From hand tillage to animal traction: Causes and effects and the policy implications for Sub-Saharan African agriculture

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by

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Introduction

1. Sub-Saharan Africa has the lowest level of mechanization (both animal traction and tractorization) of all the developing regions. This is puzzling given the relative abundance of land and the relative scarcity of labor in many of the countries south of the Sahara. Our interest in this subject was sparked by the following unanswered questions:

(i) Why has the spread of mechanization in sub-Saharan Africa been slower than in low-wage, labor abundant economies such as India, Pakistan or China?

(ii) Why have animal traction and tractorization spread fairly rapidly in restricted pockets of Africa, but left neighboring agro-climatic regions untouched? For instance, small farmers in Sukumaland, Tanzania, use ox-plows for cultivating valley bottoms while the surrounding upland areas are cultivated with handhoes;

(iii) Why have some cattle owning farm households historically failed to use their oxen for cultivation purposes? and finally;

(iv) Why have the attempts of governments and donor agencies to by-pass the animal traction stage for direct tractorization via tractor projects failed repeatedly?

2. The primary objective of the study was to identify the conditions which lead to the transition from handhoes to animal traction and the further transition to tractors. Information and data required for this study were collected during extensive field visits to 48 locations in ten countries of sub-Saharan Africa. [1] These data were complemented by a detailed review of the English and French literature on the subject. The results of this study are presented in a monograph (entitled: Agricultural Mechanization and the Evolution of Farming Systems in Sub-Saharan Africa) published by Johns Hopkins University Press (Pingali, Bigot and Binswanger, 1987). This paper will summarize the results on the transition from handhoes to animal draft power, while mentioning the further transition to tractors only in passing. Readers interested in the conditions under which tractors are profitable are referred to the above monograph.

3. This paper provides the following: a) an identification of the conditions under which farmers make a transition from handhoes to animal drawn plows; b) a summary of the farm-level benefits of the transition; c) a discussion of the real and perceived constraints to the transition to animal traction; d) an exploration of the possibility of leapfrogging directly from handhoes to tractors; and e) a presentation of the main implications for policy.

Determinants of the profitability of the transition from handhoes to animal draft power.

4. The profitability of the transition from handhoes to animal drawn plows in a given area is determined by its population density, market infrastructure, soils, and the length of the growing period. The role of each of these determinants is discussed below.

(i) The profitability of the transition from handhoes to animal drawn plows is directly related to the population density and market infrastructure of a given area.

5. In order to understand this conclusion let us first examine how population density and market infrastructure influence agricultural production. Under sparse population densities, the prevailing form of farming is the forest fallow system. A plot of forest land is cleared and cultivated for one or two years after which it is allowed to lie fallow for 20-25 years. In most agro-climatic environments this period of fallow is sufficient to allow forest regrowth. An increase in population density will result in a reduction in the period of fallow and eventually the forest land degenerates to bush savanna. Increasing population densities are associated with longer periods of continuous cultivation and shorter fallow periods. From bush-fallow, the system progressively moves through the stages of short (grass) fallow, annual cultivation and finally multi-cropping. This movement from shifting cultivation to permanent cultivation is known as the intensification of the agricultural system (Boserup, 1965; Ruthenberg, 1980).

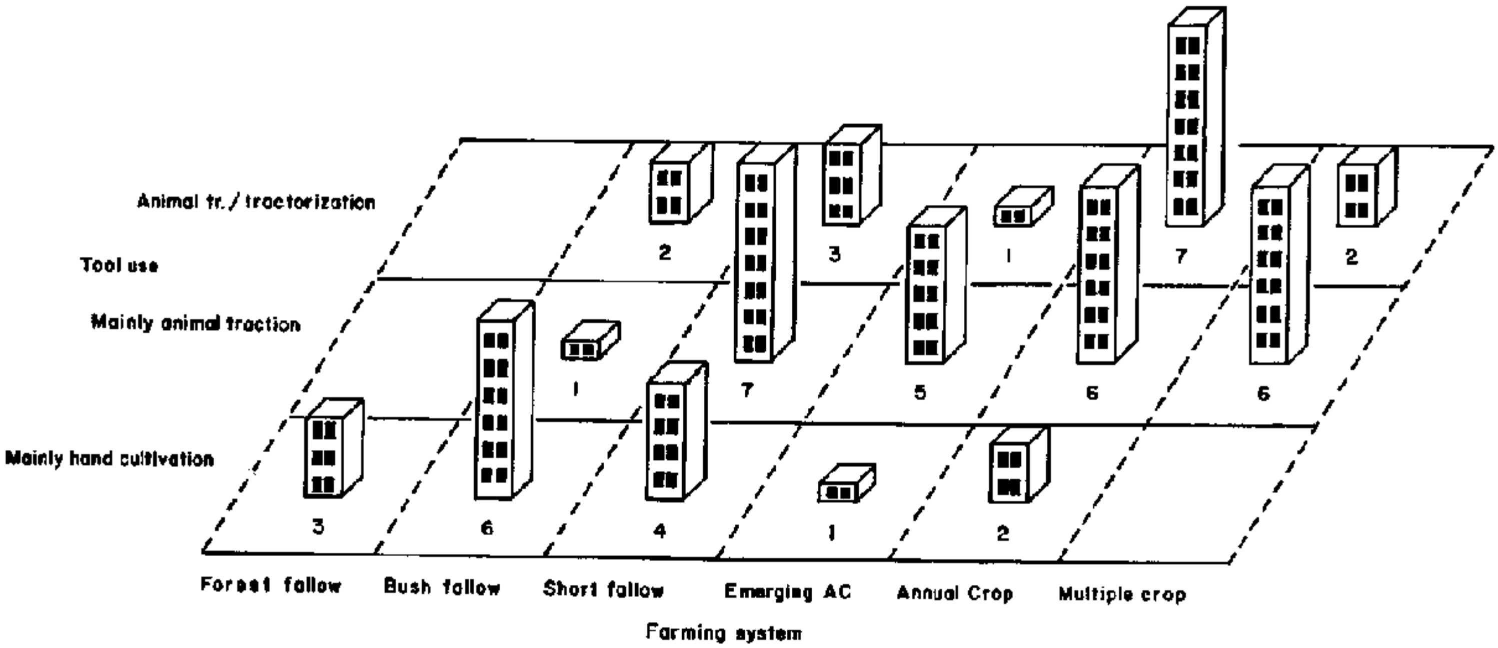
6. Holding population density constant, agricultural intensification could also occur due to improvements in transport infrastructure. This happens due to two reasons. First, high prices and elastic demand for traceable goods imply greater marginal rewards for effort, and farmers will begin cultivating larger areas. Second, higher rewards to labor encourage immigration in the area from surrounding regions with higher transport costs.

7. Our field visit data show a definite positive relationship between agricultural intensification and the transition from handhoes to animal drawn plows and/or tractors (see Figure 1 for details). All of the forest fallow cases and 6 of the 9 bush-fallow cases in our data set use hand tools for land preparation, while only 4 of the 14 short-fallow cases continue to rely on the handhoe. The dominance of mechanical tillage (via animal draft or tractors) becomes more prominent as short-fallow is replaced by permanent cultivation. Of the 30 cases under emerging or established permanent cultivation, 27 reported using animal draft and/or tractors for tillage.

8. Why is an apparently labor saving technology (the animal drawn plow) not used in forest- and bush-fallow systems when population densities are low and labor is scarce and why does it become attractive only when farming intensities increase, usually as a consequence of population growth? This puzzle has the following solution: when farming intensities increase beyond the forest-fallow stage, the number and intensity of farm operations increase (see Table 1), and labor requirements per unit of output (and per unit of land) rise faster than labor availability. Animal traction is indeed labor saving with respect to the high labor requirements (per unit of output) of handhoe cultivation in intensive farming systems. But it does not save on the relatively low labor requirements (per unit of output) of handhoe cultivation under the - forest and bush-fallow cultivation systems, but rather increases them. It does not improve the welfare of forest- and bush-fallow farmers who therefore reject it.

9. In the forest- and bush-fallow systems of cultivation, land clearing, planting and harvesting are the major tasks. Tree cover is removed during the clearing operation but the stumps are allowed to remain in the ground and planting is done in between the stumps. Because the land has been under tree cover it requires minimal amounts of land preparation and weeding. Now, suppose a plow was introduced into this system. The farmer would not only have to clear his land but also to have to remove the stumps and roots, a far more arduous task than clearing of the vegetation above the surface. Second, once the land has been destumped, the farmer would have to devote additional amounts of labor for soil fertility maintenance since forest-fallow can no longer be used for regenerating the soil. Third, since the soil is no longer under tree cover weeding requirements increase enormously. Finally, forest-fallow farmers, who usually do not keep any cattle due to the high incidence of disease and due to the low availability of grazing in these areas, would therefore have to add in the time required for animal husbandry into their decision to adopt the plow. Clearly, the introduction of a plow into the forest-fallow system would require a substantial increase in labor input, given the low availability of labor in these systems (due to low population density).

Figure 1. Evolution of farming systems and tools used



Note: The height of each column represents the frequency of each space

10. Now consider a farmer at the grass (short) fallow stage of cultivation, where two to three years of cultivation are followed by two to three years of fallow. The fallow period is not long enough for anything but grass growth. The weeding requirements are high because grass roots are hard to remove. Land preparation becomes an essential operation because the ground being exposed becomes hard and cannot be sown directly. Grassy fallows encourage the movement of animals into the area and farmers begin to keep livestock. Finally, with the reduction in fallow periods manure use becomes common as a means of augmenting the fertility of the soil. One can thus see quite clearly that the introduction of the plow at this stage would be truly labor saving since it would substantially reduce the labor requirements for land preparation and weeding without a significant increase in labor requirements for destumping, manuring and animal husbandry. It is at the grass-fallow stage that farmers first start using the plow and it becomes extremely common by the annual cultivation stage.

11. Intensification of the cultivation system is a necessary, though not a sufficient condition for the introduction of the plow. Several intensively cultivated areas, such as the Kenyan Highlands, Kano area in Nigeria, etc., have persisted in the use of the handhoe. We will examine some of these exceptions later in the paper. Given an appropriate intensity of cultivation, the profitability of plowing varies by soil type, and the length of the growing season. These constraints are discussed below.

Table 1. Comparison of operations across farming systems

Operation	Systems				
	FF	**BF**	**SF**	**AC**	**MC**
Land Clearing	Fire	Fire	None	None	None
Land Preparation & Planting	No land preparation digging sticks used to plant roots and sow seed	Land is loosened using hoes and digging sticks	Use of plow for preparing land	Animal drawn plows and tractors	Animal drawn plows and tractors
Manure Use	- Ash - Perhaps household refuse for garden plots	- Ash - Sometimes chitemene techniques - Household refuse for garden plots	- Animal dung or Manuring - Sometimes comporting	- Manure, sometimes human waste - Composting - Cultivation of green manure crops - Chemical fertilizers	- Manure, sometimes human waste - Composting - Cultivation of green manure crops - Chemical fertilizers
Weeding	Minimal	Required as the length of fallow	Intensive weeding required	Intensive weeding required	Intensive weeding required
Use of	None	As length of fallow	- Plowing	- Plowing	- Plowing

Animals Farming		decreases- animal drawn plows begin to appear	- Transport - Interculture	- Transport - Interculture - Post-harvest tasks - Irrigation	- Transport - Interculture - Post-harvest tasks - Irrigation
Seasonality of Labor Demand	Minimal	Weeding emerges as a peak	Land preparation, weeding and harvesting	Land preparation, weeding and harvesting	Acute peak around land preparation, harvest, and post-harvest tasks
Fodder Supply	None	Emergence of grazing land	Abundant open grazing	Open grazing restricted to marginal lands and stubble grazing.	Intensive fodder management and fodder crop production.

LEGEND:	FF = Forest-Fallow
	BF = Bush-Fallow
	SF = Short (Grass) Fallow
	AC = Animal Cropping
	MC = Multi-Cropping (i.e. for example double cropping)
Source: Pingali et al (1987).	

(ii) The yield response to tillage is directly related to the depth and clay content of the soil.

12. Tillage increases the total porosity of the soil and thereby improves aeration, root penetration, water infiltration and reduces evaporation. Clearly, the importance of tillage increases with decreases in soil porosity; it is unnecessary on coarse sands and absolutely essential on clays (the latter have extremely low porosity and are impermeable to air and water). In the absence of an animal or motorized power source, clayey soils are virtually impossible to cultivate and often left for grazing.

13. Clay content and depth of soil also vary by the toposequence. On the top of ridges, soils tend to be shallow and rocky. In the mid-slopes, the soil is of moderate depth while the valley bottom soils are generally deep and have a high clay content. Soils on the upper slopes, being relatively light, are easy to work by hand, while the power requirements for tillage are the greatest in the valley bottoms due to the high clay content of the soil. Therefore, when a mechanical power source is first introduced, it is commonly adopted on the lower slopes and bottom lands and then gradually moves to the mid and upper slopes. One ought to keep in mind, however, that the cultivation of the clayey soils of the bottom lands requires high levels of investment in water control and drainage. These investments are usually not profitable under low population densities due to the scarcity of labor. Therefore, the cultivation and the use of a mechanical power source on these lands is closely associated with an increase in population densities. For a detailed discussion on the soil and toposequence issues and the associated agro-climatic variations, see Pingali et al (1987).

(iii) The profitability of plow use is directly related to the length of the growing season.

14. For given yield levels, the profitability of plow use is also related to the potential capacity utilization of equipment, which in turn depends primarily on the number of days available for land preparation. Severe constrains on capacity utilization can prevent the adoption of the plow even under high intensities of farming and even where the yield response to tillage is high. Conversely, where the plowing season is long, plows may be profitably employed even with modest yield effects.

15. The number of days available for land preparation are highest in humid tropical zones and lowest in the arid zones. Within a particular zone, the length of the growing period increases with the moisture-holding capacity of the soil and with altitude. In much of semi-arid and arid sub-Saharan Africa, land preparation cannot take place during the dry season because the soils are too dry (and compact in West Africa) to be worked on without damage to soil structure and to implements. Soil preparation has therefore to wait until the onset of the rains and plowing starts when enough rains have been received to wet the soil to the required depth of plowing. In these areas, however, delayed planting often results in a reduction in the effective length of the growing season and sharply decreases crop yields. Farmers therefore face a plowing-sowing tradeoff which can be described as follows: while plowing can improve soil structure and thereby yields, it results in inevitable delays in seeding. But delayed sowing results in decreased yields. Plowing is advantageous only where its yield effects exceed the yield losses associated with delays in sowing.

16. The plowing-sowing tradeoff is more severe in lower rainfall areas and on soils which have lower moisture-holding capacity. Consider the extreme case of the arid fringe areas with rainfall less than 500 mm per annum and a growing period of less than 90 days (see Table 2). Delays in sowing in this environment result in sharply higher risks of crop loss. Since the light sandy soils can be easily prepared by hand, the yield effects of plowing are minimal. If there is any plowing at all in these environments, it is concentrated on the heavy soils of the depressions and valley bottoms which have a slightly longer growing season due to the higher water retention capacity of the soils.

17. One implication of the above discussion is that, where the growing period is short, the opportunities for increasing capacity utilization through rental markets is limited. Rental markets for land preparation equipment are more likely to be established in areas where the plowing operation is not severely time bound. This applies where dry season or post-harvest plowing is possible, or where delayed plowing and planting does not lead to sharp declines in yield. In the lower rainfall semi-arid zones, however, rental markets will be limited due to sharp conflicts about timing among the potential users. This conflict arises because it is impossible to decide in advance the best sequence in which to serve different customers of the same rental service.

Table 2. Potential for animal drawn plows by agro-climatic zone.

Climatic Zone	Average Annual Rainfall (mm)	Length of Growing Period	Remarks
Arid	0 - 400	<75	Plowing-sowing trade off severe. Plow use confined to heavy soils where absolutely necessary
Semi-Arid			
- Arid Fringe Areas	400 - 500	75 - 90	
- Low to Medium Rainfall Zone	500 - 650	90 - 120	Plow quite common.
- High Rainfall	650 - 800	120 - 150	
Sub-Humid	800 - 1200	150 - 270	Plow faces constraints other than capacity utilization.
Humid	>1200	>270	

Source: Pingali et al (1987).

Farm-level benefits of a transition to animal drawn plows

18. The most commonly cited benefits of a switch to animal drawn plows are: an expansion in area cultivated; high yields; reduced labor requirements; and development of animal husbandry skills. In this section, we will examine the existing empirical evidence on the different effects of the transition to the plow. Our review of the literature identified 22 survey studies that tried to evaluate these effects. All of these studies were contemporaneous comparisons of holdings with and without animal traction in the same agro-climatic environment. We are not aware of any comparisons over time of households that switched from handhoes to animal draft power. Summary results from these studies are presented in Table 3.

Table 3. Summary of the evidence on the effects of animal traction.

	Cases Measured (Out of 22)	**Number of Cases With Effect**			
		Positive	**NSD**	**Negative**	**Area Effect**
Area Per Farm					
All Cases	17	17			With AT 6.6 ha W/O AT 3.3 ha
Cases in Favorable Zones	9	9			With AT 6.8 ha W/O AT 3.5 ha
Cases in Unfavorable Zones	8	8			With AT 6.3 ha W/O AT 3.0 ha
Area Per Person					
All Cases	19	19			
Cases in favorable Zones	11	11			With AT 0.68 ha W/O AT 0.55 ha
Cases in unfavorable Zones	8	8			With AT 0.58 ha W/O AT 0.45 ha
Land Use for Market Crops					
All Cases	19	12	7	-	
Cases in Favorable Zones	11	8	3	-	
Cases in Unfavorable Zones	8	4	4	-	
Yield Per Hectare					
All Cases	14	4	8	2	
Cases in Favorable Zones	10	4	6	-	
Cases in Unfavorable Zones	4	-	2	2	

Unfavorable areas have less than 750 mm of rain per annum and practice upland farming.
NSD: No significant difference.
Source: Pingali et al (1987).

(i) Area effects

19. Studies that compare handhoe and animal traction farms generally find the latter to be larger in size than the former. Of the 17 studies reporting on area effects, all found a positive area effect. In general, animal traction farms were found to be twice as large as handhoe farms (see Table 3). The area effect was the same for cases in the favorable areas (above 750 mm of rain per annum) and for cases in the unfavorable areas (below 750 mm of rain per annum). These findings suggest that the transition to the plow is associated with an expansion in the private area cultivated, and therefore, an increase in agricultural production on the animal traction farm. Whether there is also an aggregate area expansion depends on the extent of land pressure in the area. Where there is substantial fallow land, aggregate cultivated area increases; on the other hand, where there is no fallow land, expansion in cultivated area can only come from a displacement of tenant farmers, and in this case, there is no aggregate area expansion.

(ii) Cropping pattern effects

20. A related question is what crops are grown on the additional area. Of the 17 cases that reported an expansion in area, 12 reported that the additional area was used for cash crop cultivation (cotton, groundnuts, rice, maize etc). The expansion in area under cash crops is more likely to occur in favorable than in unfavorable zones.

(iii) Yield effects

21. Experimental station studies have consistently shown a positive yield effect due to tillage. Yet objective comparisons of handhoe farms with animal draft farms have generally failed to show any significant yield effects. As shown in Table 3, 14 of the 22 cases examined presented yield effects of plowing; of these, 8 reported no significant difference in yield between plowed fields and fields tilled with handhoes. Even for the remaining studies, when proper accounting was made of other effects such as fertiliser use, extent of fallow land that was brought under cultivation, etc., there was no significant difference between the yield of handhoe and animal draft farmers.

22. How do we explain this apparent anomaly between experiment station results and the contemporaneous comparisons between users and nonusers of animal draft power? Let us start by noting that - apart from subsoiling - it is almost always technically feasible to achieve a given quality of tillage by using a plow or manual techniques. So, when yields between the two techniques remain the same, we can only conclude that farmers switching to the plow were not motivated by improvements in tillage quality, but that they were more interested in the area expansion or labor saving benefits accruing through the transition. Interestingly enough, comparisons of animal draft and tractor farms also showed no significant difference in yields. We are not saying that yield improvements are not possible; it is just that the farmers who made the transition were not motivated to do so in order to achieve these improvements. Most experimental studies compared plowed plots with unplowed control plots, i.e., plots that were directly seeded with no land preparation of any sort. They were not comparing plots tilled by hand versus plots tilled by animal drawn plows. Where hand tillage was indeed being used in the control plot, there were substantial differences in the quality of tillage between the two plots. Hence, the significant positive results. We are not aware of any studies where an attempt was made to hold tillage quality the same between the two groups - i.e hand-tilled and plowed plots.

(iv) Effects on labor use and labor productivity.

23. There is general agreement that a transition from the handhoe to the plow reduces the labor requirements during the land preparation period. (Assuming, of course, that we are at

the grass-fallow stage or beyond, as we discussed earlier on; otherwise, the switch to the plow in shifiting cultivation systems is not labor saving). Animal traction farmers do face higher weeding and/or harvesting labor requirements due the larger area cultivated, but most studies agree that labor requirements per hectare decline relative to handhoe farms. Consequently, labor productivity (output/manhour) increases significantly on animal traction farms relative to handhoe farms.

(v) Income effects

24. Does the adoption of animal draft power lead to higher net incomes than for handhoe farms? The income effect is a combination of the area effect, the cropping pattern effect, the yield effect and the labor effect. Of the 22 contemporaneous comparisons 16 indicated significantly larger income per household on animal traction farms. The income of animal traction households was found to have been two to five times that of handhoe using households.

Real and perceived constraints to the transition to animal drawn plows.

25. The most commonly mentioned constraints to the adoption of animal draft power are: trypanosomiasis; lack of animal husbandry skills; and the lack of mechanical skills. We will critically examine these constraints in this section. In addition to these, we will examine the constraints to animal traction in the tropical highlands and the humid tropical zone.

i) Trypanosomiasis

26. The tsetse fly is "shade loving" and can only survive under forest and bush cover. A recession in this vegetative cover leads to a recession in the tsetse fly infestation, and therefore to a change in disease incidence. Increases in population densities lead to a reduction in forest cover as larger areas are brought under cultivation and this acts as a natural control mechanism against the fly. This correlation between population density, land use intensity, and tsetse fly abatement has been observed in several parts of sub-Saharan Africa (Jahnke, 1976; Ford, 1971; Tiffen, 1976; Bourn, 1983; Jerve, 1982 among others). Low population densities rather than tsetse fly infestation can be considered the reason for low intensities of land use. If the tsetse fly were indeed the major constraint and if tillage was profitable, then one would expect to see tractor use being prevalent in these areas, but one does not.

27. Nevertheless, at the forest margin the tsetse fly is an important constraint to the use of animal traction. Where population densities increase farming intensities at the forest margin, N'dama and other trypanotolerant cattle breeds could be used for providing traction power.

ii) Lack of animals and animal husbandry skills

28. Sub-Saharan Africa is often characterized as having a historic dichotomy between crop production and livestock rearing. This supposed polarization between farmers and herders has been given as the reason for the slow spread of animal traction. The argument goes as follows: since the cultivators do not have any animals they lack livestock husbandry skills and hence are not in a position to maintain the animals required for traction purposes. Although it is easy to find examples of tribes that have historically been exclusively cattle herders (such as the Fulani, Maasai, etc.), it is hard to find crop farmers (outside the forest zone) who do not keep any livestock. By the time the farming system reaches a stage where it is appropriate to introduce the plow, the society has in general already acquired livestock husbandry skills. The question then is why some groups who own cattle and who cultivate crops do not use the animals for working their land. The general answer is that these farmers face other constraints to the use of animals (low intensities of farming, light sandy soils, extremely short growing season, etc).

iii) Lack of mechanical skills and repair services.

29. A frequent assertion among specialists studying agricultural mechanization in Africa is that the farmers lack mechanical skills required for the operation of animal traction equipment and that they do not have access to services for the timely repair and maintenance of equipment. These assertions are in general misleading.

30. The use of bicycles and mechanical mills has become very common all over sub-Saharan

Africa, even in areas where animal traction is not used. The mechanical skills required for the use and maintenance of this equipment is as high if not higher than that for the use of animal traction equipment. In our survey villages there was not one village where handhoe tillage is practiced which did not have bicycles and/or mechanical mills. Also, almost all our survey villages had a resident blacksmith capable of doing minor repairs on handhoes, plows and other animal traction equipment. As for major repairs and welding, we found that 80% of the survey villages had access to these facilities within a distance of 20 kilometers (see Table 4).

Table 4. Distance from repair facilities

	0-5 km	6-10 km	11-15 km	16-20 km	>20 km	Total
Animal Traction						
Number of cases	10	3	6	1	5	25
Percent of total	40	12	24	4	20	100
Tractors						
Number of cases	0	1	3	5	5	14
Percent of total	0	7.2	21.4	35.7	35.7	100
Bicycles						
Number of cases	7	4	4	2	7	24
Percent of total	29.2	16.7	16.7	8.2	29.2	100

Source: Pingali et. al (1987)

iv) Tropical highland areas that persist in handhoe use

31. Mountainous tropical highland areas are a primary example of intensively cultivated areas that persist in the use of handhoes. There are two reasons for the continued use of the hoe in the mountainous highlands, a) a steep terrain is often a constraint to the use of animal or tractor power, and b) many tropical highland areas have a comparative advantage in the production of tree crops and/or milk rather than field crops and therefore the opportunities for using mechanical tillage equipment is limited. Field crops such as maize are grown on small plots mainly for home consumption, handhoes are used to till these plots because the power requirements are relatively low and the period available for land preparation is very long. Rwanda, Burundi and the Kikuyu districts of Kenya, are examples of highland areas that have persisted in the use of handhoes.

v) Constraints to animal traction in the humid tropics

32. Most soils in the humid tropical zones are extremely fragile and intensive field crop production of the type observed in sub-humid and semi-arid zones leads to high levels of leaching, soil acidification and/or soil erosion (Kang and Juo, 1981). Several attempts have been made at establishing permanent field crop production in this zone with mechanized clearing and land preparation, but these attempts have generally run into problems after a few years.

33. In the humid tropical zones where population densities are high, the upland areas are planted with a dense mixture of crops of varying durations. For instance, a system of intercropping short - and medium-term crops such as manioc, yams, cassava, maize and beans under a protective cover of trees is very common in southeastern Nigeria. This system of farming closely mimics the natural vegetation and is viable over the long-run, since the soil would be covered most of the year and therefore the detrimental effects on the soil are minimized. Where market opportunities exist, the humid tropical areas specialize in tree crop production such as cocoa, oil palm-southern Cote d'Ivoire is an example. Where population

densities are small and market infrastructure is not well developed, agriculture in the humid tropics continues to be characterized by long fallow cultivation systems. Clearly, the role of animal drawn plows is limited in these systems. The only place where animal traction has a potential in the humid zone is in the cultivation of the bottom lands usually planted with rice-Philippines and other southeast Asian countries are examples where hand cultivation persists in the upland areas.

Is leapfrogging from handhoes to tractors possible?

34. We argued earlier in this paper that the most appropriate stage for introducting animal traction is the late bush-fallow or the grass-fallow stage. The question we now ask is: can we go directly to tractors at this stage without the intermediate animal traction stage? We looked at 17 projects in Africa that tried to make this direct jump and found that only two had succeeded. All the failures were located in areas of bush-fallow and early grass-fallow. The quality of destumping required for tractors is much higher than for animal draft, because in the former case all stumps and roots have to be removed to avoid damage to tractor implements. In the latter case, the animals can be used in partially destumped fields working their way around the stumps. In a few years the stumps decay and clear fields are available for cultivation with animals or tractors. Moreover, areas in which plow use is emerging have a variety of field conditions, some of which are permanently cultivated while bush fields are still periodically fallowed. Having animal drawn plows allows the farmer to till both his permanently cultivated fields as well as his bush fields.

35. It is very rarely that one sees a complete shift from one power source to another. In parts of India and Philippines, where tractors do tillage and transport, interculture continues to be done by animal draft power while harvesting is done by hand. In low wage conditions, tractors and animals are complements, with tractors concentrating on operations which require high levels of power while animals are used to work on operations that require a greater degree of care and judgement, such as weeding. If a direct transition is made to tractors this complementary would be lost.

36. Finally, economies in the early stages of mechanization are often characterized by capital scarcity and poor infrastructure facilities. It would therefore be easier for farmers to obtain and maintain animals and animal drawn equipment rather than tractors which require a more sophisticated network of repair and spare parts facilities. We would therefore argue that in most cases it would not be cost effective to make the direct transition from handhoes to tractors.

37. In the two cases where the transition was successfully made, both of them were in areas which were stump free, such as the grassy savannas of central Sudan and floodplain areas such as those in northern Ghana. Both these cases had the following characteristics: destumping costs were low; soils required deep tillage; they were not cultivated prior to the advent of tractors; the growing period was very long due to the water retention capacity of the soils; a government sponsored and subsidized tractorization program was in place; a government parastatal marketed the output.

Transition from animal draft power to tractors

38. While the choice between the handhoe and the animal drawn plow is closely tied to the evolution in farming systems, the choice between animal power and tractor power falls within the choice of techniques framework. Consider a society with a well-established animal drawn plow-based farming system. With the advent of tractors into the region, the farmer has a choice of power sources for performing various operations such as tillage, transport, etc., while holding all other aspects of the farming system constant. In other words, all the farmer wants to do is substitute one power source for another for a particular operation. Whether he chooses animal draft power or tractors depends on: relative costs of labor and capital, interest rate, capacity utilization, farm size, fodder availability, maintenance cost of animals versus tractors, and the difficulty of obtaining spare parts, fuel and repair services. We ought to emphasize that the choice of techniques analysis implies that not all operations are transferred from one power source to another, and that one observes a co-existence and complementarity of power sources for prolonged periods of time.

Policy implications

39. In the 1960s and the 1970s modernization of agriculture was considered synonymous with rapid tractorization. Accordingly, several African countries initiated large-scale tractorization programs, in the form of mechanized state farms, co-operatives farms that shared tractors, government tractor hire services, and by the provision of subsidised credit and preferential tariff's for the acquisition of tractors. Despite these concerted efforts, examples of sustained and economically viable tractor use are hard to find. In most cases, these tractors were abandoned, the few cases where they continue to be used (on government-run farm), the domestic resource costs of keeping them running, especially in terms of foreign exchange requirements, has been enormous, and without any appreciable increase in food or export crop output.

40. The appropriate power source to use for an agricultural operation depends on the physical and economic conditions facing the farmer rather than the cosmetic appeal of modem machinery. The idea that a group of thirty to fifty farmers could share a tractor and be better off than if each had a team of oxen and a plow is ill-founded, given the time bound and time synchronic nature of the land preparation and seeding operation. In cases where cooperative members operate individual holdings, it would be extremely difficult for the farmers to agree on an appropriate sequence in which each of their fields should be plowed. The resulting conflict would lead to the demise of the arrangement. Equally problematic is the notion that a government-run farm equipped with the best of modern machinery would produce more output per hectare than a group of private farmers with simpler equipment. So it is not surprising that since the 1980s several governments have begun to take a second look at animal draft power.

41. As discussed in this paper, land abundance and labor scarcity do not always imply the profitability of mechanical power. The chances of leapforgging directly from hand-tools to tractors, even in land abundant economies, are quite small. While the transition from hand tools to animal draft will occur only when the farmer perceives that his welfare will increase in the process, this depends on the stage in the evolution of farming systems that the farming society is in. Governments ought to be sensitive to these farming systems issues when designing their interventions on mechanical power.

42. Where the returns to output expansion have been high due to the existence of a good domestic or export market, small farmers have proven to be extremely responsive to new technologies. In the case of animal traction, one can find numerous examples of spontaneous adoption when the agro-economic conditions, such as population densities, market infrastructure, soils etc., were appropriate.

43. The potential for plow use is higher: on more intensively cultivated areas; on heavier soils; and in areas with a relatively long growing season. In terms of these variables, regions and sub-regions within all but the smallest countries vary enormously. The planning of project interventions to promote any form of mechanization, therefore, ought to be done at levels which can properly take account of these (within-country) regional/sub-regional variations and not on a nation-wide scale.

44. One way the government could help in the adoption of animal draft power, in locations where it is appropriate, is to identify and alleviate some of the short-run constraints to the transition. These constraints are: credit availability; veterinary services; training programs for farmers and animals; and training programs for blacksmiths.

45. Where the transition from animal to tractor power is profitable, one observes rapid adoption of tractors often with minimal government factor in involvement. Supply side constraints are not a major factor in their adoption. Repair and service facilities follow demand (where not restricted by government policy), and privately operated machines typically have a long life and high utilization rate. The historical record is quite clear on government involvement. Mechanization in such of the developed world did not depend on government intervention in machinery development, production, technology choice or finance. In the developing world, the most successful cases of mechanization such as milling, pumping and harvest processing did not depend on special interventions either.

46. Mechanical technology is sensitive to agro-climatic factors such as soils, terrain, etc., and economic factors such as wage rates, capital availability etc.. Hence, the opportunity for direct transfer is limited. Accordingly, where demand exists and where the returns to innovation are appropriable, one observes a great deal of invention and/or adaptation of mechanical technology to meet local conditions. Such work is usually done by small manufacturers in association with farmers. In this process, mechanically minded individuals provide direct solutions to problems perceived by farmers. The emergence of a diversified machinery industry out of small shops in the Indian Punjab, the power tiller industry in Thailand and the Philippines all followed similar patterns. Large government corporations in a central location do not have the advantage small workshops have in adapting to local constraints.

47. Given this dominant role of individual initiative in the development of agricultural machinery, the appropriate government interventions to encourage mechanical innovation (for animal traction or otherwise) are: a) patent laws to enable the innovator to caputre a portion of the economic rent generated by the innovation; and b) testing and information dissemination.

Footnotes

[1] Countries visited (and number of field visit locations in each) included:

Botswana	(4)
Burkina Faso	(4)
Cameroon	(6)
Cote d'Ivoire	(2)
Ethiopia	(5)
Guinea	(5)
Kenya	(7)
Nigeria	(4)
Tanzania	(6)
Zambia	(5)

Source: Pingali et al (1987).

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