Farm Power – Present and Future Availability in Developing Countries

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1. Introduction

The availability of power is a pre-requisite for any agricultural activity whether the source is human, animal or motorized. In developed country agriculture, the general availability of virtually unlimited amounts of farm power in its different forms is almost taken for granted and comes almost exclusively from internal combustion engines or electric motors. The human is just the "brain" and control of the system. However, in most developing countries, the human is also a major source of farm power. Just how significant is this and to what extent is human power used? How will this change in the future and can the required farm surpluses required to feed burgeoning urban populations be produced from an agricultural situation in those countries which rely to a large extent on human labour?

In developing countries there is a great variation in the proportional use of the three primary sources of farm power. In some countries there is a dynamic situation in which human and animal power is being replaced by mechanical power, but in others, farmers are having to give up mechanical and animal power and revert back to human power. In some others which are tragically hit by HIV/AIDS and other diseases, even the human power base is shrinking.

As we are moving into the third millennium, we take a look at the most fundamental requirement for progress in the expansion and adoption of mechanized technologies: the present and future availability of farm power in developing countries. In this presentation we would like to share with you some of the interesting factors which are emerging from the work that FAO is carrying out as we believe that this is of vital importance if we are to understand and attempt to influence the progress of agricultural engineering development into this millennium.

2. FAO's Activities

In FAO over the past few years we have been gathering information on the different sources of farm power in developing countries. We are in the process of generating a global picture and making projections as to how this might change over the next 20-30 years and identifying which factors will influence these changes. At this stage of the work we are only looking at farm power used for field cultivations and not at a total farm picture as the latter is extremely complicated and data is not readily available. Also in manually based systems, field work is probably the most arduous.

In order to examine the contribution of different power sources to agricultural production, two approaches[3]

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[3] *For a fuller explanation of the methodology used see Annex I*

Clarke, L. and C. Bishop. "Farm Power—Present and Future Availability in Developing Countries". Agricultural Engineering International: the CIGR Journal of Scientific Research and Development. Invited Overview Paper. Presented at the Special Session on Agricultural Engineering and International Development in the Third Millennium. ASAE Annual International Meeting/CIGR World Congress, July 30, 2002, Chicago, IL. USA. Vol. IV. October, 2002.

were considered. The first was to base the discussion of the relative contributions of the different power sources to the total power input to agriculture, and the second was to take an area-based approach, focusing on the proportion of the total harvested area cultivated either humans, draught animals or tractors at a country level.

The first method starts with estimating the number of people, draught animals and tractors working in agriculture; converting each of the three power sources into a kW equivalent; aggregating the total power input to agriculture; and then expressing the contribution of each power source as a percentage of the total. There are, however, four principal concerns with this approach; (a) the lack of availability and reliability of the base data, (b) the conversion into kW equivalents which relies on estimates of the power equivalents of human beings, draught animals and engine powered machines; (c) the expression of the data as a percentage of total power equivalents (due to the fact that the power produced by humans is so insignificant when compared to tractors); and finally (d) the difficulties in projecting over time particularly the substitution between power sources which occur over time.

As a result of these problems in using a kW equivalent and after a great deal of discussion, an area-based approach was adopted, initially focusing on the proportion of the total harvested area cultivated by either humans, draught animals or tractors at a country level and then aggregated at both sub-regional and regional levels. There are two premises under-pinnng this methodology: (a) the power source used for primary tillage because land preparation represents one of, if not, the most significant use of power and it is usually one of the first tasks to benefit from additional power inputs and, (b) the area cultivated by each power source as a percentage of the total harvested area.

On the basis of information we have collected as well as expert opinion, we have attempted to characterize different countries into different groupings according to their use of farm power. We have also examined whether there are any similarities in economic and social indicators between countries with a similar mix of types of farm power. And, finally, using these indicators and data we predict how the farm power situation will change from country to country and from region to region over the next two to three decades.

As a basis for the work countries were categorized into six farm power typologies:

- Humans are the predominant source of power for land cultivation, with modest contributions from draught animals and tractors;
- Significant use is made of draught animals, although humans are still the most important power source;
- Draught animals are the principal power source;
- Significant use is made of motorised power;
- Tractors are the dominant power source;
- Land cultivation is fully motorised.

3. Global, Regional and Country Overviews

As an overview, the World map (Fig. 1 over) shows individual countries assessed according to the farm power typology in use (developing countries excluding the P.R. China). All three sources of power (human, draught animal power (DAP), tractor) are widely used and widely dispersed, however, the use of the different sources and the extent to which they contribute to agricultural production varies from region to region, within a region

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NOTE: The views expressed in this paper do not necessarily reflect the official views of FAO or its member countries

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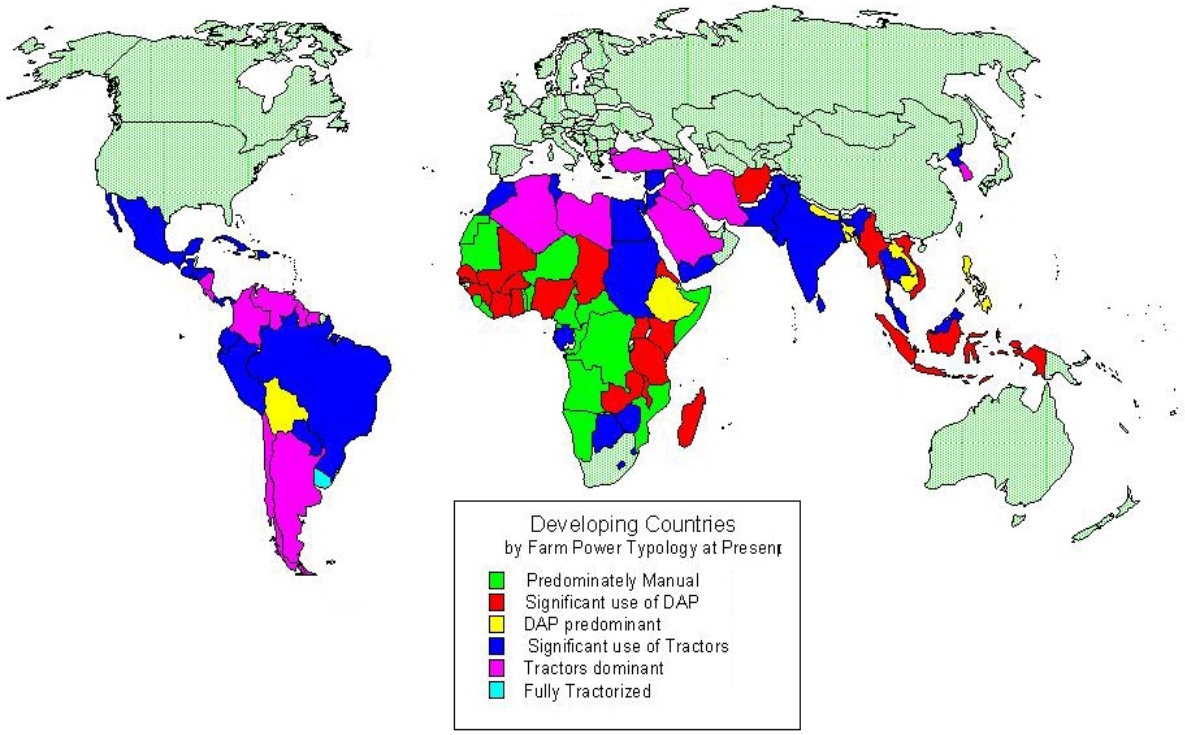


Fig 1 Farm Power Typology - Developing Countries (Present)

and even within a country[4].

In Sub-Saharan Africa, in overall terms, humans are the principal power source, cultivating two thirds of the area under cultivation but there are regional differences with manual power being dominant in the Central region, draught animals being used to a greater extent in Western and Eastern Africa and in Southern Africa there is an increasing use of tractors (see Fig 3).

In Asia, one third of the land is prepared by draught animals whilst tractors are a significant source of farm power in much of Central and South America and the Caribbean. The use of tractors is also well established in the Near East and in North Africa. The extent of these differences is shown in Fig 2.

[4] Even within individual countries considerable differences exist. Some areas might utilize draft animal power and in others farmers will rely solely on manual methods. The reasons for these differences are complex but are generally related to cultural, climatic and economic factors.

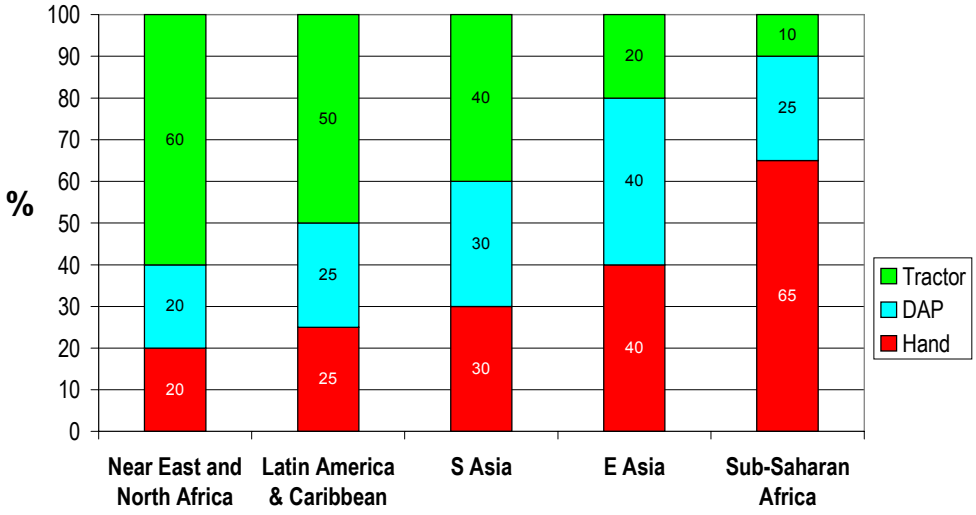


Fig 2 Proportion of Land Cultivated by Different Sources of Farm Power - 1998

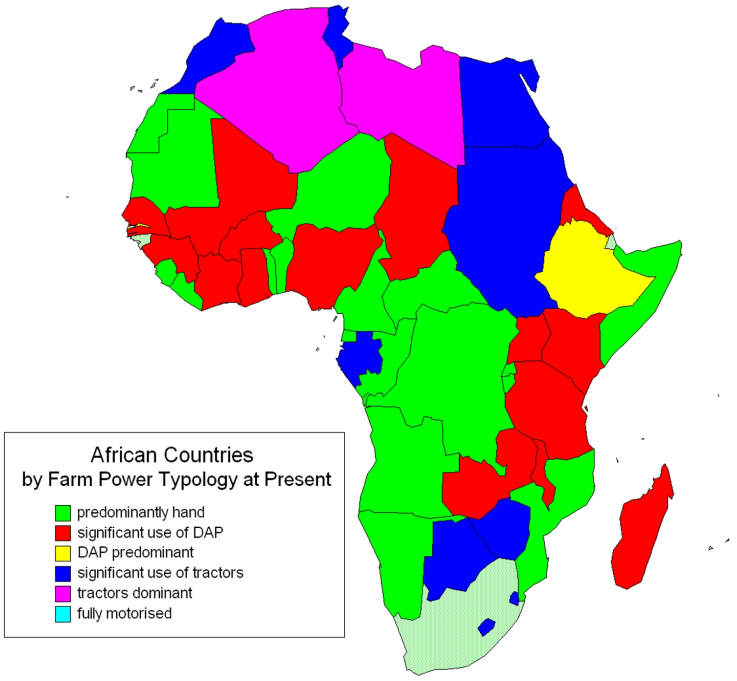
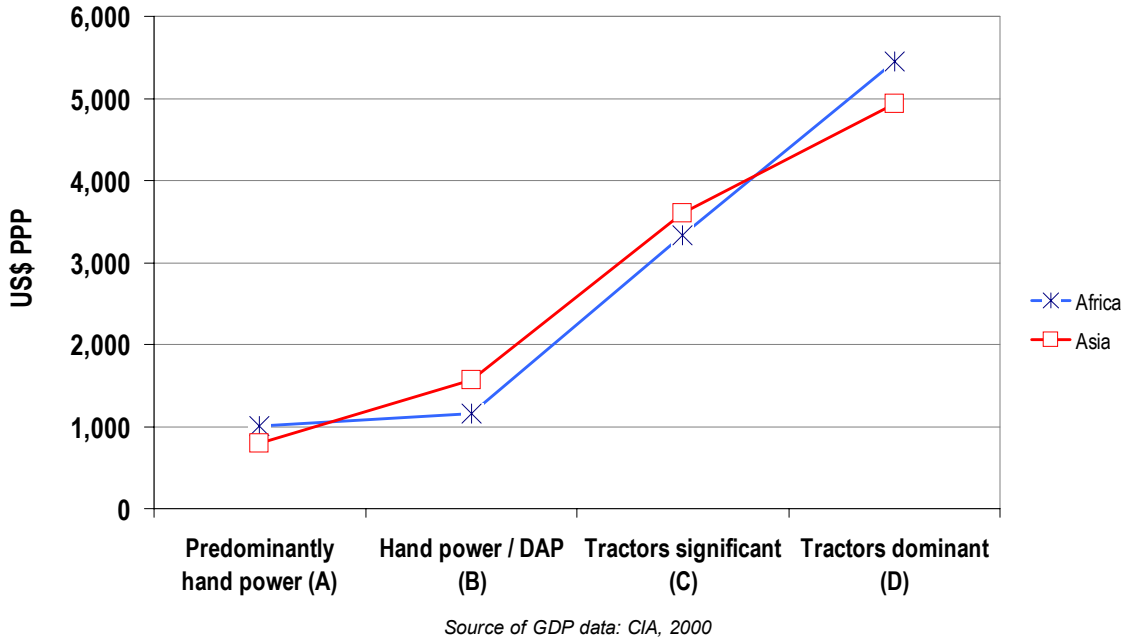
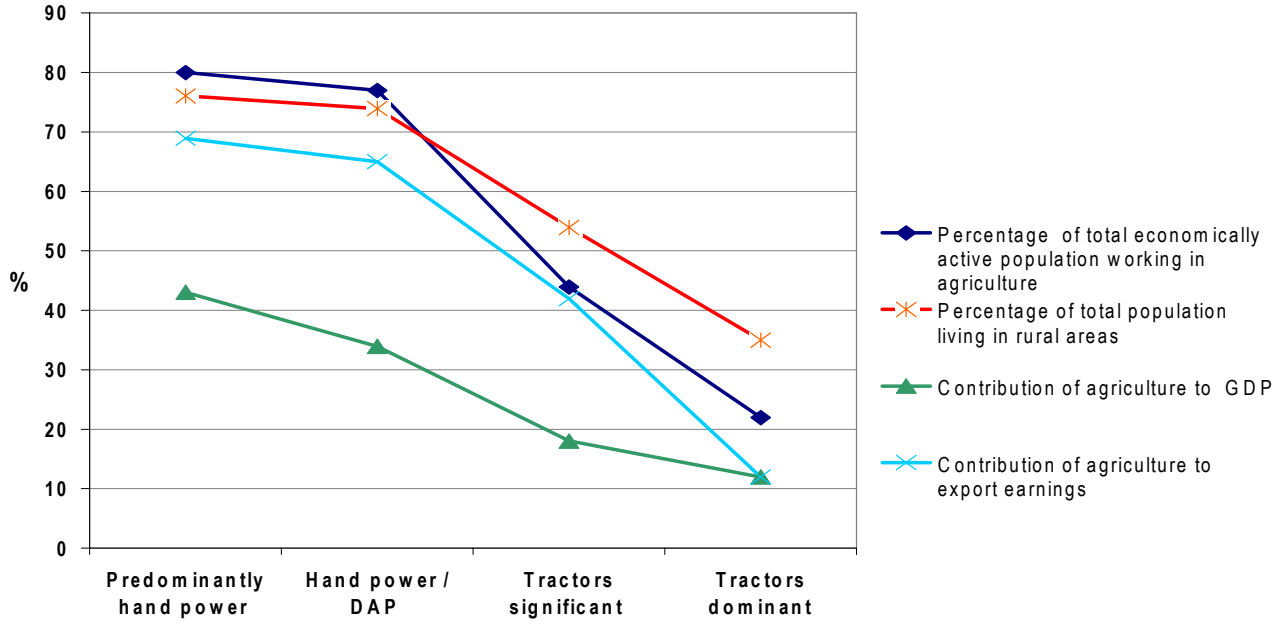


Fig 3 Africa – Developing Countries by Farm Power Typology (Present)
(Note: South Africa not classified as a developing country)



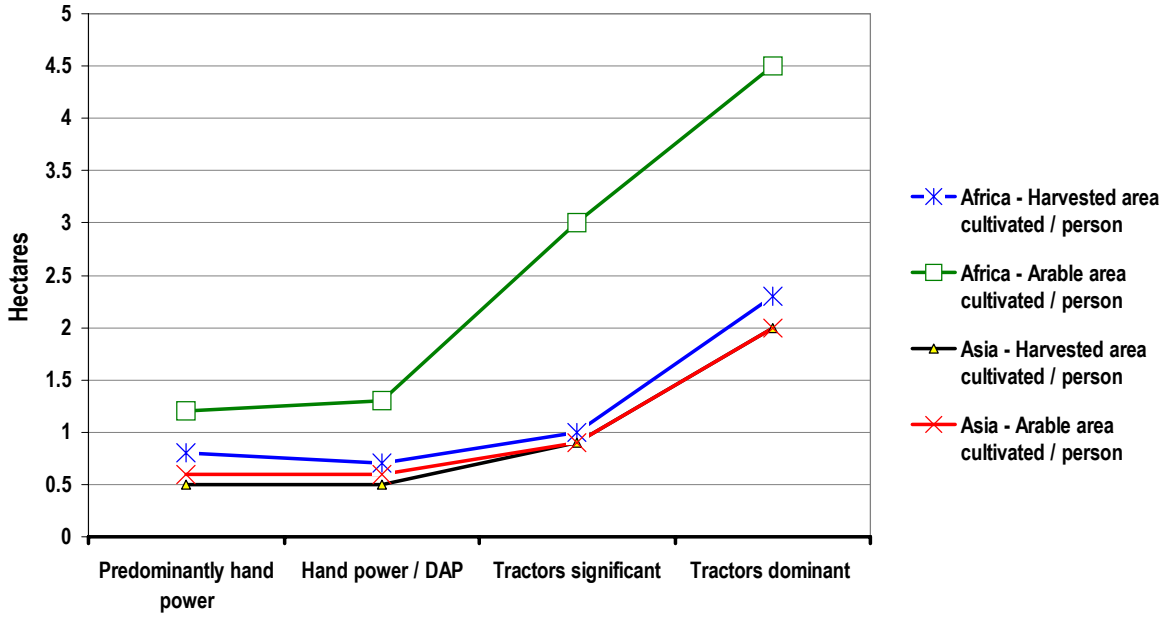
Source of GDP data: CIA, 2000

Fig 4 GDP per caput by farm power typology in Africa and Asia (1999 est.)



Source of population data: FAOSTAT, 2000
Source of GDP, manufacturing and export earnings data: World Bank, 2000

Fig 5 Changing role of agriculture by farm power typology in Africa, late 1990s



Source of area data: FAO-Agriculture Towards 2015-2030;
Source of population data: FAOSTAT

Fig 6 Area cultivated per person economically active in agriculture - Africa and Asia - 1996

In Asia there is a dominance of draught animals in South-East Asia, a significant use of tractors in South Asia, and tractors as the dominant power source in Eastern Asia.

4. Characteristics of Economies using different Farm Power Typologies

4.1 General Socio-Economic Factors

An analysis of several socio-economic parameters allows us to find common characteristics for the different farm power typologies. We present here just a selection.
In areas dominated by hand power, the economy relies on the agricultural sector which typically employs more than two thirds of the workforce, generates over one third of the GDP, and income per head is below $500 (see Fig. 4). In economic terms, areas using draught animals are not very different from those using hand power, although the DAP-based countries experienced higher rates of growth in GDP during the 1990s (over 3% per annum) than those relying predominantly on hand power (around 1%).

Areas dominated by tractor power have substantially different parameters: agriculture is no longer the dominant sector, employing less than half of the workforce and generating less than one quarter of GDP (see Fig. 5). Usually, these economies are more buoyant and income per caput are at least three times higher than in the hand power and DAP countries within the same region. The rate of growth in the agricultural workforce is low and in some countries the absolute number of people working in agriculture has started to decrease. This is often considered to be one of the more significant turning points in the process of economic development.

It can also be seen that in both Africa and Asia, the area cultivated per person working in agriculture in

countries where tractors are dominant is substantially higher than in those countries that rely predominantly on manual power and DAP (see Fig 6).

4.2 Countries in which humans are the predominant power source

Humans are the most significant power source in Sub-Saharan Africa (see Figs 2 and 3). In Central and Western Africa, they account for an estimated 85% and 70% of harvested area respectively. In these areas, a relatively high proportion of rainfed land is under cultivation (45% of the potential area) but the cropping intensity is low and very little use is made of irrigated land. The incidence of tsetse fly (which inhabits the forests and forest margins) makes the forest areas unsuitable for many types of draught animals.

4.3 Countries in which draught animals are a significant or predominant power source

There are two regions of the world where draught animals are a significant source of power for farm activities: Sub-Saharan Africa and South-eastern Asia. In Sub-Saharan Africa, draught animals (mostly oxen) are concentrated on rainfed land in the cotton-based farming systems in the northern parts of West Africa, throughout the maize mixed systems of Eastern Africa and the highland mixed systems of Ethiopia (FAO, 2001b). In South-East Asia, buffalo and cattle are dominant sources of power in the lowland rice and the upland intensive mixed farming systems (FAO, 2001b) where they are used mainly for primary tillage with limited use in secondary operations such as planting or weeding. DAP is also important in the rice and rainfed mixed farming systems of South Asia (FAO, 2001b), and in the mountainous areas of Latin America where the terrain is not suitable for the use of tractors. In some parts of the world, however, social customs and cultural barriers inhibit the use of animals for draught power.

The principal difference between countries with significant use of DAP and countries in which manual methods are predominant is in terms of land use. Access to additional power in Sub-Saharan Africa is associated with an increase in intensity of cultivation and an increase in the area under irrigation (but no expansion of rainfed land). Indeed, the highest cropping intensities occur in DAP countries in all regions of the world. In South Asia, for example, cropping intensities on rainfed land fall from 125% (countries using DAP) to 85% (in countries using tractors) and on irrigated land, cropping intensity falls from 145% (countries using DAP) to 115% (countries using more tractors).

It is interesting to note that during the 1990s in Sub-Saharan Africa, the growth rate of the agricultural labour force in countries using significant amounts of DAP was higher than in economies where humans were the dominant source of power. This suggests there are no labour displacement effects associated with the use of draught animals.

4.4 Countries in which tractors are a significant or predominant source of power

Tractors are a significant power source in many parts of the world. High levels of mechanisation are generally associated with relatively well developed economies and the production of cash crops. Non-agricultural revenues can stimulate their adoption; for example, the oil wealth in several countries in the Near East and North Africa, or remittances from expatriate workers in some Southern Africa countries. Historically, many governments have intervened to encourage the use of tractors in pursuit of various political objectives as for example in Sudan, Pakistan, Saudi Arabia, and Nicaragua. This has been more successful in some countries than in others.

In the Near East and North Africa, mechanised farming occurs in irrigation schemes and is becoming increasingly important in rainfed agriculture (FAO, 2001b). In Central and South America, much of the cash crop production is fully mechanised in the irrigated and coastal plantation farming systems (FAO, 2001b). Tractors are used extensively in the rice farming systems throughout South and East Asia.

The increased use of tractors is consistently associated with expanding the area under irrigation, but cultivating

it less intensively than in countries using hand or animal power.

5. The drive to change

When looking at whether countries will change their farm power inputs for cultivating the land (particularly changes towards increased investment in tractors) the following table summarizes the characterizations of tractor and hand power systems:

	Tractor based cultivation systems	**Predominantly hand power systems**
GDP per caput	• > US$ 3 000	• < US$ 1 000
Kcal consumption per caput	• > 2 500 daily	• < 2 000 daily
Contribution of the agricultural sector to the economy	• < 20% GDP • < 40% of export earnings • < 30% of manufacturing GDP	• 40% GDP • 70% of export earnings • > 40% of manufacturing GDP
Proportion of the economically active population working in agriculture	• < 50%	• > 80%
Cropping intensity	• Relatively low (Africa)	• High in Africa, but low in Asia
Proportion of arable land in cultivation	• High	• Relatively low
Proportion of potentially irrigable land under cultivation	• High (70%)	• Low (20% in Africa) (35% in Asia)
Area cultivated per person working in agriculture	• Large (> 1 ha of harvested area)	• Small (0.5-0.7 ha of harvested area)

The drive to change the composition of farm power inputs will come from either changes in the demand for farm power or from supply-side changes, or both.

Any increase in total agricultural output (be it from area expansion, an increase in cropping intensity or an increase in yield) requires additional power**,** if not for the application of advanced cultivation technologies then for handling and processing of increased volumes. Similarly, earth works (such as terracing, drainage or irrigation structures, etc.) and water harvesting techniques frequently place additional demands on power resource base. In response, farmers can either increase their inputs of farm power or increase the productivity of existing inputs through the use of improved tools and equipment.

Alternatively, adopting different practices or changing cropping patterns can lead to reduced power requirements. For example in Conservation Agriculture, the use of direct seeding and the elimination of conventional tillage means less time and drudgery for land preparation. Broadcasting rice overcomes the labour intensive activity of transplanting seedlings and the use of cover crops, residue management or benevolent herbicides can overcome labour bottlenecks associated with weeding.

Motivations to mechanize may also arise from the availability and productivity of farm power inputs, as well as a wish to reduce the drudgery of farm work. In particular, in systems dominated by manual power, the health, nutritional status, the age of the workforce and the climate all affect the productivity of labour. The availability

of household members for farm work is also influenced by other claims on their time, such as household tasks, schooling, and opportunities for off-farm work. Moreover, household composition changes through rural-urban migration or the death of key household members. The productivity of draught animals is affected by their health and nutrition, the training of animals, operator skills, and availability of appropriate implements. Productive and sustainable use of motorised inputs is dependent on operator skills and resources, appropriate equipment and access to an infrastructure capable of providing timely and cost effective access to repairs and maintenance services.

6. Changes in the Future

6.1 Overall changes in farm power sources

Based on the analysis of the farm power typologies and their characteristics discussed above, the countries that are expected to experience a change in their composition of farm power inputs will demonstrate some or all of the following features:

- high rates of growth in total GDP and per caput GDP (particularly for switches from hand to DAP and from hand/DAP to tractors)
- high rates of growth in the agricultural and industrial sectors for switches from hand to DAP
- high rates of growth in the industrial sector for switches from hand/DAP to tractors
- high rates of growth in the service sector for tractor based systems

For developing countries in general, the projected changes in the use of the three different forms of farm power are given in Fig 7. It can be seen that in overall terms the use of tractors will increase from approximately a third of the cultivated area to over 50%. This will mainly replace manual methods and also to a lesser extent, DAP.

By 2030, tractors are expected to be the dominant source of power for land preparation in North Africa, the Near East, South and East Asia, Latin America, and the Caribbean. South East Asia is expected to shift from draught animals to making greater use of tractors.

Also, in a few countries, it is expected that the present composition of farm power inputs will not be sustainable. In East Africa, for example, the number of draught animals has been decimated in some areas due to livestock disease and cattle rustling. During the next 30 years it is expected that some countries will revert from tractors to increasing use of hand or draught animal power. This will occur where access to fuel and inputs is becoming increasingly difficult and where agriculture is not profitable enough or where government-based initiatives for introducing mechanization are not compatible with the state of economic development and political stability.

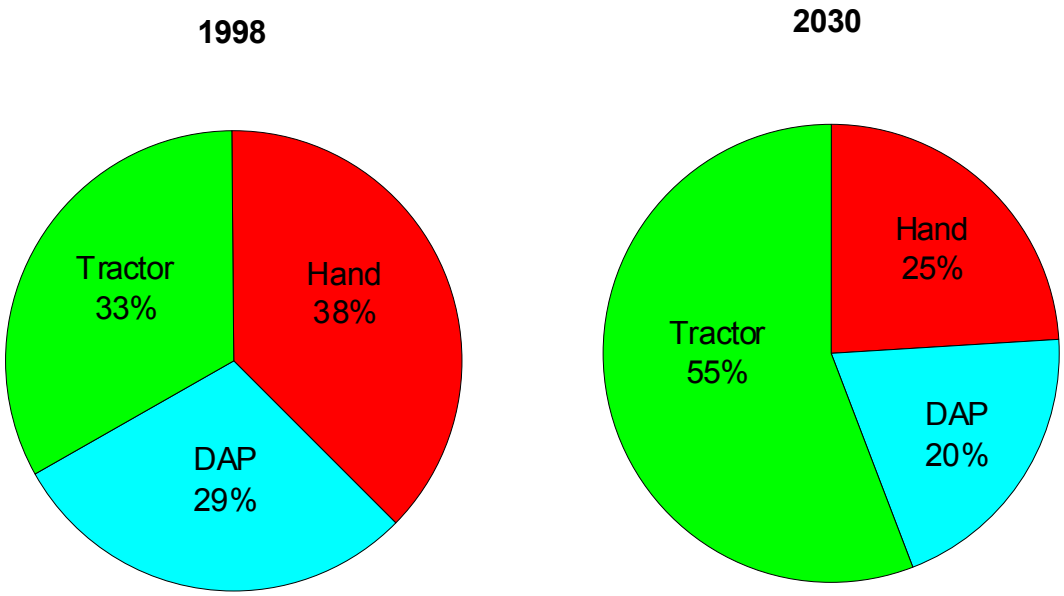


Fig 7 Land Cultivated by Different Power Sources
(Developing Countries excl. P.R. China)

6.2 Persistence of hand and animal power in Sub-Saharan Africa

According to our projections for sub Saharan Africa, the countries which are expected to change either from hand power to DAP, or from DAP to tractors, are those that will experience the lowest population growth rates and the highest income per caput growth rates. They will also enjoy relatively high incomes per head (over $1200 per head). In contrast, the persistence of hand and DAP typologies would appear to be associated with high population growth rates (greater than 2.5% pa) and poorer economies with projected GDP per caput of around $500 per head.

Based on historic and present trends, our assessment is that two thirds of the countries in Sub Saharan Africa will probably not significantly change their mix of farm power inputs for land preparation between now and 2030. Although there may be some modest movements in the relative contributions between hand, animals and tractors, it is expected that most countries will remain within their original farm power typology. This is particularly marked amongst countries relying on hand and animal power.

The greatest change is expected among countries already making significant use of tractors, however, we do have concerns that some countries might be unable to maintain their present tractor fleet due to the poor outlook for economies and as well as uncertain political environment.

In geographic terms, the most change is expected among countries in West and Southern Africa.

The process of urbanisation will also provide some stimulus to switch power sources. The movement of rural

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populations to urban areas is most pronounced in countries switching from DAP to tractors, as well as those already using tractors as the dominant source of farm power. Countries that will continue to use draught animals as a significant source of power are projected to remain predominantly rural.

Another factor driving the process of change in Eastern and Southern Africa will be the impact of HIV/AIDS on the workforce (see box). Those countries which are expected to switch from hand power to DAP are projected to lose almost 20% of their agricultural labour by 2020, which is more than twice as much as in those countries continuing to use hand power. Similarly, those countries shifting from DAP to tractors are expected to experience higher losses in their labour force (12% by 2020) than countries continuing with DAP. Some of the highest losses (16% by 2020) are projected for countries already making significant use of tractors. Thus, if agricultural production is to even to remain stable, the impact of HIV/AIDS will make it vital for farmers in many countries to change their agricultural production systems - through farm power shifts or other alternatives such as Conservation Agriculture - in order to overcome serious labour shortages at critical times of the farming year.

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6.3 Increasing use of tractors in Near East/North Africa and Asia

Prospects for mechanization in these regions are based on projections of buoyant economies and high rates of growth in income per caput, given conditions of political stability.

The development of regional markets and strong links with markets in Europe are expected to be important engines of growth for North African countries. Oil wealth will continue to underpin development in the Near East. Economic development and urbanisation will play a major role in the shift towards mechanisation. By 2030, over 75% of the population in Near East/North Africa will be living in urban areas. The option of using

Household Vulnerability to the Loss of Human and Draught Animal Power

Households reliant on human power, and draught animals to a lesser extent, are extremely vulnerable to the loss of their principal power source. More than 15 countries in Sub-Saharan Africa are projected to lose at least 5% of their workforce to HIV/AIDS by 2020. The brunt of the pandemic will be felt in the agricultural sector where losses will typically account for at least 10% of the workforce and, in five countries, more than 20%. Occurring in a region where people are a significant, and often the dominant, source of power for both household and farm activities, suggests that this loss of labour will have a dramatic impact on rural livelihoods.

HIV/AIDS usually strikes at the heart of the household, killing women and men in their economic prime. Not only do households lose key family members, they lose time spent by other household members caring for the sick and regularly attending funerals, lasting several hours and even days. The situation is exacerbated by the practice of urban dwellers returning to their villages when they fall sick, thereby placing further strain on rural households. In addition to the immediate emotional, physical and financial stresses the remaining family members have to take on the long term care of orphan children. In some cultures, widows also have to cope with the threat of property grabbing by the deceased's relatives. Relatives typically dismantle the home, removing bricks, iron sheets and furniture, as well as taking productive assets (such as hoes and cattle).

An important strategy to cope with labour shortages is to reallocate tasks between household members, adapting the division of labour, traditionally based on sex and age, to reflect the household composition. Thus women in female headed households without recourse to adult male labour, may clear and prepare land, including ploughing with oxen (tasks which would traditionally be performed by men). Conversely, widowed men may take on activities which would traditionally be the responsibility of women and children, such as planting and weeding.

In parts of Eastern and Southern Africa, the vulnerability of rural livelihoods has been worsened by the decimation of the draught animal power base. The switch from hardy local breeds to cross breeds, coupled with the failure to carry out regular healthcare practices, increased livestock susceptibility to disease (such as East Coast Fever). Cattle rustling is also a threat, particularly in areas close to national borders. In the absence of alternative power sources, such as tractor hire, households have reverted to hand power. Areas under cultivation have fallen significantly and households, which once were food self-sufficient and producers of surplus for sale, now regularly experience food shortages. Household transport has become more problematic and the opportunity to earn additional income from hiring out draught animals has disappeared.

Food insecurity, arising from the inability to produce or purchase sufficient food for the household throughout the year, may be considered to be an enduring characteristic of subsistence agriculture. Short term coping strategies include reducing the number of meals eaten per day, with very poor households spending up to two days between meals, or by switching to less nutritious foods. The poor may gather and sell natural products (such as wild fruits, mushrooms, tubers, firewood and grass thatch) or beg for food. Some households engage in off-farm activities, trading and making handicrafts, or rely on remittances from family members living elsewhere. Some survival strategies, such as the sale of assets to buy food, taking out loans to purchase inputs, or hiring out family labour to work on other farms, invariably placed the household at greater risk in subsequent seasons.

tractors also becomes more viable with increasing costs of labour and pressure on land for fodder production.

In Asia, economic growth and industrialisation which will increase wage rates and draw labour from agriculture, will also stimulate the further use of tractors especially in irrigated farming. The process of mechanization will be facilitated in this region by the development of local manufacturing capacity and the proximity in the region of manufacturers, namely India (as the world's largest manufacturer of tractors) and China (a source of cheap tractors and power tillers).

6.4 Stable use of tractors in Latin America and Caribbean

According to our projections almost half of the countries in the region are not expected to change farm power typologies during the next 30 years. Several countries are already at the limits of technical change in terms of farm power. In some countries (such as El Salvador, Guatemala, Mexico, and Paraguay) the shift towards Conservation Agriculture, with its consequent use of lower levels of farm power, may obviate the need for further mechanisation.

7. Conclusions

In the Agricultural Engineering Branch in FAO we have long held the view that in developing countries, particularly those relying predominately on manual sources of farm power, one of the main constraints to increased agricultural production is a shortage of farm power. The work we have started on this in the last few years is designed to give us (a) a comprehensive picture of the sources and uses of farm power on a global basis and how this will change in the future, (b) to try to identify which factors determine the mix of farm power in a particular country and region, and, (c) through this, project expected changes in the composition and use of farm power.

The analysis of the current use of different sources of farm power and future projections demonstrate a strong association between economic growth and the use of specific inputs. Effective demand for agricultural products, generated by a growing urban population, high incomes per caput, off-farm employment opportunities and rising wage rates, create both the need and opportunity for farmers to switch their sources of farm power. Political stability and a dynamic infrastructure responsive to the changing needs of the farming community are essential for their sustained use. Poverty and high population growth rates, particularly when accompanied by political instability, act as brakes on this process of change.

To date, most of the change in the composition of farm power has taken place with respect to changing the principal power source associated with land preparation. As one of the most time consuming and arduous tasks, it is often the first to benefit from additional inputs of power. Similar patterns of change have occurred with stationary power operations, such as lifting water and grinding food, switching from hand power to simple engines (pumps and maize mills). Opportunities to substitute power sources in more technically complex operations, such as transplanting, weeding and harvesting, will be dependent on continued economic growth, the profitability of the agricultural sector, the availability of different sources of farm power and their relative costs.

Of particular concern are many countries in Sub Saharan Africa where populations are rising, particularly in the urban areas, and where growth in food production is not keeping up with population growth. In many of these countries as well, the rural population is increasingly heavily hit by HIV/AIDS and which is decimating the farm labour base. Given the present economic conditions in many of these countries, and with the present apparent low priority of agriculture (both nationally and internationally), it is questionable as to whether the required increases in farm power to maintain and increase crop production can be realized. We believe that this issue should be revisited and that innovative ways of providing additional sources of power be initiated. This does not have to mean a return to national tractor hire schemes which were, by and large, financially

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unsuccessful. Tractor services serving groups of small farmers can be successfully provided through private and cooperative ownership, but for this to happen there will have to be major changes in government (and donor) policies and programmes as well as a fresh look at credit and other services that need to be in place to support mechanized agriculture.

For engineers, particularly those involved in developing country agriculture, the information we are now producing can guide us on several issues. There is still a widespread belief that if we can develop the "right machine or tool" then it will be magically manufactured and adopted. This leads to engineers, both in the public and private sectors, to concentrate on engineering development. However, there is evidence that engineers and engineering technology alone can do little to affect the adoption and use of mechanized farm power inputs, which, as has been highlighted in many of the characteristics discussed in this paper, seems to be determined by much wider social and economic developments. Engineers therefore need to create linkages to groups discussing much wider issues, for example the wider farming community, development fora, the manufacturing and commercial sectors and policy issues within their own governments. This will improve our ability to develop and offer the right engineering solutions that are capable of being delivered, i.e. technologies that can be manufactured profitably, can be sold profitably and be used profitably.

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Annex I - Methodology

There are two principal strands to the Agricultural Engineering Branch's (AGSE) ongoing work on Farm Power. The immediate interest was to contribute to FAO's publication 'Agriculture Towards 2015/30'[5] regarding the role and significance of farm power in agricultural production in developing countries. A longer term interest is to establish a reliable world wide database of the principal components of farm power and associated equipment.

To these ends, AGSE has initiated a number of activities:

- development of a methodology for projecting the composition of farm power inputs in the medium term, including a review of alternative approaches;
- preparation of in-country case studies on present and future use of farm power in agriculture; and
- development of a world wide database, in particular consolidating tractor numbers from FAO and other sources (and draught animals).

Rationale for Developing Area-Based Farm Power Typologies

There are two approaches which could be adopted to examine the contribution of different power sources to agricultural production. The first would be to base the discussion of the relative contributions of the different power sources to the total power input to agriculture. This method starts with estimating the number of people, draught animals and tractors working in agriculture; converting each power source into a kW equivalent; aggregating the total power input to agriculture; and expressing the contribution of each power source as a percentage of the total. There are, however, four principal concerns with this approach:

(i) *the reliability of the base data*: for example, comparisons between the tractor numbers published by FAO with data from other sources reveal significant differences in the potential tractor fleet. The number of tractors actually working in agriculture is highly dependent upon several key variables, all of which have to be estimated: the working life of a tractor (ranging from 15 to 20 years); the proportion of tractors working in agriculture, as opposed to off-farm activities such as haulage and road maintenance; the proportion of tractors in an operational state; the size of the second hand and third hand tractor market (particularly if there are cross border movements). Similarly, the number of draught animals working in agriculture may vary considerably from published data, depending on their life expectancy, non-agricultural uses of their time, and the demand for meat.

(ii) *the conversion into kW equivalents*: assumptions are made to estimate the power equivalents of: women, men and youth working in agriculture; different types of draught animals; and different engine sizes and working efficiency of tractors.

(iii) *the expression as a percentage of total power equivalents*: the significance of humans to farm power can become lost in the process of expressing their contribution as a percentage of the total power input because they represent such a small source of power (say how much equivalent compared to a draught animal (amount) or tractor (amount).

(iv) *projections over time:* how to make realistic projections, including the substitution between power sources to occur over time.

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[5] To be released in late 2002.

The first point explains the Agricultural Engineering's Branch's interest in establishing a reliable database. The third point explains the rationale for developing an alternative approach to power equivalents as a basis for examining relative power contributions to agriculture. Moreover, for the purposes of the global farm power assessment study it was considered important to meet the following criteria:

- to present results which are readily comprehensible to a general readership;
- to highlight the significance of humans in those parts of the world where they are the principal source of power in terms of area cultivated: this is fundamental for understanding the concerns arising from future projections of the size and composition of the agricultural labour force, particularly in countries where 15% or more of the population is expected to die due to HIV/AIDS within the next 20 years;
- to provide a basis for aggregating results from individual countries into sub-regional and regional data; and
- to take into account when projecting likely future combinations of farm power at a country level, albeit intuitively, the broad economic and political climate, likely developments in the structure and composition of the agricultural sector, competing claims on resource use, and opportunities for substitution between power sources.

As a result, an area-based approach was adopted, initially focusing on the proportion of the total harvested area cultivated either humans, draught animals or tractors at a country level. The data may then be aggregated at both sub-regional and regional levels. There are two premises under-pinnng the methodology:

(i) power source used for primary tillage: land preparation represents one of, if not, the most significant use of power. Moreover, because it is power intensive (as opposed to control intensive) (Rijk, 1989), it is usually one of the first tasks to benefit from additional power inputs. Hence any change in the relative contributions of different power sources to land cultivation may act as an indicator for subsequent changes which may occur elsewhere in the production process. This perspective is especially relevant when considering projections of farm power inputs;

(ii) the area cultivated by each power source as a percentage of the total harvested area: the latter represents the actual area cultivated in any year and takes account of any double cropping and short term fallow.

Others have used a similar approach, either at an individual country level or at a regional level (for example, Gifford, 1981 and Mrema, 1992). These data have been used to validate individual country classifications generated by the study.

Farm Power Typology Methodology

The approach hinges around the identification of six farm power typologies, representing the relative contributions from different power sources to land preparation. The analysis uses two data sets: one set is based on the distribution of country farm power typologies by sub-region and region, whilst the other converts the farm power typologies into the proportion of harvested area cultivated by different power sources. These data are generated for both the present and future (2030) scenarios.

In order to give a quantitative dimension to these definitions, percentages of the harvested area cultivated by different power sources were stated (see Table 1). This had two advantages. First, it ensured that when different experts were classifying individual countries, they were using the same criterion to distinguish between the various typologies. Second, the classification process became more manageable because it obviated the need for individuals to estimate the actual percentages under each power source for individual countries. It should be noted that the percentage ranges for each power source are indicative, with overlapping alternatives, rather than a discrete data set for each power type.

Table 1 Farm Power Typologies at Country Level

Farm power typology	Area cultivated by each power source (%)		
	hand	draught animals	tractors
A = predominantly hand power	over 80	up to 20	up to 5
B = significant use of DAP	46 – 80	21 - 39	up to 19
C = DAP predominant	15 – 45	40 and over	up to 19
D = significant use of tractors	20 – 50	15 - 30	20 - 49
E = tractors dominant	up to 25	up to 25	50 - 75
F = fully motorised	up to 10	up to 10	over 75

Classification of Countries

Individual countries were classified by farm power typology with reference to their current composition of farm power inputs, together with any foreseeable likely changes in that composition by 2015 and 2030. Fifteen experts (from FAO, DFID, Asian Development Bank, universities, and the private sector) with substantial field experience from around the world, participated in this process.

When possible, country classifications were verified with reference to secondary data. In particular, reference was made to the individual country studies commissioned by the Agricultural Engineering Branch, FAO as part of the Global Farm Power Assessment Study and prepared by in-country experts. Other sources included published reports and journal articles.

Whilst the methodology is largely based on individual expert opinions derived from field observations and intuition, and can be argued to lack precision, the classifications from various sources have proved to be fairly consistent. When significant differences arose (which happened occasionally), discussions were held with senior staff within FAO in order to reach a consensus.

Conversion into Harvested Area

The typologies were converted into the proportion of the harvested area cultivated by the different power sources at country level. For each typology, one percentage figure was selected for each power source The data for the harvested area were taken from FAO's database. For the present position, the base year figures for harvested area were used (based on a three year average, 1997 - 99); for the future position, the 2030 projections for the harvested area were used.

Methodological Limitations

There are two main limitations associated with the methodology. The first relates to the selection of one farm power typology to represent power use for land cultivation within a whole country. This overlooks the diversity which exists within many countries, particularly when the use of a specific power source is highly influenced by typography and terrain, cropping patterns, or highly differentiated between commercial/estate and smallholder sectors. Examples include mountainous regions with DAP in the hills, tractors on the flat lands; tea and coffee where land is not cultivated on an annual basis, and countries with a highly mechanized commercial sector, with smallholders relying on hand or DAP.

The second limitation relates to the percentage of land cultivated by each power source. The sensitivity analysis has demonstrated that the specific percentage points chosen for each power source within each typology appear

to be reasonable, and the sub-regional and regional classifications do not alter substantially if the percentage points are changed within a modest range. However, because fixed percentage points have been used (rather than actual percentages), it sets the upper and lower limits to the area cultivated by each power source. Thus (with reference to Table 2), the lower and upper limits for hand cultivation range from 5 to 90% of harvested area; for draught animals, from 5 to 70% harvested area; and for tractors, from 2 to 90% harvested area.

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