, the trend has been different. While the number of tractors in use in SSA in 1961 was greater than in both Asia and the North Africa and the Middle East region (172 000 versus 120 000 and 126 000 units, respectively), it increased very slowly compared to the other regions, peaking at only 275 000 by 1990 before declining to 221 000 units by 2000.

A poignant point to emphasize is that Africa (here including North Africa) had more tractors in use in 1961 than Asia (235 000 and 139 000, respectively), and by 1970 the numbers were in the same range (333 000 and 398 000, respectively). By 1980, however, the number of tractors in use in Asia had increased to three times more than in Africa (1.27 million against 0.44 million, respectively); by 1990 this ratio had increased to almost six times, and by 2000 to ten times (at 0.52 million in Africa and 5.30 million in Asia).

In brief, there has been phenomenal growth in the use of tractors in Asia and Latin America relative to Africa, and the number of tractors in those regions now dwarfs figures for the African continent. Further, while Latin America had more tractors in use than Asia and Africa in the 1960s and 1970s, Asia surpassed Latin America by 1980, and by 2000 had three times more than in Latin America. This demonstrates the impact of the Green Revolution, which was more pronounced in Asia than in the other two regions, thus fuelling this large increase in demand for farm power.

Further, to demonstrate the extent to which SSA has lagged behind, a comparison of its tractor use figures with those of other individual developing countries is illustrated by Figure 2. This figure shows that in 1961, SSA had 172 000 tractors in use, which was 2.4, 3.3, 5.6 and 3.4

Figure 2 Tractors in use in sub-Saharan Africa compared to other developing countries



Source: FAOSTAT/AGS (2004).

times the corresponding numbers in Brazil, India, the People's Republic of China and Thailand, respectively. By 2000 the reverse was the case: India, the People's Republic of China, and Brazil had respectively 6.9, 4.4, and 3.7 as many tractors as SSA. Thailand alone had as many tractors as the entire SSA region including South Africa.

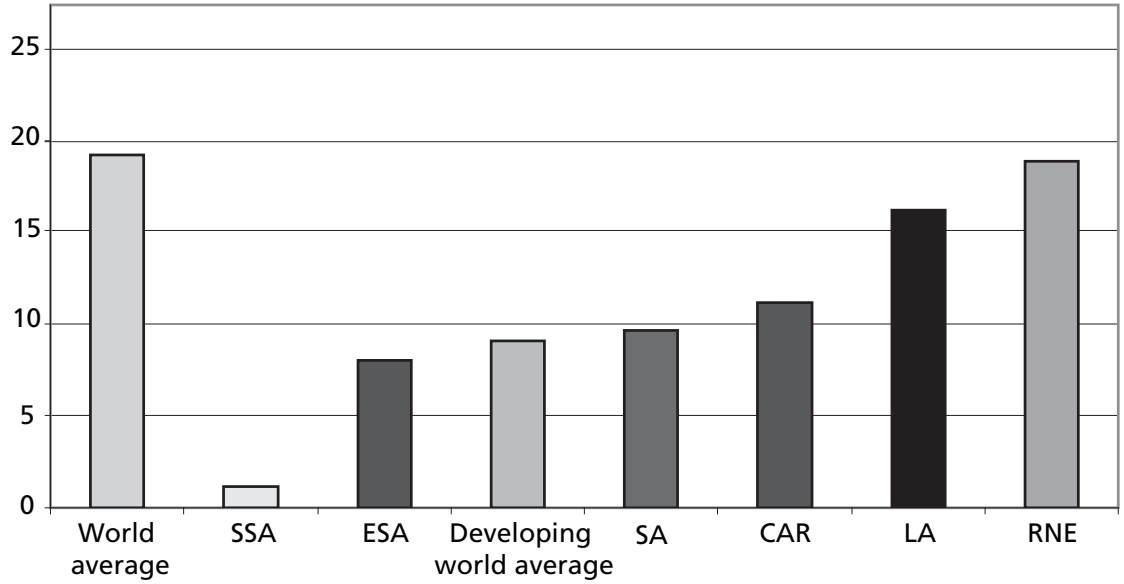
Figures 3 and 4 together show the extent to which SSA is an outlier compared to all other developing regions. Figure 3 gives data for 2000 on tractors in use per 1 000 ha of agricultural land cultivated. Figure 4 gives the number of agricultural workers per 1 000 ha of agricultural land in use for 2000.

Figure 3 shows that among developing regions, tractor use is highest in North Africa and the Middle East region at 18.8 tractors per 1 000 ha, followed by Latin American and then the Caribbean region (CAR). The number of tractors in use is by far the lowest in SSA, at 1.1 tractors per 1 000 ha.

Figure 4 shows that in the regions with the highest numbers of tractors, the number of agricultural workers per 1 000 ha of agricultural land is the lowest, as would be expected. Figure 4 also shows, as is widely known, that the number of agricultural workers remains very high in Asia – both south Asia and eastern and southeast Asia – compared to other developing regions. Nevertheless, as shown in Figure 3, the number of tractors in use in Asia nearly reaches the average for all developing regions combined, and vastly exceeds the number in SSA. In sum, the

two figures point out that SSA is the only developing region where the number of agricultural workers is no more than half the average for all developing regions and the number of tractors in use is also a small fraction of the number in the other regions.

Figure 3 Tractors in use per 1 000 ha of agricultural land in the year 2000



Source: (FAOSTAT/AGS (2004).

Figure 4 Agricultural workers per 1 000 ha of agricultural land in use in the year 2000

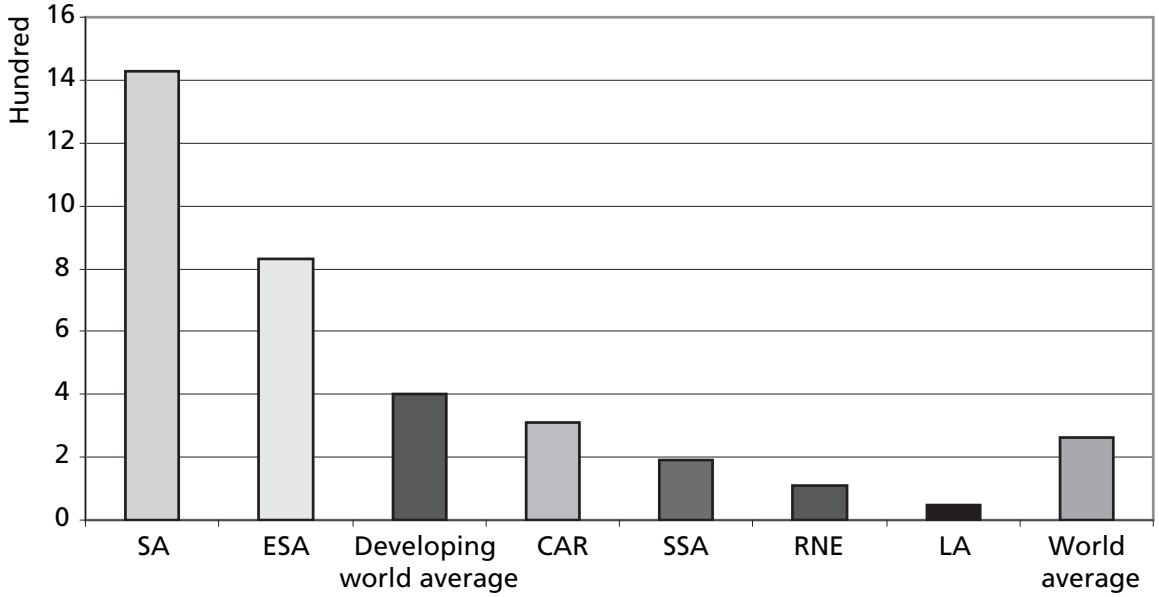
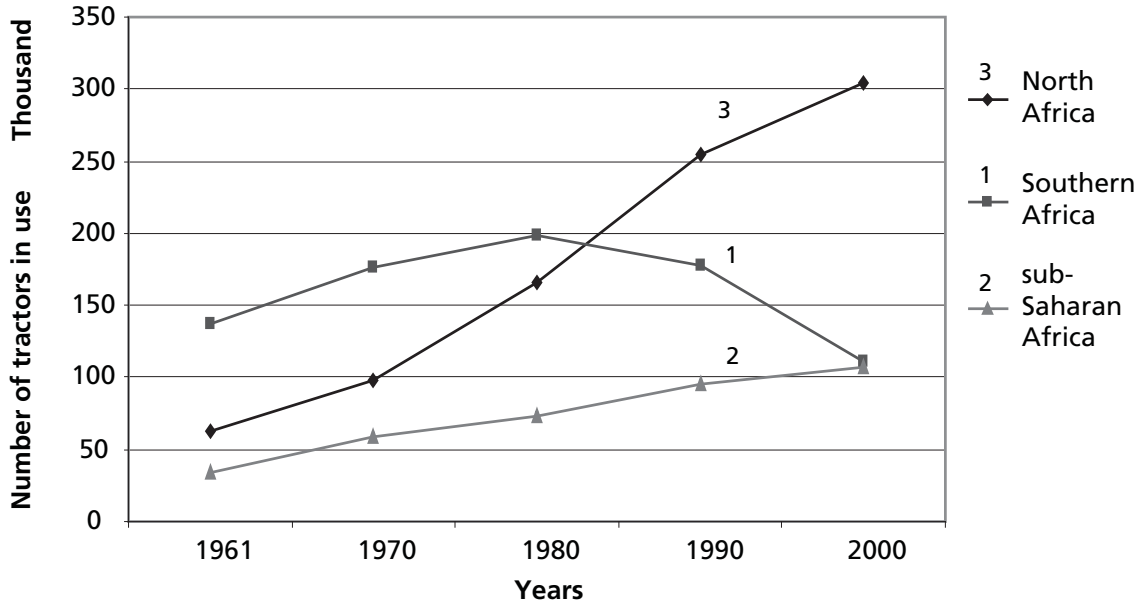


Fig. 3 & 4:
CAR – Caribbean region
ESA – Eastern and Southeast Asia
– including the People's Republic of China
LA – Latin America
Source FAO/STAT (2003)
RNE – North Africa and the Middle East
SA – South Asia -including India
SSA – sub-Saharan Africa including South Africa

Within SSA, most of the tractors are concentrated in relatively few countries, so the number of tractors in use in the vast majority of SSA is extremely low. The history of tractor use on the African continent can be divided into two subregions:

1) The Southern Africa region – covering South Africa, the other Southern African Customs Union (SACU) countries (Botswana, Swaziland, Lesotho and Namibia), and Zimbabwe – historically had large settler populations that influenced the farming systems and tractor ownership. Furthermore, the large mining and industrial sector of South Africa significantly competed for labour and increased the availability of tractors and other farm machinery, which were locally assembled or manufactured. For this region, tractor numbers were already quite high in 1961 at 137 000 units, being four times the rest of SSA. The number of tractors in use increased throughout the 1960s and 1970s and peaked in the 1980s at about 200 000 units before declining to 111 000 units by 2000. This increase and decrease in this region was very much influenced by the situation in South Africa where tractor numbers peaked at 173 000 in 1980 before declining to 72 300 units by 2000. As in Europe and North America, this decline in tractor use was caused by large-scale farmers moving to higher powered tractors, thus requiring fewer units than before.

Figure 5 Tractors in use in different regions of Africa



1. Southern Africa: all countries that are members of the SACU, i.e. South Africa, Botswana, Namibia, Swaziland, Lesotho and Zimbabwe.
2. sub-Saharan Africa: all other countries except those mentioned for Southern Africa and North Africa above (38 countries).
3. North Africa: Algeria, Morocco, Tunisia, Libya, Egypt and Sudan.

Source: FAOSTAT/AGS (2004).

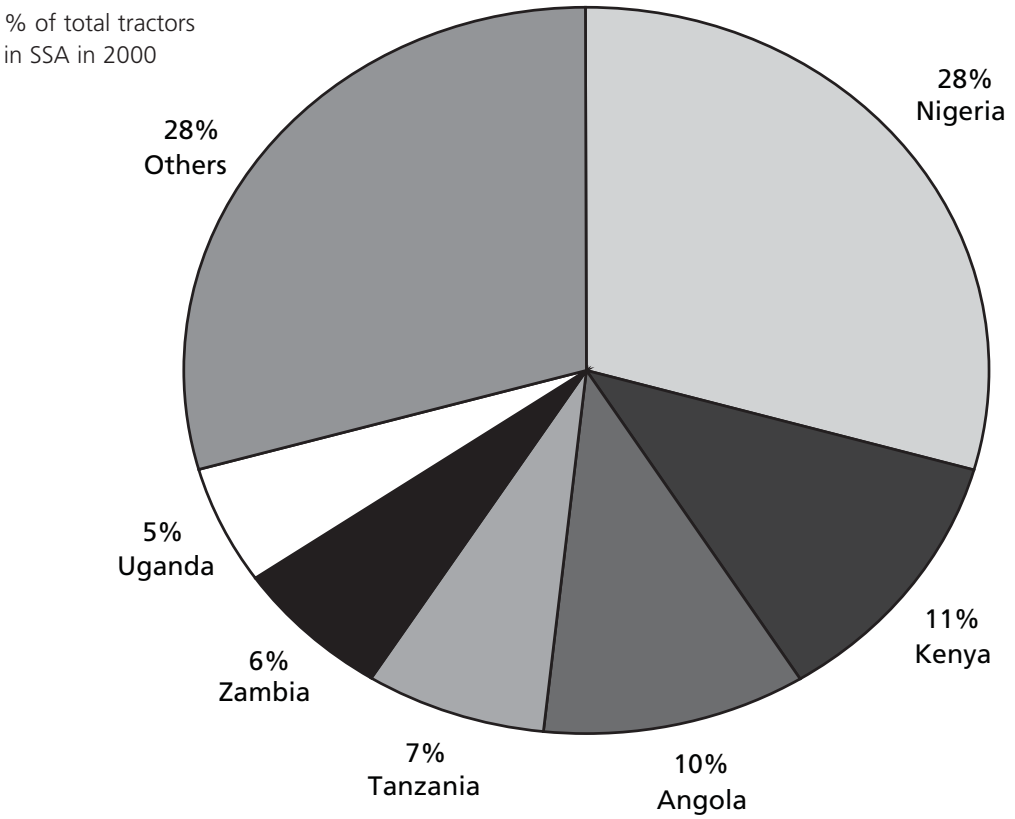
2) The second subregion is the remaining 37 countries of SSA, from Mozambique, Angola and Zambia in the south, to Ethiopia and Eritrea in the northeast, and Senegal and Mali in the west. In 1961, tractor numbers in this subregion were at 34 400 units, about 25 percent of the corresponding figure for the southern Africa subregion, although slightly higher than the number of tractors in use in India at that time (at 31 000). The number

of tractors in use in these 37 countries of SSA (an area larger than that of the People's Republic of China, India and Brazil combined) almost doubled by 1970, but thereafter increased very slowly so that by 2000 there were only 107 500 tractors in use. Furthermore, in 2000 for these 37 countries, around 72 percent of the 107 500 tractors in use were in only six countries, 28 percent of which were in Nigeria. Indeed, if the numbers for Nigeria, Kenya and Angola are deducted from the total for the region, then the number of tractors in use in the other countries has hardly increased (Figures 5 and 6).

3) In the North African Arab countries, tractor use has increased from 60 000 in 1961 to over 300 000 by 2000.

The use of tractors as a source of farm power is therefore extremely limited in SSA and is concentrated in relatively few countries. For example, in 2000, South Africa and Zimbabwe accounted for, respectively, 50 and 17 percent of the tractors in the Southern African Development Community (SADC), while Nigeria accounted for 68 percent and the other 15 countries with the remaining 32 percent of the tractors in use in the Economic Community of West African States (ECOWAS).

Figure 6 Percentage of tractors in use in different countries in sub-Saharan Africa in the year 2000



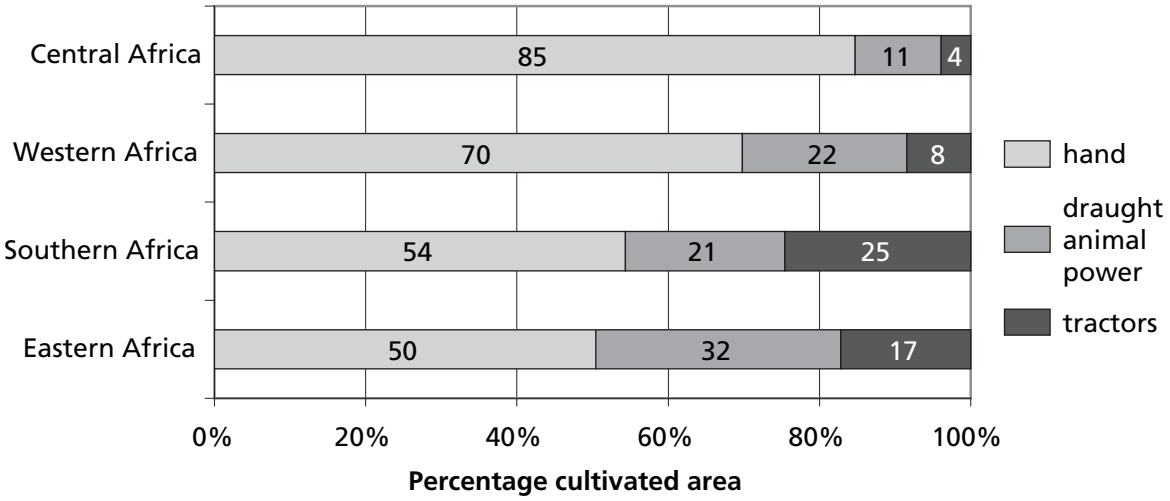
- SSA here excludes North Africa Arab countries and SACU countries + Zimbabwe and Mauritius.
- Others include 37 countries in SSA not mentioned above.
- Total number of tractors in use in 2000 – 107 500 units.

Source: FAOSTAT/AGS (2004).

Use of draught oxen, also quite limited in SSA, is particularly limited in Central Africa and large parts of semi-arid areas of West Africa (Figure 7), and is similarly concentrated in relatively few countries. Recent figures for draught animals in use in SSA agriculture are difficult to obtain, however, both Winrock (1992) and Starkey (1988) estimated that in 1985 there were about 11 million draught oxen and perhaps 2–3 million donkeys and horses being used for agricultural purposes in Africa (compared to the People's Republic of China and India where there were over 80 and 53 million oxen in use, respectively). About 77 percent of these draught oxen were in five countries – of which Ethiopia had 53 percent and Zimbabwe, Kenya, Tanzania, and Uganda each had 5–7 percent of the total. The numbers of draught oxen in use are declining in some parts of SSA as a result of epidemics of animal diseases and droughts, and in the People's Republic of China and India because of tractorization. Singh (2001) reports, for example, that the numbers of draught oxen in use in India in 2000 was almost half that in 1950.

These trends in use of mechanization inputs show a decline in almost all the countries of SSA. This compares unfavourably with fertilizer use, which although showing great variability in national trends in consumption since the 1980s, means SSA-wide consumption has increased from an average of 1.09 million tonnes per annum during 1980–1989 to 1.26 million tonnes during 1996–2000 (Jayne *et al.*, 2003). As noted by these authors, while fertilizer use has stagnated or declined in some countries, fertilizer consumption has increased dramatically in others. The same cannot be said of mechanization, which has declined in most countries. Granted, fertilizer use is still low by world and Asian standards, the total figures are at least increasing. Mean fertilizer use per hectare per annum under annual and permanent crops rose from 7.54 kg over the period 1989–1990 to 7.92 kg over the period 1996–2000. When Nigeria's figures are excluded, fertilizer use in the rest of SSA per cultivated hectare rose by 15 percent during this period.

Figure 7 Estimates of areas cultivated by different power sources by subregion



Source: Bishop-Sambrook (2001) based on FAO (2001), three-year average 1997–1999.

A clear finding from Figure 7 is that Africa south of the Sahara remains the least mechanized region. As noted by Mrema and Odigboh (1993), hand tool technology with entire reliance on human muscle power remains the predominant power source used for primary land preparation in Africa, while draught animals and tractors are used on only 20 percent of the cultivated land. Moreover, when compared to Latin America and Asia, agricultural mechanization has stagnated in Africa. If anything, there are indications that agricultural mechanization has retrogressed in a number of countries (FAO, 2005).

From the above analysis there is no doubt that there are many success cases in the field of agricultural mechanization over the past 30 years, with considerable impact in both the developed and developing world. The history of mechanization in Asia is of considerable interest and attraction to many African leaders because of the rapid progress achieved despite early prorogations of specialists in the development community (Singh, 1998). In the light of this interest and the stark contrast in trends between Asia and SSA, mechanization experiences in these two regions will now be briefly reviewed.

Mechanization experiences in Asia

The experience of Asian countries in agricultural mechanization cannot be separated from the broader rapid changes that affected small farmers in south and southeast Asian countries starting in the 1960s. Foremost was the Green Revolution that had dynamic and far-reaching implications. The impetus for the Green Revolution was technological improvements in high-yielding seed varieties, which together with fertilizer increased productivity and intensified production. The biological technologies in effect provided the impetus for mechanization. Initially, these technologies were most suited to irrigated farming systems found in the higher potential areas of the continent and among "better-off" farmers. Later, attention shifted towards smallholder farmers in more vulnerable, rainfed areas.

Mechanization in Asia was driven by the intensification of agriculture, not only through the demand for farm power, but also because the greater profitability of farming-generated surpluses that could be spent on capital equipment. The success of this economic growth had backward- and forward-linkage impacts, generating a demand for goods and services in response to rural growth.

The nature of irrigated farming, with multiple cropping systems, increased pressure for rapid land preparation and reduced turnaround time between crops. The larger and more prosperous farmers were the first to adopt the seed-fertilizer package of the Green Revolution and then to mechanize. For example, in Pakistan in 1972, 80 percent of privately owned tractors were on the 2 percent of farms with more than 50 acres (20 ha) (McInerney and Donaldson, 1975). In India in 1971, 96 percent of privately owned tractors were on farms of over 25 acres (10 ha) in size. Both of these farm sizes were regarded as medium- to large-scale by South Asian standards (see Figure 8 on page 19). The rate of adoption of mechanization among larger-scale farmers stemmed from the imperfect market characteristics of the region (Farrington *et al.*, 1982) in terms of access to information and capital, and capacities to acquire land and displace labour. In addition to the difference in farm size, adoption of mechanization

can also be explained by the differences in land tenure systems. In India, some 80 to 85 percent of farmers were owner-operators in the mid-1960s; in Pakistan the comparable figure was about 50 percent (Duncan, 1974).

The findings on the rate of private return for all farm sizes were extremely high, although in some countries much of the private gains derived from re-distributive effects rather than net productivity increases (Farrington *et al.,* 1982). In some countries, financial profitability was enhanced by the promotion of government policies of subsidization. Subsidies provided were both direct and indirect, including research and development, concessionary access to foreign exchange, tax breaks and subsidized fuel, to name a few. In Sri Lanka, for example, the social benefits were substantially lower than private profits, resulting in large net benefits accruing (Farrington *et al*., 1982). In India, subsidies were promoted largely as a result of farmer lobbies pressing politically for government support. In the latter period of the Green Revolution, farmers began to find it increasingly tedious to manage hired labour gangs for harvesting, and further pressed governments for subsidies on combine harvesters.

Yet, in other countries of Asia both high private and social net benefits were realized, especially for medium- and large-scale mechanized farming operations of around 20 ha (see Figure 8 on page 19). This was particularly noticeable in the semi-arid areas of Pakistan and India where the land-man ratio is high and tractorization resulted in more timely land preparation and an expanded area under cultivation. McInerney and Donaldson (1975) found in their research in Pakistan, high private rates of return to combined packages of tractors and tubewell investments over the period 1966–1970 that were also justified economically (Binswanger, 1978). Tractorization in effect led to an increase in size of farms through consolidation, increasing the cost advantage towards larger farms.

The shift came about as a direct result of the increased profitability of farming. In India, the rising wage and bullock costs also contributed to the higher viability of tractors in the region. Tractorization resulted in increased cropping intensity and created the conditions for diversification into high value crops and the provision of mechanization services at competitive rates, to their more numerous small-scale farmers. The findings further suggested that the benefits to smallholders could also be increased through tractor hiring services (Binswanger, 1975). In all of these situations the returns to tractor investments appeared attractive but depended on market access and satisfactory product prices.

Mechanization also reduced the need for hired labour to perform power-intensive and arduous field operations such as hoeing. The increase in crop productivity led to high labour demand to handle increased production. Also, the increased farm-level production resulting from the use of mechanization and other biochemical inputs enabled disposable income to be reinvested on the farm for further capitalization and farm expansion (where this was possible). It should also be pointed out that the studies at the time failed to value the non-agricultural benefits of tractors, i.e. reduced drudgery and transportation, the impact of which would have markedly enhanced economic viability.

The changes brought about by the Green Revolution, however, varied markedly between countries, both with respect to the nature of the change and the rate of adoption. Even within the irrigated areas of Asia, there was regional disparity in the distribution of mechanical

equipment. Mechanization in the Punjab in India and other areas close to the large river systems took place at a very rapid pace following the spread of the high-yielding varieties (HYVs) of seed. In other parts of India, however, particularly in rice-based farming systems, there was a demand for smaller and cheaper threshers and diesel engines, which were ultimately adopted. In contrast, the level of mechanization in Pakistan was far slower. Moreover, in some of the more densely populated countries, such as Java in Indonesia, farm size and land tenure inhibited the spread of mechanization. Within the irrigated areas of the region farm size was seen to be the single most important factor determining the pattern of mechanization. Larger (by Asian standards) and higher-cost tractors, threshers and tubewells could be found on larger farms; smaller and lower-cost machinery and implements were found on smaller ones.

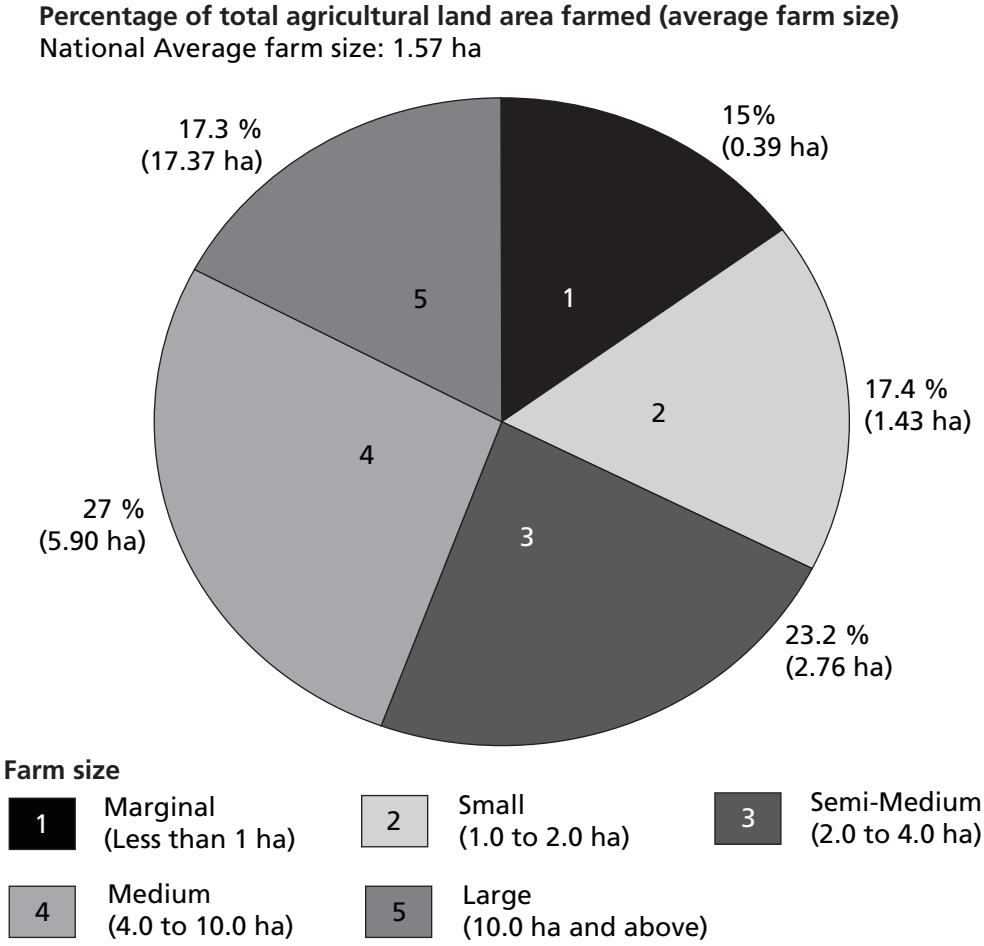
While different mechanization patterns emerged in Asian countries because of a combination of factors, it is evident that supportive government policies played a dominant role. Sri Lanka, Thailand, India, the Philippines, Taiwan and the Republic of Korea are examples of countries with persistent policies in favour of mechanization and high rates of adoption. Many Asian countries did provide some subsidies for equipment investments, both directly and indirectly (APO, 1995). In India, government policies encouraged the development of smaller and low-cost equipment (Gotsch, 1973). In the Philippines, subsidies were provided through special credit programmes and subsidized fuel. To some extent, these incentives encouraged capital-intensive farm development. Because of Thailand's low government intervention in the establishment of a local agricultural machinery manufacturing industry, its experiences stand out as an exception to this general pattern. However, the government sector played a key role through providing technical assistance to manufacturers, developing practical handbooks for equipment operators, and establishing quality standards for equipment (Krishnasreni and Kiatwat, 1998).

In general, the Asian experience shows that local manufacture and supply of agricultural machinery and implements emerged as a response to a perceived demand in agriculture. The diesel engine and tubewell industry in Pakistan, and the water pump and power tillers manufacturers in Thailand are good examples. The Indian tractor industry is another case in point: tractor sales have doubled every decade for five decades (Singh, 1998). Singh (2001) attributes this to the dynamism of tractor manufacturers and pragmatic governmental policies. The high cost and unsuitability of imported machinery from developed countries have also influenced these local efforts.

During the early stages of mechanization in Asia, mechanical technologies concentrated productive resources into fewer hands and may have increased the income gap between larger and smaller farmers. Labour was displaced and, in some cases, mechanization led to lower incomes, both absolutely and relatively, for small-scale farmers and landless labourers. The empirical evidence, however, shows that the private benefits to larger-scale farmers and the extent to which mechanization negatively impacted on labourers and small-scale farmers depended greatly on the specific mechanical operation involved. Research findings showed that mechanization for land preparation was likely to reduce the demand for family labour and draught power, while mechanizing threshing operations ran the risk of hired labour losing their jobs (Binswanger, 1978; 1986). In the absence of alternative employment opportunities, this led to lower levels of income. Alternatively, where underemployment already existed, the negative social impacts for hired labour were likely to be slight. Labour use in the Philippines, India,

Pakistan and Nepal actually increased during the period, largely as a result of the introduction of modern rice varieties, but the productivity increases resulting from the switch to HYVs are, at least in part, because of the complementary effects of mechanizing land preparation and threshing.

Figure 8 Distribution of operational holdings in India, 1990/1991 census



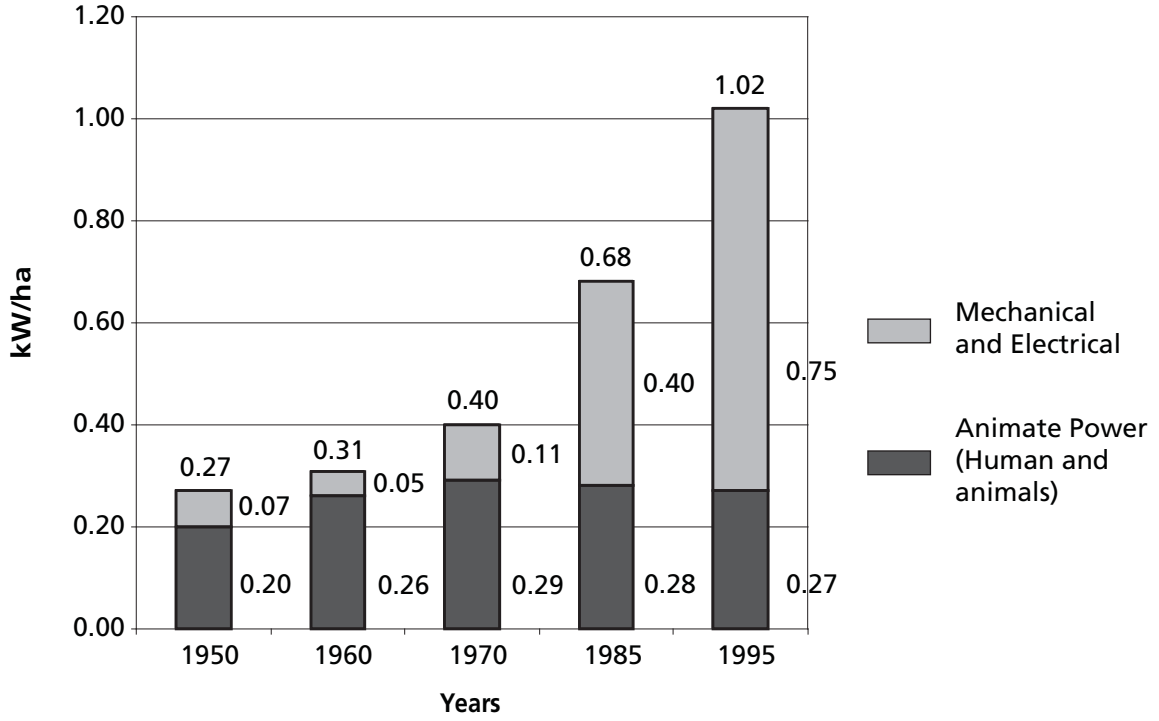
Source: Government of India (GoI) - STAT 2000.

In addition to various effects of the Green Revolution, major factors driving mechanization in Asia since the 1960s have been rapid urbanization and economic growth in non-farm sectors. In Japan, Taiwan and the Republic of Korea, labour use fell rapidly throughout the 1965–1978 period, reflecting the increasing urbanization of those economies (APO, 1995). The principle motivation for agricultural mechanization in much of Southeast Asia, in particular, was the rising rural wage rates induced by these trends (Binswanger, 1987). Rapid industrialization in Thailand, as well as other Southeast Asian countries, was a key factor leading to acute farm labour shortages and rising labour costs (Krishnasreni and Kiatwat,1998).

The Asian experience revivifies the role of farm power in increasing agricultural production, as first enunciated by Professor Giles (Giles, 1967; Fluck and Baird, 1979; Singh, 2001). The average power available per hectare in India increased from 0.27 kW/ha in 1950 to

0.40 kW/ha in 1970 and to 1.02 kW/ha by 1995 (see Figure 9) (Singh, 2001). In some states in India the power available per hectare is as high as 2.96 kW/ha (Punjab), of which 74 percent is mechanical, 22 percent electrical, and the remaining 4 percent from animate (human/animal) sources. These states have been at the forefront of the Green Revolution in India, which would seem to prove the hypotheses first postulated by Giles (1967) that there is a correlation between the farm power used and agricultural productivity. He was then criticized as being too mechanical, with some of his critics even denigrating tractorization as inappropriate in the then Third World farming systems. Further, the fact that India is now the largest producer of four-wheel tractors in the world is indicative of how things have changed since 1975 (Singh, 1998).

Figure 9 Power availability per hectare in India 1950–1995



Source: Singh, 2001.

Mechanization experiences in sub-Saharan Africa

In SSA, efforts to promote agricultural mechanization through improved hand tools, draught animal and tractor mechanization date to the early 1900s.[1] From 1900 to 1930, the main thrust of mechanization was the introduction of improved hand tools on the native peasant farms. On the European settler farms, a combination of hand tool and DATs (where draught animal could be kept) was used. The European farmers settled mostly in eastern and southern Africa, and the hand tools and draught animal implements were procured largely from South Africa and India. In West Africa, hand tools were largely fabricated by local blacksmiths.

1 The experiences of different countries in SSA in agricultural mechanization over the past 60 years have been reviewed from different perspectives in a number of reports, including Mayne, 1954, 1955, 1956; Lord, 1963; de Wilde, 1967; Kline *et al.*, 1969; Sargent *et al.*, 1981; Eicher and Baker, 1982; Starkey, 1986; Pingali *et al.*, 1987; COMSEC, 1991; Mrema, 1991; and Mrema and Odigboh, 1993.

From the 1930s to the 1950s, mechanically powered mechanization was introduced on European settler farms in eastern and southern Africa. A number of government-operated tractor units were established by the colonial authorities. There were also schemes established to provide native and settler farmers with credit to acquire tractors and farm machinery. Following independence in the early 1960s, most SSA countries inherited these projects and expanded them. Also, in the 1930s and 1940s, DAT was introduced in many parts of SSA, especially in the moist savannah zone where pastoralists settled and began to grow cash crops such as groundnuts and cotton. Under colonial government schemes, these annual cash crops were normally promoted in packages, which included animal traction mechanization.

Cultivation of the major perennial cash crops (including cocoa, oil palm, coffee, tea, cashew and copra) by smallholder farmers in most of SSA, which increased significantly from 1930 to 1960, was largely undertaken by the use of hand tool technology. For these crops, the demand for mechanization inputs decreased (e.g. for primary tillage) once the trees were planted, and where there was such a demand (e.g. for weeding), this was often during the off-season and hence did not interfere with subsistence food production. In most cases, the main subsistence food crop was cultivated by hand tool technology with women and children playing a leading role in the tillage operations.

In the 1950s and 1960s, tractor mechanization was promoted as part of large-scale agricultural schemes for which initially the colonial, and subsequently independent nationalist governments directly imported tractors. For medium- and smaller-scale farmers, tractor hire schemes were launched to spread the fixed costs of the tractors and equipment (Mayne, 1954; 1955; 1956). In this period, public sector schemes such as cooperative and communal farming, state farms and parastatals were introduced, all of which promoted large-scale mechanization.

By the late 1960s and early 1970s, policy concerns increased in Africa, as elsewhere, over the welfare effects (employment and income distribution) and the economic benefits of tractor mechanization. Studies on the economics of private tractor ownership raised concerns over financial and economic returns, and distorted incentives as a result of the widespread use of subsidies. Also, by the early 1970s clear evidence had emerged that most government-managed and operated tractor hire schemes were not successful. Government-run tractor hire schemes prevalent in the 1960s and early 1970s were largely ineffective as a result of management failures, shortfalls of government financial support and poor supporting infrastructures (de Wilde, 1967; Seager and Fieldson., 1970; Kolawole, 1972; Lele, 1976; Eicher and Baker, 1982). Other factors identified in this failure included the absence of economies of scale, low incentives under civil service regulations for tractor drivers to work extended hours, low machinery productivity, low rates of effective machine utilization (because of poor maintenance of tractors and scattered small farms) and civil service bureaucratic systems, which were not conducive to running a business such as tractor hiring.

It should be noted, however, that while the government tractor hire projects attracted a great deal of attention, the number of tractors in these schemes in many countries was a small fraction of the total number available in the national tractor fleet. As Kaul (1991) noted, the total number of tractors in these government-operated hire schemes (estimated at less than 3 000 from 1945 to 1980 in the entire SSA region) was just too small a sample to conclude

with blanket prescriptions on the use of tractors in African agriculture. As de Wilde, then Chief Economist at the World Bank, noted in 1967: "One is impressed by the diversity of experiences with animal-drawn and tractor-drawn implements in tropical Africa, and by the fact that no comprehensive effort is apparently being made to analyse these experiences and make the conclusions of this analysis to all countries of tropical Africa. … In many cases, for instance, it is difficult to determine whether mechanization has failed because it was inherently uneconomic, or because it suffered from certain technical and managerial problems that could have been avoided or overcome" (de Wilde, 1967). Thirty-seven years later, it is still difficult to state conclusively why Africa has not made much progress in agricultural mechanization.

Because of the failure of tractor mechanization in Africa and shifts in development paradigms, the development community from the late 1960s turned to other types of technologies in an effort to tackle the mechanization problem. Considerable amounts of money and other resources were invested in research and development efforts aimed at developing "appropriate" machinery and implements for mechanization in SSA in the 1970s and 1980s (Mrema, 1991; Mrema and Odigboh, 1993; Balis, 1978). Particular attention was devoted to developing intermediate types of tractors suitable to African (or developing countries) agriculture (Boshoff and Joy, 1966), for example, the *Kabanyolo* and *Tinkabi* mini-tractors in Uganda and Swaziland, respectively. Most of the intermediate types of tractors were not successful in the market, and by 1990 had been abandoned (Holtkamp, 1991). Research was also undertaken on improved animal-drawn implements such as the Mochudi two-wheeled tool carrier and other similar implements (Starkey, 1986; Mrema and Patrick, 1991). As Starkey (1986) noted, while these two-wheeled carriers were perfected in the workshops and experimental fields costing over US$50 million in research and development, they were nevertheless rejected by farmers throughout Africa. It became apparent by the late 1980s that little progress was being made in mechanizing agriculture in SSA, be it by appropriate hand tools or animal- and mechanically-powered implements (Pingali *et al.*, 1987).

In some cases where tractor mechanization did occur in SSA, it was associated with the technical problems of unsuitable and unreliable machines, as well as economic problems – the inability to achieve high work rates and speedy repairs. Many tractor owners found it difficult to maintain tractors in rural areas where the supporting infrastructure was weak (lack of repair shops and spare parts). The application of tractors and heavy mechanization in unsuitable situations led to lower agricultural production and environmental degradation. Under these circumstances, tractor mechanization easily became a burden to national economies and to individuals, rather than an essential input with the potential to increase productivity. Several studies carried out in the 1990s supported the view that policies favouring tractors and other forms of capital-labour substitution have had negative impacts on production and productivity (e.g. Van Zyl *et al.*, 1987; Belete *et al.*, 1991; Taylor, 1992; Panin, 1994; Seleka, 1999).

Despite the poor record with tractorization programmes, many African leaders remained convinced that agriculture had to be mechanized if development and economic growth were to occur on the continent. They continued to devote resources although at reduced levels to tractorization programmes up to the late 1980s. Most governments were forced by economic structural adjustment programmes (SAPs) to abandon support to such projects. By the late 1990s, most government tractor hire schemes had folded with most of the tractors either abandoned or sold off to farmers and private tractor drivers.

Overall, efforts to promote animal traction fared better with some uptake, especially in the drier areas where small- and medium-scale farmers with a livestock husbandry tradition settled and begun to grow cash crops such as cotton and ground nuts (Starkey, 1998). Nevertheless, field level studies from the late 1980s through the 1990s continued to find that animal traction is often not profitable or beneficial under small-scale farmer conditions (Jansen, 1993; Jolly and Gadbois, 1996). The studies that did find use of animal traction profitable, emphasized that benefits are strongly dependent on specific situations, for example, where soil and economic conditions permit intensive land use and profitable farming (e.g. Williams, 1996; Adesina, 1991).

In addition to limited profitability, problems affecting the use of animal traction include the substantial financial burden on farmers during the early years of adoption (Panin, 1988), lack of appropriate recommendations for the pertinent tillage system (Willcocks and Twomlow, 1992), and the opportunity cost of labour and capital for maintaining animals outside of the cropping seasons (Ehui and Polson, 1992). Finally, as a result of the tsetse fly problem, keeping livestock and hence using draught animals is restricted to the drier zones of Africa. Further, adoption of this technology for people who have no animal husbandry tradition is extremely low even after prolonged extension efforts. The recurring droughts in many parts of Africa as well as the outbreaks of epidemics of animal diseases have also contributed to reducing the use of DAT, even in areas where it had been widely adopted in the 1960s, as in the southern province of Zambia.

Since the start of the 2000s, there has been little progress and few new initiatives or new ideas on mechanization in SSA. This stands in contrast to a growing number of success stories in Africa that show the vitality and responsiveness of farmers and private sector firms in introducing new enterprises and biophysical technologies when presented with favourable domestic conditions and policy incentives (Gabre-Madhin and Haggblade, 2004).

Lessons learned from mechanization experiences

In general, key driving factors responsible for the uptake of mechanization in Asia in the 1970s and 1980s can be summarized as:

- the presence of a sizeable number of medium-scale farmers providing mechanization and other services to the more numerous smallholder farmers;

- availability of registered land that could be purchased or leased by individual farmers, thus increasing farm size and subsequent profitability as well as providing farmers with an opportunity of using their land title deeds as collateral for credit to buy machinery;

- entrepreneurial capacity of farmers and versatility in adapting to changing markets, technologies and policies (adaptive management);

- opportunities to use tractors and other agricultural machinery in off-farm activities, such as transport, construction, repair and maintenance of rural infrastructure;

- policies encouraging industrialization, resulting in rising real wages, and complementary policies contributing to the private profitability of farming;

- high levels of effective demand for mechanized equipment, leading to the development of suitable low-cost equipment (tubewells, power tillers, diesel engines) as an alternative to purchasing high-cost and often unsuitable machinery from developed countries;

- presence of local entrepreneurs dealing with repairs and manufacturing, and development of machinery supply chains ensuring availability of spare parts;

- business- and enterprise-friendly policies, laws and regulations as well as physical and institutional infrastructures, which encourage commercial activities and entrepreneurship in farming, input supply as well as produce handling, processing and marketing.

Some other points emerging from mechanization experiences in Asia and SSA include: (see Binswanger, 1978, 1986; Sargent *et al.*, 1981; Farrington *et al.*, 1982 ; Burch, 1987; Pingali *et al.*, 1987; Nagy *et al.*, 1988; Starkey, 1998):

- Mechanization of processing and pumping has tended to precede the mechanization of crop husbandry and harvesting operations.

- Mechanization of power-intensive processing and pumping operations can be profitable at low wage rates.

- Mechanization of difficult and arduous tasks, such as land preparation, does not necessarily lead to unemployment.

- Field productivity increases stem from combinations of technologies used as a package, including farm power mechanization and biological technologies.

- To pay for investments in mechanical technologies, farmers have to be able to generate income and profit from their production; sustainable mechanization has often been associated with programmes that facilitated or supported access to organized markets for crops such as cotton.

- Tractorization has often led to increases in farm size through land consolidation and procurement of adjacent farms.

- Because of the high capital costs associated with tractors, only larger farms were in the position to exclusively utilize them efficiently.

- Farmers who purchased tractors were able to use them profitably only if the tractors were also used for purposes such as transport and other off-farm activities in addition to on-farm activities.

- Where rental markets exist or can be established, farm size has had less influence on the pattern of mechanization (e.g. in India).

- Substitution of labour by tractors tended to occur as a result of the high supervision costs associated with hired labour, particularly on larger farms.

- Government subsidies, tax concessions and overvalued exchange rates may have accelerated the pace of tractorization.

- Efforts to design and promote implements and machinery especially for particular farming systems or specific groups of farmers have not fared well.

- There is a perception that mechanization programmes operated directly by government agencies have been more dominant in the process of mechanization in SSA than in Asia.

From these experiences, four main policy lessons for mechanization in SSA can be gleaned from the Asian and African experiences over the past three decades:

First, attention should be placed on increasing the profitability of investments in mechanization for farmers by encouraging commercial agriculture and focusing investments and support on both farm and non-farm enterprises. The overriding issue facing countries in Asia in the 1970s was how to develop a highly productive agricultural sector that could meet food security needs and compete effectively in national, regional and global markets. At the farm level, a critical factor has been whether there are entrepreneurs ready to invest in machinery for use on their farms as well as provide mechanization services to other small-scale farmers who are unable to marshal such levels of capital investments.

> Where machines came into use in Asia they were accompanied by wide-ranging changes. At the farm level, adjustments were made to the entire farming system and mechanization changed the constraints and possibilities that determined the evolution of farming in the region (Duncan, 1975).

Second, mechanization should be viewed strategically within a longer-term time frame. Despite the array of studies demonstrating that mechanization is often not profitable (Binswanger, 1978), medium- and larger-scale farmers in South Asia continued with their shift to tractor use, and farmers in Southeast Asia introduced diverse types of powered equipment while successful industrialization policies drove up rural and urban wage rates (Balis, 1978; Sarma, 1982). In general in Asia, policy-makers disregarded the short-term impact of mechanization as less relevant and important. They took a more strategic longer-term perspective of mechanization, viewing it as part of a broad-based economic development strategy aimed at economic growth and agro-industrialization. To this end, governments both stimulated and responded to the trends through favourable tax and subsidy policies and support to nascent input supply industries. Short-term social costs were at times ignored, looking instead to the likelihood of increased labour demands following intensification. The result, as seen above, was a dramatic transformation over a 30-year period. While certainly there have been inefficiencies and undesirable distributional impacts during this process, the transformation of agriculture throughout Asia, in which mechanization has been an integral part, is positively viewed from the African perspective as a success story in achieving productivity gains and export competitiveness.

Third, mechanization is a complex and dynamic process that cannot be appraised only from the standpoint of factor substitution or net contribution to production (cf. Binswanger, 1986). Where mechanization has taken place worldwide, there have been fundamental, interlinked changes in the structure of agricultural sectors, in the nature and performance of agricultural support services, and in the livelihood strategies of farmers and agroprocessors. The changes do not necessarily take place simultaneously and do not impact on all people the same way.

Fourth, while political leaders and governments in Africa and Asia have actively promoted agricultural mechanization, its successful development has not depended on governments' direct involvement in machinery supply, development and financing, or on offering mechanization hire services. Instead, where mechanization has been successful, essential mechanization supply systems and support services have developed in response to economic demand – in most cases starting with support services targeting medium- and larger-scale farmers. Decision-makers therefore need to focus on the longer-term developmental dimensions of building public and private sector institutions and services to support mechanization rather than attempt to accelerate short-term technology transfer rates through direct government involvement in machinery supply and services.

In conclusion, it may be said that given globalization and the resulting free flow of information, many Africans are able to see the progress in mechanization in Asia over the past three decades. African presidents and ministers who have been visiting India, the People's Republic of China, Thailand and other Asian countries therefore find it difficult to understand and appreciate those who advise them to adopt a different and untested route in mechanization to that which Asian countries have taken during the second half of the twentieth century, and which Western countries took during the first half.

Rethinking agricultural mechanization in sub-Saharan Africa

The last decade has been a period of rapid change in Africa: globalization and market liberalization have occurred side by side with economic structural adjustment and government decentralization. These have interfaced with urbanization trends and a growing number of middle-income consumers with increasing demands for better quality and value-added products. Agriculture is therefore required to be more commercial and more market-oriented. Globalization has resulted in opportunities and challenges for farmers but within the context of structural readjustment. With structural adjustment there has been a breakdown in the provision of public sector services. The public sector has been compelled to increasingly withdraw responsibility for providing agricultural support services, and in some cases, even rural infrastructure. The private sector has been expected to take over the role of the government, which facilitates this process by creating an enabling economic environment for businesses to thrive.

Market liberalization and globalization have provided the opportunity for mechanization to emerge as an important area of development as farmers become more commercially and market-oriented. Other emerging factors such as urbanization and the HIV/AIDS pandemic are also pushing for an agricultural system that will require higher levels of mechanization inputs than before. At this point, however, the way forward on mechanization in Africa may appear to be unclear, and most countries have yet to formulate coherent well-considered mechanization policies and strategies that factor in the realities of the twenty-first century. There remains strong political will favouring mechanization, as indicated above, but there is also widespread recognition that many past efforts to promote and support mechanization were not successful. In the context of the changing climate for investment and economic growth in SSA, it is time to rethink the role and importance of agricultural mechanization as a component of the future vision for its agricultural development.

When considering the future of mechanization in SSA, it is important to recognize that one key problem undermining the success of past mechanization initiatives has been a preoccupation with introducing animal traction or tractors for land preparation. In part, this preoccupation stems from an old adage in the mechanization literature that mechanization starts with power-intensive operations, followed by operations and equipment that require greater precision. In part, this preoccupation stems from the expectations created during the early days of the Green Revolution, as noted above, when the shift to multiple cropping and associated increases in productivity put a premium on timely and high quality land preparation. The reality, however, is that mechanization is not only an issue of substituting labour with animate or motorized power in land preparation – although very visible, this is only one of its dimensions.

Even in the specific context of technological change, there are many mechanization options and opportunities in addition and complementary to mechanization of land preparation. This often was overlooked in Africa when governments imported tractors and set up government tractor hire schemes, and when more than 20 years of investment was poured into promoting and subsidizing the introduction of animal traction in the savannahs of West Africa. Meanwhile, under the radar scope of donors and many African governments, mechanization was slowly moving ahead with much less support in activities where African farmers and processors had a felt need to break farm power constraints.

Some of the quiet success stories in Africa include various types of water pumps including the treadle pumps, hammer mills for grain milling, cassava graters, driers and other preservation technologies, tractor and donkey carts for transport, spraying equipment for pesticide and herbicide application, and chainsaws for forest clearing. Even with respect to traction use in field operations, one might ask why there is such preoccupation with land preparation when the majority of field studies in Africa point to the pervasive importance of labour constraints during the weeding period. Timely land preparation is important in some areas, but is not everywhere the main bottleneck (Eicher and Baker, 1982). In summary, mechanization is about many types of power and equipment, not just land preparation with tractors and animal ploughing.

In addition, mechanization is not an "all or nothing" process. Levels and types of improved mechanical technologies need to be compatible with local economic, social and agronomic conditions. For example, tractor power is likely to be best suited to the moist savannah areas and flood valleys (Pingali *et al.*, 1987), while mechanization of agroprocessing may be more important in the more humid areas where farming systems are dominated by perennial crops. Moreover, neither animal nor tractor cultivation are exclusively suitable for all regions and districts. Hand cultivation will continue to be necessary where:

- topography makes tractor or draught animal ploughing difficult, e.g. highland slopes;
- tree crops can be grown, such as coffee and tea, which make it possible in other ways to obtain a satisfactory output;
- labour can be hired at reasonable cost to cope with peak labour requirements.

In brief, it is desirable to think of agricultural mechanization not as a short-term commitment to replace human labour with machinery and equipment, but rather, as a longer-term developmental process that involves various mixes of farm power sources over time. No single source of farm power (human, animal, mechanical) is mutually exclusive, and the most effective results ensue from a combination of them, synchronized and targeted to address specific local problems. The key challenge, however, is to create incentives and enabling conditions so that farmers and managers of non-farm enterprises can mechanize those difficult, arduous and power-intensive operations that constrain productivity growth and are difficult to perform, when relying entirely on human muscle power. Such reliance on human muscle power makes agriculture a very unattractive sector, largely contributing to the exodus of the young and educated from farming.

We now turn to reasons why mechanization, understood as a multifaceted longer-term developmental process, should have an important place in the future vision for agricultural development and economic growth in SSA. It should be noted that in the discussion below it is not intended to imply that mechanization is a sufficient condition for agricultural development. Rather, the policy issues are: should mechanization be viewed a necessary dimension of agricultural development strategies in SSA, and should efforts to promote and support mechanization in SSA receive greater attention.

Improving productivity and growth

The task facing the agricultural sector in SSA is huge. The agricultural sector in Africa is required not only to produce enough food to feed its increasing population (a large percentage of which will be living in urban areas), but also to provide the main source of foreign exchange earnings for many countries in Africa. As is too well known, the agricultural sector has not been performing well enough to make the required contributions to the economic development of SSA. Some of the key trends illustrating this poor performance are shown in Tables 1, 2 and 3 – each comparing SSA to all developing countries combined.

Table 1 presents selected agricultural sector indicators for 1980, 1990 and 2001. As of 2001, agricultural value added per capita in SSA was less than 40 percent of the average for all developing countries, and had a decline of nearly 40 percent compared to 1980. Agricultural imports remain a high share of total imports; twice the average for all developing regions, and show no downward trend. Crop production per hectare has increased since 1980, but is well below half the average for all developing countries, and is lower in SSA in 2001 than the average for all developing countries in 1980.

Table 1 Agricultural sector indicators for developing countries and sub-Saharan Africa

	Developing countries			SSA		
	1980	1990	2001	1980	1990	2001
Agricultural value added per capita (US$)	122	144	218	139	114	86
Crop production per ha of land use (US$ 1989–1991 prices)	396	512	646	187	238	298
Percentage share of agricultural products from total merchandise imports	14.4	11.1	7.5	15.4	16.3	15.8

Source: FAO (2004).

Table 2 shows average annual growth indicators for two periods, 1980 to 1990, and 1990 to 2001, for developing countries as a whole compared to SSA. In both periods, rates of growth in SSA were distinctly lower for total agricultural production, per capita food production, and agricultural production per agricultural worker. One result of slow productivity growth during 1990–2001 was negative growth in the value of agricultural product exports, including the value of cereal exports. The overall value of agricultural imports grew moderately below the developing country average during 1990–2001, reflecting broader economic conditions affecting the capacity to pay for imports, while the rate of growth of cereal imports was more than double the average for developing countries.

Table 2 Average annual growth indicators for developing regions and sub-Saharan Africa

	Developing countries		SSA	
	1980–1990	1990–2001	1980–1990	1990–2001
Total agricultural production	3.7	3.8	2.8	3.0
Per capita food production	1.6	2.3	-0.2	0.3
Agricultural production per agricultural worker	504	672	330	373
Value of agricultural product imports	2.3	3.9	-0.6	2.9
Value of agricultural product exports	2.1	2.9	-1.4	-0.4
Value of cereal imports	2.0	3.2	0.1	6.9
Value of cereal exports	2.3	7.5	11.6	-7.9

Source: FAO (2004).

Not surprisingly, selected food security indicators presented in Table 3 show that per capita food availability, although greater in the period 1999–2001 than two decades earlier, remains well below the average for developing countries. Moreover, one-third of the population of SSA is undernourished, which is nearly twice as high as the rate for all developing countries combined, even taking into account the amount of food aid received, which is three times the average for all developing countries combined.

Table 3 Food security indicators for developing regions and sub-Saharan Africa

	Developing countries		SSA	
	1979–1981	1999–2001	1979–1981	1999–2001
Per capita food availability (kcal/day)	2 310	2 680	2 090	2 210
Percentage population undernourished*	28	17	36	33
MT[1] food aid per million total population**	2 655	1 621	6 926	4 946

Source: FAO (2004).

1 Metric Tonne

* Second period: 1998–2000.

** Aid received 1980–1981 divided by population 1980; aid received 2000–2001 divided by population 2000.

The poor performance of the agricultural sector in SSA is particularly significant in the light of the importance of agriculture as a share of overall value of domestic production and international trade, and because a large share of the labour force (43 percent) works in the agricultural sector.

In brief, SSA countries need to redress food insecurity and poverty by boosting agricultural production and value addition, by targeting domestic markets while increasing production of exports to generate foreign exchange. This goal has been made more difficult because of increased competition in world markets. Achieving economic growth through the agricultural sector will not be easy and will require innovative solutions that challenge past pre-conceptions. Considering the above trends over the past decades and increasing globalization of the world agricultural economy, a key question that arises is whether African countries can realistically achieve a significant turnaround in agricultural value-addition growth with agricultural sectors that rely to the extent that they do on human muscle power and hand tools.

The argument that mechanization is essential to agricultural development and economic growth cannot be proven or disproven. However, trends in mechanization worldwide show clearly that there are strong correlations between economic growth and mechanization (Clarke and Bishop, 2002): those countries that have achieved unprecedented economic growth over the past three decades and have succeeded in solving their food problems have also moved to higher levels of mechanization of their agriculture. Countries that have stagnated economically, with significant numbers of their citizens steeped deeper in poverty, have also lagged behind in agricultural mechanization.

There would appear to be at least three reasons for linking mechanization with the evident need for substantively transforming the agricultural sector in SSA:

1) Lessons based on areas where mechanization has progressed rapidly show that increased power and better equipment contribute to increasing production, productivity and the profitability of farming. The benefits of mechanization must be seen in conjunction with other inputs, such as improved seed varieties, fertilizers, pesticides, and water availability and control. Nevertheless, intensification of agriculture and timeliness of cultivation require an adequate supply of power during peak periods, for which a high degree of mechanization is essential. In brief, a combined and synchronized approach of promoting biochemical technologies together with mechanization is needed. The original hypothesis advanced by Giles (1967) that the major inputs – fertilizers, improved seeds, pesticides, water, and machines – interact and are very interdependent for growth in agricultural productivity and overall production is pertinent. Even more important is how all these inputs are integrated together and the sequencing of their introduction, singly or in combination, into a farming enterprise (Mrema and Odigboh, 1993).

2) During the late 1970s and early 1980s, debates on mechanization were confounded with debates about transformation versus incremental change approaches to agricultural development in SSA. Colonial and post-independence programmes that tried to introduce complete packages generally failed, and by the early 1980s there was a consensus – at least among experts working in Africa – that farmers adopt changes incrementally. More than 20 years of research in Africa went towards support of client-driven, staple food crops-oriented, incremental change of low-input farming systems (Collinson, 1999). It is not entirely coincidental that during these same two decades, agriculture in Africa stagnated with productivity gains falling well below population growth rates. Experiences in Africa with incremental change and continued reliance on low-input systems stand in stark contrast with the cropping systems approach in Southeast Asia that underpinned the shift to high input and intensity multiple-cropping systems.

3) Related to the first two points, there is a need for realism with respect to the levels of private sector investment required to advance African agriculture and how that investment might be mobilized. In all other developing regions, and in parts of SSA, medium- and large-scale commercial farmers were early drivers for investment and productivity growth, complemented by growth of agribusiness firms (for inputs supply, processing, marketing, transport, etc.). In part, through capital-labour substitution, commercial farmers and agribusinesses have higher potential for savings and investment. The incentive to invest is higher when entrepreneurs can avoid dependence on unskilled labour, particularly when

timely and high quality operations are required. There are already a number of illustrative experiences in SSA in which entrepreneurs have invested in developing partially or largely mechanized production and processing food chains, in many cases involving contracts and inter-linked services with smaller-scale farmers. Examples include development of industries for pineapple exports and juice in Ghana, dairy and horticulture in Kenya, paprika in Zambia and outgrower sugar cane production in Kenya, Tanzania and Swaziland, etc. (FAO, 2003).

Together with the third point above, experiences of the past 50 years of agricultural development in Africa show that small-scale farmers have been quite successful in increasing their productivity and overall production in those commodities. These commodities have also been produced by medium- and large-scale farmers (e.g. coffee, tea, pyrethrum in East Africa, tobacco in East and Southern Africa, cocoa in West Africa, beef cattle in Botswana, Namibia and Zimbabwe, and maize and wheat in Kenya and Zimbabwe, etc.). This is largely because of the higher transaction costs in Africa of input supply and output recovery, which require large volumes to be available before agribusiness can profitably venture into such undertakings. Therefore, it is because of the medium- and large-scale farmers that viable and sustainable input and output recovery enterprises are established, and in turn are able to provide the small-scale farmers with their services at an affordable cost (i.e. providing services to the small-scale farmers is piggybacked to serving medium- and large-scale farmers).

In brief, the process of agricultural mechanization can be seen as a catalyst for enabling agricultural development and structural change that is necessary if agriculture is to become more commercially oriented and competitive in national, regional and international markets (FAO, 2005).

Improving rural livelihoods

The case for mechanization cannot rest only on an appraisal of the expected economic benefits. Many rural Africans are scratching out an uncertain existence while waiting endlessly for governments – which themselves have no resources as a result of the low overall state of economic development – to develop roads and bring electricity and water. All Africans share a concern that the farming population in Africa increasingly comprises older and poorer people. Younger Africans see farming as a last refuge, leading to a life of drudgery for those who cannot find other types of work. The exodus of forward-looking, entrepreneurial and innovative young people will continue until the nature and image of farming changes. A shift to tractors and other machine-powered equipment, therefore, can be seen as part of a broader strategy to make agriculture attractive for new energetic and innovative generations of farmers and other entrepreneurs.

> Broad-based poverty reduction in Africa simply will not occur without a vibrant agricultural sector providing income, employment and affordably priced staple foods (Gabre-Madhin and Haggblade, 2004).

Moreover, the prevalence of HIV/AIDS and its devastating effect on population growth, with a decline in the growth of the labour force, will affect migration, the costs of labour and the competitiveness of the labour-intensive agricultural sector. Afflicted households are seen to shed capital assets as a coping mechanism, and are forced to reduce their usage of cash inputs in agriculture. The cumulative effect is likely to be a decline in agricultural productivity and a direct and detrimental impact on food security and poverty. Mechanization is needed to create the economic growth necessary to alleviate poverty.

There is a more immediate need to combat the degenerating farm power situation that many farming communities face. A recent series of farm- and community-level case studies from several African countries showed that farm power systems in parts of Eastern and Southern Africa have collapsed in the last two decades and most tractor hire services have closed (FAO, 2005). Further, because of inter-relationships among households, all suffer from the deterioration of the community's farm power base. The main conclusion from the multicountry study was that in the absence of concerted efforts by governments, non-governmental organizations (NGOs) and the donor community to intervene to address the vulnerabilities of various farm power systems, it is likely that the communities where the farm power base has already been destabilized will face a continuing state of collapse.

Even in areas where farm power systems have not been destabilized, labour demands in rural households reduce the quality of life. The drudgery associated with farm operations is perhaps the most important factor that has made agriculture unpopular among the youth of Africa (Kaumbutho, 2001). In addition, there continues to be large and inflexible requirements for arduous household tasks, such as water and firewood collection, and hand processing of food for home consumption and sale. In many parts of Africa, farmers continue to walk long distances to their fields, sometimes requiring two or three hours each day. Powered equipment and transport that can alleviate some of the hard work would make a substantial, direct contribution to improved livelihoods and release labour for other, more remunerative activities, particularly for women who continue to bear the greatest burden of household tasks.

Employment generation

One of the persistent concerns raised with respect to mechanization is over labour displacement. This stems in part from the dominance of South Asia in the mechanization literature, but also from the low total number of hours in agricultural activities reported in many studies for Africa. Almost certainly there is available labour that can and will respond to adequate incentives, as reflected yearly when family members and communities mobilize in order to meet peak season requirements. It is well known that the livelihood strategies of most African rural households are well diversified. In many areas, arable farming provides half or less of household incomes and in some, substantially less. Even in areas that are heavily reliant on crop farming, significant amounts of income are derived from beer-making, transport, small trading, brick-making and other activities, as well as wage employment and remittances. There are, in brief, many competing demands from other activities. Most of these other activities have low real wage rates, but unfortunately, returns to labour in agriculture are often even lower, except in peak periods when labour flows from other activities to agricultural ones.

Introduction of mechanization to address peak season labour constraints could consequently be expected to have two benefits leading to an increase in employment and wages. One is the substitution of capital for labour when meeting peak season labour constraints, thereby allowing household members to continue to engage in their other non-farm activities that are put on hold during peak seasons though otherwise remunerative. The second and more important is the increase of labour demand in agriculture in the non-peak seasons through increases in scale and/or increases in land productivity because of more timely and high quality land preparation. Based on studies he reviewed from the 1950s to the 1970s, Cleave (1974) estimated that reduction of the extreme seasonality of labour in agriculture could lead to an increase in time devoted to agricultural production from 15 percent up to 50 percent. The potential employment benefits of attenuating peak season constraints could well become significant in the coming years in light of the HIV/AIDS pandemic and other factors that reduce the numbers of healthy people available for peak season farm work. However, it should be noted that there is evidence to show that the cost of unskilled agricultural labour may not rise, as an upward pressure on agricultural wages is likely to induce reverse urban-rural migration from the informal sector (Jayne *et al.*, 2003). In contrast, however, the cost of skilled labour is expected to rise as the HIV/AIDS disease has been seen to deplete the ranks of skilled workers faster than their replenishment.

In all events the trends indicate that there will be a pressing need to increase agricultural productivity, while taking cognizance of the relative diminishing labour force in agriculture and the changing gender balance. A broad range of technical and institutional solutions are most likely to be needed to respond to the effects of the HIV/AIDS pandemic in Africa, which include overcoming labour shortages by the adoption of labour-saving techniques and practices while increasing the use of farm power. The need for agricultural mechanization in both production and post-production operations lies at the centre of the response.

In summary, powered machinery and commercial agriculture is the future vision to which African leaders and most African farmers aspire. Not all African farmers will succeed, but African agriculture will not contribute to overall economic development until there is an acceptance of modernization and structural change, including commercial farming and agro-industrialization. It is no wonder, therefore, that the recent strategies for modernization/improvement of agriculture developed by many countries in Africa call for transformation of the sector (e.g. The Plan for Modernization of Agriculture in Uganda). Even small-scale farmers and agroprocessors living in lower potential areas face power constraints that negatively impact on their livelihoods and quality of life. Mechanization can be critical in improving Africa's future; the question is how to move forward in the most sustainable, commercially viable and inclusive manner, building on lessons learned since the previous policy push on mechanization in the 1960s and 1970s.

Critical factors for successful and sustainable mechanization

Efforts to accelerate mechanization in SSA need to be strategic and well focused, building on lessons learned over the past several decades. One of the key lessons is that there is no single pattern or pace of mechanization; ultimately, mechanization processes must be suited to particular situations. This is especially important in Africa, where the conditions for mechanization are not the same and may not be favourable in many locations and for all farmers.

One of the key success factors in mechanization, therefore, is a sound comprehension of the field situation and the priority operations to mechanize. As de Wilde (1967) noted, detailed understanding is needed of the requirements and performance of different types of machinery in varying contexts. The mechanization requirements of different farm types need also be appraised in order to identify bottlenecks and solutions. This requires close contact with farmers, agroprocessors, input suppliers, service providers and other stakeholders. The kind of questions that need to be considered are: What operations should be mechanized? Where should mechanization be applied (location, crops, production bottlenecks)? What level of mechanization should be applied (manual, draught, animal, motorized)? What is the most appropriate way of promoting mechanization? What are the lessons (success and failure cases) from similar locations in Africa?

With the above caveat on the importance of location specificity and stakeholder engagement and consultation, the rest of this section turns to three key success factors that past experiences indicate are absolutely essential to the efforts to promote successful and sustainable agricultural mechanization.

Effective demand

Effective demand for agricultural products, generated by a growing urban population, high incomes per capita, off-farm employment opportunities and rising wage rates creates both the need and the opportunity for mechanization (Clarke and Bishop-Sambrook, 2002). Mechanization therefore needs to be linked to market-oriented enterprises in order to generate necessary cash flow to cover capital costs and make loan payments. As Cleave (1974) pointed out in his seminal review of nearly 50 studies based on farm surveys on labour use, the establishment of markets – along with management guidance and inputs provided by traders and government – stimulated production increases and corresponding adjustments in resource management including labour use. Adjustments made in farm management following the introduction of market-oriented crops have led to a doubling or tripling of farm income.

Effective demand for products translates into effective demand for equipment and machinery services only if farming is profitable. Farm profitability needs detailed attention

because the farm value of crops in many areas in Africa is too low to support high production costs per unit of area. While mechanization may make the difference in farm profitability, its costs are elevated because of the high foreign exchange rates, high costs of maintenance and repairs, and the need for thorough land clearance, which exacerbates costs. Therefore, if farms are not profitable before mechanization, the likelihood of becoming profitable as a result of mechanization alone is low. In most circumstances, it is perhaps more realistic to view farm profitability as a condition that makes mechanization feasible, rather than as an outcome of mechanization.

There are many regions and pockets within districts in many parts of SSA where the production potential is high, access to markets is favourable and the provision of private sector services from urban centres is feasible. It should be possible to accelerate the pace of mechanization in such areas. Unfortunately, many African farmers have only limited access to local, national, regional and international markets, for both the provision of inputs and the marketing of outputs. For farming to be profitable and ultimately to mechanize in these latter areas, farmers will first need opportunities to compete in a wider range of markets. In brief, for there to be sufficient and sustainable effective demand for mechanical technologies, efficient marketing and distribution systems need to be in place to ensure that whatever is produced on the farm can be transported, processed, packaged and marketed to consumers, whether locally, in towns and cities, or through export.

Considering the low profitability of many small farms and the levels of investment required, medium- and large-scale (10–200 ha) commercial farmers are in the most favourable position to mechanize in the near future – if they have not done so already. Even medium-scale commercial farmers, however, face many constraints that limit farming profitability, and in recent years have found it difficult to maintain and replace equipment. Efforts to increase the profitability of medium-scale commercial farming can be expected to boost effective demand for mechanical technologies and would undoubtedly augment the supply of tractor hire services to small-scale farmers. Misra (1991) and Byerlee and Husain (1993), for example, reported that medium-scale farmers in India and Pakistan hire out their tractors for about 700 tractor hours per annum in each country, which represents more then 50 percent of what is normally taken as economical annual utilization rates for tractors in developing countries. There is a need to identify such farmers and encourage the development of viable commercial farming operations together with the potential of providing tractor services to smaller-scale farmers (Adams, 1988).

Economic use rates

Consistent findings from field level studies show that the costs of tractors and full packages of equipment put into question the profitability of mechanization at the level of the individual farm. This has been one of the main arguments against investments in bulky and expensive technologies, such as tractors or promotion of entire technology packages. The cost of machinery and equipment services, however, is greatly reduced by extending use over a large number of hours annually. Because the size and fragmentation of holdings is a restriction in most circumstances, this calls for hiring out, asset-sharing, and careful planning of machinery and equipment use, bearing in mind the seasonality of demand.

Because small-scale farmers cannot, in most cases, afford to procure machinery and equipment, hire services offer a viable alternative. Despite recent setbacks in the supply of tractor hire services, there are hundreds, if not thousands, of individuals scattered throughout many countries in Africa who own tractors and who are still providing tractor hire services to farmers. Although hire services, particularly for tractors, can be successfully provided through private or cooperative ownership, policies and other support systems need to be in place to support hiring or leasing services. Because the role of hiring and rental markets for privately owned and operated tractors is likely to increase in the future, it is important to understand factors affecting the development and sustainability of rental markets for machinery. Lessons should be drawn from cases, such as the privatized minibus passenger transport services throughout Eastern and Central Africa (*matatus* and *daladalas,* etc.), the *boda boda* motorcycle transport service operators in Uganda, as well as hammer mills in Tanzania and Zambia. Unfortunately, these do not normally inspire researchers to find out how these services are able to survive in an environment often hostile to business.

Asset-sharing arrangements also can lead to higher utilization rates for capital machinery. There is already a strong tradition of asset-sharing in Africa to build on. For example, it is not uncommon for two households to combine their draught animal and human labour resources to undertake field operations (e.g. Baker, 1988). Similarly, households that do not have their own implements often borrow from one another. Many of these arrangements are reciprocal and based on traditional practices. Alternatively, farmers may come together in groups where such arrangements are part of broader collaborative activity. In Kenya, for example, farmers have formed smallholder organizations, groups or associations to save money, share labour and receive credit, extension, training and other services. Similar approaches have been introduced in other countries, particularly in the Francophone parts of SSA. Women's groups in particular have achieved a great deal of success in this way.

Sharing of machines for operations that are less time-bound, such as milling and threshing, is the easiest task to manage because it can be carried out over a much greater time period. The success of hiring and asset-sharing strategies for increasing utilization rates of field machinery and equipment is limited, however, by the very short time span available to undertake key cultivation operations on different farms at the same time. This is particularly true for land preparation in semi-arid environments under rainfed agriculture. Weeding operations must also be well-timed and are often undertaken at the same time on different farms. Developments in telecommunication infrastructures, as is now occurring throughout Africa, will undoubtedly lead to lower transaction costs for machinery hiring. Farmers and enterprise managers, for example, are increasingly using mobile telephones to obtain not only market information, but also to contact service providers, such as transporters and tractor owners.

In areas with a short time frame for land preparation, utilization rates will be constrained despite efficiently organizing a combination of own use, hire services and asset-sharing. This constraint could be resolved by taking advantage of rainfall isohyets by latitude (mainly in West Africa) or altitude (common in Eastern Africa), in order to move tractors according to peak land preparation seasons. Movement of tractors across borders used to occur in Eastern Africa during the 1960s and early 1970s, but stopped as a result of insecurity in Uganda following the Idi Amin coup of 1971 and the collapse of the East Africa Community in 1977 (Mrema, 1991).

Whether through own use, hire-out services or asset-sharing arrangements, the most common and practical approach for further increasing utilization rates is through the use of tractors for transport and other non-agricultural tasks, such as improvement of rural road infrastructure and other building works. This requires close coordination with the organizations responsible for rural infrastructure as well as policies that encourage use of tractors for such activities.

Finally, a shift in focus to organizational and institutional approaches for increasing utilization rates through tractor hire and equipment-sharing could help address persistent problems of inefficiency and poor quality in machinery use. It is simply not necessary or desirable for all farmers to become experts in equipment and machinery use and maintenance. Rather, over time, mechanization services might increasingly be supplied by specialized commercial service providers using well-trained and professional machinery and equipment operators.

Machinery and equipment supply chains and services

The availability of machinery, equipment, spare parts and other supplies is essential for successful and sustainable mechanization. Consequently, agricultural mechanization includes the development of local industries for production of machinery and implements, and where production is not feasible, the establishment and development of local franchise holders to import them. Even more important is the need to establish efficient and effective distribution channels for equipment, spare parts and repair services, as well as other supplies such as fuel and oil. Viewing mechanization as including development of supply chains and services ensures a better choice of equipment for particular types of users and uses, while guaranteeing the availability of spare parts and technical assistance.

Priority attention needs to be given to establishing reliable and low-cost supplies of tractors and related equipment, as well as other engine-powered machines. A strategy with potential might be for SSA countries to consider establishing new supply chains for agricultural machinery and spare parts from Asia. The People's Republic of China and India, in particular, have become important global suppliers of low-cost, appropriate equipment. Most of the machinery available from the high-income industrial countries is too expensive and too complicated, as well as often of high power rating and being adapted for extremely large-scale farms. At the same time, India,the People's Republic of China and Pakistan, among other developing countries, produce and export tractors and implements at prices that are a small fraction of prevailing prices of the equipment imported from developed countries currently on the market in most African countries. Procuring machinery from such countries will go a long way towards accelerating agricultural mechanization in Africa. Also, elimination of import duties on agricultural machinery and equipment, except in countries that have a realistic plan to develop local production capacity, could significantly increase access to appropriate, low-priced machinery and equipment.

Development of local industry for manufacturing machinery and equipment is a feasible option in some countries and has the advantage of generating alternative employment, reducing dependence on imports, saving foreign exchange and facilitating the supply of parts

and services. Although it is unlikely that the equipment for large-scale commercial farmers could be manufactured locally, most of the machinery and equipment needed – such as small diesel engines, fodder-choppers and threshing machines, as well as a range of draught animal-powered equipment – could be manufactured and serviced in some of the countries of SSA. In fact, implements that are specific to the local circumstances (agricultural conditions, soil types, etc.) can best be made by small-scale industries, and this has the benefit of reducing manufacturing and transportation costs and generating employment. This argument also applies to hand tools and animal draught implements, which should be manufactured in the country where they are to be used.

In brief, opportunities exist in the urban centres and towns for harnessing the potential entrepreneurial talent available in SSA to promote the development of input supply and manufacturing agribusinesses. The potential impact is likely to be considerable and the amount of employment created indirectly as a result of manufacturing and dealer operations could be substantial.

Caution is also needed in the light of recently rising costs of energy linked to increasing costs of oil. The increasing costs of energy may be a drawback to mechanization in the 2000s just as it was in the 1970s. Global energy shortages stress the need to introduce energy as a criterion of efficiency in addition to land, labour, and capital efficiency. As pointed out earlier, however, the energy utilized in manufacturing and operation of agricultural machinery and implements at the peak of energy crisis of the 1970s and early 1980s, even in the most mechanized parts of Asia, was found to be about 8 percent of the commercial energy used in agricultural production, with chemical fertilizers and pesticides accounting for 84 percent (Fluck and Baird, 1979; Rijk, 1983). It is important, therefore, that this issue of energy is taken in the right context. However, the price of fuel and availability of regular supplies bears directly on the profitability of using mechanical power sources in agriculture and have to be accounted for at the appraisal stage.

Mechanization services also cannot be viewed in isolation from access to complementary services. Most farmers and agroprocessing enterprises in Africa, for example, have accumulated very little capital and have little access to the levels of financing required for machinery and equipment. There may be a need to select farmers and enterprise managers who have a potential for handling and managing agricultural machinery and to take steps to increase their access to term financing services. Governments could then consider providing credit guarantees to local banks to provide loans to such farmers.

Public sector priorities

Over the past 20 years, a major shift in macro-economic and sectoral policies has occurred in SSA, involving a move away from direct state intervention.

At the same time there have been large reductions in government investments in agriculture. Shifts in policy have been prompted by the recognition of state failure in its direct involvement in agricultural production and other economic activities, among other things. One of the attractions of market liberalization – removing the state from areas that the private sector could undertake – was that it would be easier than reforming and reinvigorating public and parastatal organizations. There are clear indications that progress has been made in many countries in establishing more stable macro-economic environments, liberalized markets, tighter fiscal regimes and stronger institutional frameworks. However, as public interventions and investments have declined, in many cases the private sector has not stepped in to provide farmers and other entrepreneurs with essential market, business and financial services. Because markets are very poorly developed and general levels of economic activity low in many areas of SSA, public sector initiatives and actions are required to encourage mechanization.

It was expected that as the role of the public sector shifted away from direct ownership and operation of machinery and from the provision of mechanization services, it would nevertheless make important contributions to agricultural development through providing public sector goods and services. Unfortunately, weak capabilities in providing public goods and services continue to be a major constraint to agricultural development in SSA, including mechanization. This section turns to four critical public sector priorities that need to be addressed if there is to be an accelerated provision of mechanization services in SSA.

Enabling environments

Perhaps the first and most urgent priority is for governments to redouble efforts to create enabling environments for private sector initiatives. This of course pertains to all spheres of economic activity and not only to agricultural mechanization. Minimum features of such enabling environments include: appropriate macro-economic policies, legal and regulatory frameworks, an efficient and effective judiciary, land ownership and tenure policies. Creating enabling environments for domestic and foreign private investors is a major ongoing challenge that transcends mechanization, needing continued attention and intensified action.

In the context of larger public sector action to establish enabling environments for private sector economic activity and investment, priorities should be identified that would be particularly conducive to enhanced utilization of mechanical innovations in agriculture. African governments, with donor support, could foster the development of mechanization through the following high priority actions:

- improving rural infrastructure and strengthening agricultural support services, which reduce costs and therefore increase profitability, expanding the supply and effective demand, not only for machinery and mechanization services, but also for other input supply and output marketing services;

- providing direct support to companies involved in machinery supply and hiring services through technical assistance and business advisory services;

- reducing or absorbing transactions and information costs for the provision of mechanization services to smaller-scale farmers;

- removing legal and regulatory constraints against leasing, ensuring that effective procedures are in place for supply, and where necessary, repossession of assets;

- promoting cross-border, subregional and regional collaboration for the movement of equipment and provision of mechanization services;

- removing or reducing import and sales taxes on agricultural machinery and equipment;

- making risk management tools, such as insurance, widely available.

In addition to these priority actions, from the standpoint of public poverty reduction policies, it would be desirable to "kick start" mechanization through risk-sharing schemes and interventions that directly reduce transaction costs and enhance effective demand. Innovative approaches need to be explored to achieve this, including exit strategies that will result in the long term in creating a sustainable and profitable farming sector.

Training and human resources development

Another high priority is to rethink, adjust and increase training and human resources development programmes for the agricultural sector (Mrema and Woodend, 1994). Entirely new skill sets are needed, not only for the machinery and equipment users, but also for suppliers and service providers in the entire input supply and output marketing chains. Training needs include not only technical skills, but the development of business and managerial skills as well. The following are among the highest priorities for human resource development in order to accelerate mechanization in SSA:

- Establish or upgrade training and extension facilities for the users of mechanical equipment, be it manual, animal draught, or motorized. More progressive farmers could be trained to use animal-powered or motorized equipment. Special courses could be developed for machinery operators, including tractor drivers, maintenance technicians and artisans, creating skills that could lead to employment by private sector machinery service providers.

- Strengthen the entrepreneurial skills of commercial farmers and agribusiness managers in Africa for better decision-making. Training is needed in contract negotiation, conflict

resolution, price setting, business and financial management, and marketing. Farmers and entrepreneurs should also receive training to make the integrated use of farm machinery with other inputs more efficient. Training programmes are also needed on safety issues and accident prevention.

- Provide technical training for mechanics, technicians and engineers who design mechanical equipment, conduct mechanization research and supervise mechanization programmes. Skills should be leveraged so that current expertise can be extended to support many enterprises and entrepreneurs. Such leveraging can be achieved through outgrower arrangements, subcontracting, mentoring, commercial associations, and joint efforts between public sector research and extension services, and private sector organizations.

- Provide training to accelerate mechanization which should address the importance of term financing for machines, implements and draught animals. Rural financial services in SSA are relatively weak overall, but a particular problem area is longer-term financing. Information is available on good practices for term financing and related financial products and services (FAO/GTZ 2004). Governments could have a role increasing the supply of term financing for machinery and equipment investments by training financial and non-financial service providers in strategies and products for term finance.

Strengthening local organizations

One way to promote mechanized farming among small-scale farmers and small-scale agro-processing enterprises is to encourage them to organize into groups, associations or cooperatives. These organizations can effectively establish more efficient scales of operation and utilization for many types of machinery through resource-sharing mechanisms. Local organizations of farmers and agribusiness entrepreneurs are also building blocks for access to financial and non-financial services and linkages to larger agribusiness entities. The organization of farmers and rural entrepreneurs into groups has been effective in assisting the more vulnerable members of the rural community in negotiating with input suppliers, processing plants and other market organizations. Farmer organizations are also often a pre-requisite for small-scale farmers to attaining better contractual linkages with nucleus estates and agroprocessing ventures and reducing transaction costs (FAO, 2003).

Once local organizations have developed the capability to manage as independent entities, they can be organized into higher level apex institutions or agribusiness associations. This higher level of organization is often very useful in generating economies of scale from performing service functions for its members. Apex organizations and agribusiness associations also provide a political forum and "voice" to lobby for common interests more effectively. A sound economic and political base strengthens their bargaining position *vis-à-vis* the public sector as well as larger national and multinational agribusiness firms.

Furthermore, efforts are needed to support development of partnerships and strategic alliances among producer and processor organizations, and with NGOs, equipment suppliers and dealers, and financial institutions. NGOs can play an important role in making appropriate technology locally available and in training farmers and processors to choose the right

equipment and manage it properly. Through partnerships and strategic alliances, it is generally easier to negotiate better conditions and to reduce some of the risks (moral hazard) in the provision of services.

Research and development

Research and development is needed to provide sound guidance on mechanization policies and programmes, to increase the pool of appropriate machinery and equipment, and to better match mechanical technologies to specific needs of specific farmers and firms in specific locations. The formulation of mechanization strategies and programmes requires a systematic approach towards the interdependence between mechanization and specific economic, social and environmental conditions. An essential area of research for strategy formulation is assessing farm power requirements under different agro-ecological and farm conditions. Experiences with the implementation of mechanization on small farms, medium-size commercial farms and through tractor hiring schemes need to be gathered and analysed with the objective of arriving at good practices to formulate and implement mechanization strategies and programmes.

At present, there is virtually no supply of appropriate mechanical technologies from developed countries. This is because of the fact that commercial companies in developed countries are at a different stage of industrialization. Although equipment manufacturers, for example, have the resources to develop new equipment, they do not find it economically attractive to do so for countries at the level of technological development found in SSA. They understandably prefer to develop equipment for their home market first and then attempt to find new markets for the same equipment in developing regions.

Nevertheless, globally the potential machinery pool is wide and varies in size and function. New supply chains for agricultural machinery and implements are being established as a result of globalization and the emergence of Asian countries as major suppliers of equipment. These new chains will have to set up the requisite machinery servicing and maintenance centres as well as spare part depots. The proliferation of internet and other modern communication tools lowers the transaction costs of doing business; enterprises involved no longer require keeping a large inventory of spare parts that can now be ordered and supplied from overseas with short lead times. As new players establish such enterprises, they will need assistance and training on how to manage and operate such businesses effectively and efficiently.

Research systems on all aspects of agricultural mechanization are quite weak in SSA. This applies to both the public and private sectors. The National Agricultural Research Systems (NARSs) and the International Agricultural Research Centres (IARCs), which dominate the agricultural research systems in Africa, have virtually no research capabilities in agricultural engineering and mechanization. Further, many of the advanced research institutes in Europe and North America that were active in research in this area from 1960 to 1980 have closed down or significantly reduced their overseas programmes.

The situation in Africa is in contrast to that in Asian countries, which invested significant resources in agricultural mechanization research, both from an engineering and socio-economic perspective. Indeed, the success of the Green Revolution in Asia is attributed to the research

efforts in the biochemical field (HYVs, fertilizers, better agronomical practices), which were complemented by national research efforts (undertaken by both public and private sector-funded centres) in agricultural mechanization and machinery systems. Research in developing hardware was complemented by research in developing software, for example, studying socio-economic and agribusiness factors. Such factors include the set up and operations of efficient input supply and output recovery systems, covering both institutional and organizational structures, as well as the business skills required to run them efficiently.

In the 1970s and 1980s, many countries in Africa established Agricultural Machinery Testing Units (AMTUs) and appropriate technology centres for testing and appraising agricultural machinery, implements and other equipment. Most of these centres have been closed or phased out as part of the SAPs implemented during the 1990s. The few still operating are underfunded, with many of their staff about to retire or at post-retirement age. Yet research requirements in this field remain many and critical. Research is required to appraise and improve the performance of individual equipment as well as of systems and combinations of agricultural machinery and implements for different farm sizes or groups of farms. In some cases it may be necessary to change the layout and structure of individual farms to optimize on machinery use through land consolidation, rather than trying to design and develop machinery and implements to cater for the different categories of farm sizes.

Changes in farm power also need to be tested in conjunction with other kinds of innovations, and their individual and complementary contributions assessed. Selection of mechanization technologies for testing will need to be closely related to the scale of farmers' resources. Specific attention is needed on the balance between the benefits and costs of different types of mechanical technologies in different circumstances. Furthermore, such research should be conducted not only with respect to small farmers but also including medium-scale commercial farms and agroprocessing enterprises using supply chain frameworks.

Economic and multistakeholder appraisals are needed on the backward-forward linkages and institutional options for the provision of mechanization services. Particular attention should be given to private sector tractor hire schemes, identifying constraints and opportunities, using the results to design operational plans of action and related training programmes. Research is also needed for establishing efficiency standards and assessing the financial viability of different models for the delivery of mechanization services.

Considerable headway has been made in many parts of the world over the last several decades to mitigate possible negative impacts of mechanization on the environment. Ways have been developed to ease the pressure on resources, curtail environmentally destructive processes and identify new sources of energy. Further research is required, however, to monitor the potential environmental consequences of mechanization, particularly within the medium- to larger-scale commercial farming sector. Longer-term environmental implications should be assessed and incorporated as part of future technical and economic analyses impacting on the net benefits to society.

As a general rule, research and development activities relating to mechanization should be carried out in close collaboration with the private sector. Public-private partnerships (PPPs) in research and development are more likely to focus research and development activities on

the needs of commercial farmers and agribusiness entrepreneurs, and provide opportunities to improve efficiency and increase investments in research. PPPs in research and development can be undertaken through multi-stakeholder networks and field programmes, but in most cases the public sector will need to take the lead in developing these partnerships.

Finally, not all countries will be able to establish, operate and fund research centres that can undertake all of the above activities; regional collaboration may be the best way for countries in SSA to carry out these research tasks. Alternatively, this is an area in which regional networking may be most effective, as it was in Asia from 1970 to 1995 through the Regional Network for Agricultural Mechanization (RNAM). This network played a major role in the exchange of information and experiences among the Asian countries at a critical phase of mechanization of their agriculture. RNAM has now been replaced by the United Nations' Asian and Pacific Centre for Agricultural Engineering and Machinery (APCAEM) established in 2002 with its headquarters in Beijing, the People's Republic of China.

Conclusions

Despite the poor record of agricultural mechanization in SSA, it is time to reconsider its potential role in agricultural development and the priority to be given to mechanization by African governments and developmental agencies. At the local level, agricultural mechanization can help improve rural livelihoods by breaking labour bottlenecks that constrain productivity and rural income growth while reducing the drudgery associated with hand hoe land preparation and other household tasks. 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 firms 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.

If efforts to promote and support mechanization in SSA are to receive greater attention, then it is essential to fundamentally rethink the nature of mechanization and how it might be accelerated without unsustainable subsidies and overly burdensome regulatory frameworks. The preceding analysis of mechanization policy debates, experiences, and success factors building on lessons learned from Africa and Asia makes it clear that mechanization is a complex and dynamic process that cannot be appraised only from the standpoint of factor substitution or farm level profitability. Policy decision-makers need to realize the complexities of the political environment and the trade-offs between competing short-run goals and longer-term development dimensions when drawing up mechanization strategies and policies.

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 contrast to the incremental approach to development followed in SSA over the last three decades. 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 agribusiness. These farmers and firms can provide mechanization services to small-scale farmers and processors. They are the ones who spearheaded the mechanization revolution in Asia over the past 40 years. There is an immediate need to develop the managerial and entrepreneurial capacity of such farmers and firm managers in SSA, and to provide planning and logistical support.

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 firms may be agroprocessing,

transport or related non-farm tasks. The preoccupation in Africa with promoting animal traction and tractors for land preparation should give way to flexible strategies for promoting diverse types of mechanical technologies that are compatible with local economic, social and developmental conditions.

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 earlier failures will be repeated. The public sector can nevertheless effectively promote mechanization processes, as indicated above by the establishment 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.

Efforts to accelerate mechanization in SSA will no doubt require substantial long-term political and financial commitments while grappling with new problems. Unless commitments are made to address these problems, the prospects for African agriculture and African farmers remain bleak. The process may at times be turbulent, but governments and leaders in the agricultural sector must remain steadfast, as Asian governments were in the 1960s and 1970s. Otherwise, African agriculture in the twenty-first century will be doomed to seventeenth century tools and implements, to the detriment not only of food security, but overall economic growth of the continent. As suggested earlier, now is the time for a new look at agricultural mechanization in this region!

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Agricultural mechanization in sub-Saharan Africa: time for a new look

This Occasional Paper examines the role of agricultural mechanization in the agricultural and economic development of sub-Saharan Africa (SSA). The paper argues that in the light of global changes and challenges the time is ripe to reconsider the potential of mechanization and the priority that needs to be given to it by African governments and developmental agencies. It purports the view that if efforts to promote and support mechanization in SSA are to receive greater attention then it is essential to rethink the nature of mechanization and how it can be accelerated. The paper suggests that successful and sustainable mechanization should not be established by direct public sector provision of mechanical technologies and services but rather through creating a conducive enabling environment for private sector engagement. It concludes by making the case that efforts to accelerate mechanization in SSA will require substantial long-term political and financial commitments in order to effectively respond to the new challenges facing the continent.

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