The Evolution of Farming Systems and Agricultural Technology in Sub-Saharan Africa

by

Hans P. Binswanger and Prabhu L. Pingali

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Today we honor Vernon Ruttan for one specific and two more general achievements. The specific achievement in his book on Agricultural Research Policy. Following the lead established by T.W. Schultz and Zvi Griliches, this book not only discusses the contribution which scientific agricultural research can make to development, but provides detailed guidance on how to institutionalize and manage agricultural research and how to focus it on high payoff activities which capitalize on a country's or region's abundant resources while saving on its scarce ones.

The first more general achievement (shared with collaborators such as Hayami, Binswanger and others) is the resurrection of the theory of induced technical change from the obscurity into which an intellectual misconception of W.E.G. Salter had placed it, and to show empirically its relevance for explaining success and failure in agricultural development. The second general achievement is Ruttan's theory of induced institutional change, by which the same economic forces shape the evolution of institutions which influence the rate and direction of technical change: final demand, constraints and opportunities implied by factor endowments, as well as a number of other material forces. Most, but not all, of the empirical work of Ruttan and his collaborators, concentrates on technical changes arising from science-based research and the mechanical and chemical agroindustries, and on the institutional changes observed in "modern" agriculture.

Vernon Ruttan was not alone in emphasizing the endogeneity of technical and institutional change in agriculture. Ester Boserup, whose work was badly neglected by agricultural economists, dealt with the same two topics, but in the context of what T.W. Schultz called "traditional" agriculture. She focused on farmer generated changes in farming systems, technologies and land rights, which over the course of history have been independently developed in numerous locations across the world along systematic lines. Her work is particularly relevant today for understanding the pattern of agricultural development in sparsely settled areas of Sub-Saharan Africa. But even elsewhere the relevance of Boserup's work lies in the continued complementarity of farmer generated innovations with science and industry generated innovations.

Boserup's work was badly neglected, perhaps because she focused solely on population density as the main driving force of agricultural intensification. In this paper we briefly discuss other important determinants of agricultural intensification such as: transport infrastructure, external final demand, and the endogenous distribution of population across different agroclimatic zones. We treat the overall rate of population growth of a country as exogenous for this enquiry. Nevertheless and in accordance with Boserup, we recognize that the rate of population growth has important endogenous components. These endogenous components are not, however, relevant for the topic at hand, as the rate of growth itself is exogenous to the farmer. We then discuss the consequences of agricultural intensification.

In Boserup's (1965) analysis, intensification has eight principal effects: (1) it reduces fallow period; (2) it increases investment in land;

(3) it encourages the shift from hand hoe cultivation to animal traction; (4) it encourages soil fertility maintenance via manuring; (5) it reduces the average cost of infrastructure; (6) it permits more specialization in production activities; (7) it induces a change from general to specific land rights; (8) it reduces the per capita availability of common property resources (forest, bush and/or grass fallows, communal pastures). To these effects we add agroclimatic and soils considerations which were almost totally neglected by her, but were emphasized in the seminal work of Hans Ruthenberg on Farming Systems in the Tropics. Our own particular addition is a discussion of the systematic changes in land-use patterns and soil quality preferences associated with intensification.

The discussion in this paper is illustrated by two-way frequency charts using data from 56 villages in 10 countries of Sub-Saharan Africa and India. This data was collected in 1983-84 using the group interview technique as part of a larger research effort on agricultural mechanization and the evolution of farming systems in Sub-Saharan Africa. Although not substitutable for rigorous empirical testing these frequency tables provide preliminary support for the proposition presented in the paper.

I. Determinants of the Intensity of Land-Use

Population Density

The existence of a positive correlation between the intensity of land-use and population density has been shown by Boserup (1965, 1980). She argues from the premise that during the neolithic period forests covered a much larger part of the land surface than today. The replacement of forests by bush and grassland was caused by (among other things) a reduction in fallow periods due to increasing population densities.

> "The invasion of forest and bush by grass is more likely to happen when an increasing population of long fallow cultivators cultivate the land with more and more frequent intervals." (Boserup, 1965, p. 20)

Table 1 presents the relationship between population density and the intensity of the agricultural system. At very sparse population densities, up to perhaps four persons/square kilometer, the prevailing form of farming is the forest fallow system. A plot of forest land is cleared and cultivated for one or two years and then allowed to lie fallow for 20-25 years. 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 savannah. Bush fallow is characterized by cultivation of a plot of land for two-six years followed by six-ten years of fallow. The period of fallow is too short to allow forest regrowth. Increasing population densities are associated with longer periods of continuous cultivation and shorter fallow periods. Eventually the fallow period becomes too short for anything but grass growth. The transition to grass fallow occurs at population densities of around 16-64 persons per square kilometer. Further increases

Table 1

Food Supply Systems in Tropics

Food Supply System[5]		Farming Intensity[1] (R-Value)[2]	Population Density Group[2] Persons/km^2	Climatic Zone[3]	Tools Used
G.	Gathering	0	0 - 4		
FF.	Forest fallow	0 - 10	0 - 4	Humid	axe, matchet & digging stick
BF.	Bush fallow	10 - 40	4 - 64	Humid & semi-humid	axe, matchet, digging stick and hoe
SF.	Short Fallow	40 - 80	16 - 64	Semi-humid, semi-arid, & high altitude	hoes, animal traction
AC.	Annual Cropping	80 - 120	64 - 256	Semi-humid semi-arid, & high altitude	animal traction & tractors

[1] R = # of years of cultivation *100/# of years of cultivation + # of years of fallow. Source, Ruthenberg, 1980, p. 16.

[2] Source: Boserup, 1981, pp. 19 and 23.

[3] Source: Ruthenberg, 1980.

[4] Source: Ruthenberg, 1980 and Boserup, 1965.

[5] Description of food supply systems:
Gathering: wild plants, roots, fruits, nuts

Forest-fallow: one or two crops followed by 15-25 years of fallow

Bush-fallow: two or more crops followed by 8-10 years of fallow

Short-fallow: one or two crops followed by one or two years of fallow: also known as grass fallow

Annual cropping: one crop each year

Multi-cropping: two or more crops in the same field each year

Note 1: The above food supply systems are not mutually exclusive. It is quite possible for two or more of the systems to exist concurrently (e.g., cultivation in concentric rings of various lengths of fallow, as in Senegal).

Note 2: The above population density figures are only approximations, the exact numbers depend on location specific soil fertility and agroclimatic conditions.

in population result in the movement to annual and multi-cropping, the most intensive systems of cultivation. All along the course of this transition farmers make investments in land. Initially, they are confined to land clearing and destumping. Drainage investments leveling erosion control investments and eventually irrigation investments follow. The capacity to double or triple crop usually requires very large investments.

Since the turn of this century we have observed a substantial increase in the natural rate of population growth across the world, mainly due to a sharp decline in the death rates caused by rapid advances in public health services. At the worldwide level, and at the level of a specific country, the decline in arable land per capita must be attributed primarily to this general increase in population. Within a country and within regions, however, population concentrations vary by soil fertility, altitude and market accessibility. These intra-country variations are briefly discussed below using examples primarily from Sub-Saharan Africa. Table 2 provides the major causes and consequences of population concentration.

Soil Fertility

The marginal productivity of labor is relatively higher on more fertile soils and hence one would expect immigration from less endowed areas leading to reductions in cultivable areas per capita. Ada district, Ethiopia; Nyanza Province, Kenya and the southern province of Zambia are a few examples of fertile areas that are relatively densely populated and intensively cultivated. High altitude areas are similarly densely populated due to immigration from the lowlands because of lower disease incidence (notably malaria and sleeping sickness). Population concentrations on the Ethiopian and Kenyan Highlands are popular examples of this phenomenon.

Table 2

Causes and Consequences of Population Concentration

Causes			Direct Consequence	Implications
Natural population growth:	improved public health and lack of emigration		Reduction in available area per capita	Reduction in fallow periods: Movement from shifting to permanent cultivation Mechanization: Plowing: where agro-climatic and soil conditions make it profitable Transport: where markets exist for food and other crops Milling: in response to higher opportunity cost of time for female household members Land investments: for soil fertility, drainage, terracing, etc. Increase in the marginal lands brought under cultivation Land rights: from general use rights to specific land rights
Soil fertility:	immigration to capture the benefits of higher returns to labor input			
Transport facilities:*	immigration to capture the benefits of reduced transport costs			
Urban demand:*	immigration to capture the benefits of market proximity			
Health:	avoidance of malaria and tsetse fly	immigration to cooler highlands		
Historic:	tribal war/slave trade	immigration to inaccessible highlands		
Land laws, rights	restrictions on the right to open new land			

* In the case of improved transport facilities and urban demand one may observe an expansion in the area under cultivation in in the absence of immigration.

Given suitable soil conditions, areas with better access to markets either through transport networks or those in the proximity of urban centers will be more intensively cultivated. Intensification occurs due to two reasons:

a. Higher prices and elastic demand for exportables implies that marginal utility of effort increases, hence farmers in the region will begin cultivating larger areas; and

b. Higher returns to labor encourage immigration into the area from neighboring regions with higher transport costs.

Intensive groundnut production in Senegal, maize production in Kenya and Zambia and cotton production in Uganda have all followed the installation of the railway and have been mainly concentrated in areas close to the railway line. Similarly, agricultural production around Kano, Lagos, Nairobi, Kampala and other urban centers is extremely intensive compared to other parts of these countries. It should be noted that agricultural intensification in response to improved market access could occur even under low population densities due to individual farmers expanding their area under marketed crops. The consequences of intensification in these circumstances do not differ from those in areas with high population densities.

Soil fertility and transport infrastructure interact in two ways. First, a large region of high quality land provides incentives for the construction of infrastructure to exploit that potential. Second, where roads or railway lines are built for non-agricultural purposes such as to the copper mines of Zambia, they will cross both fertile and infertile areas. The impetus for intensification, however, is felt only in the fertile areas, as the infertile areas are unable to compete in output markets due to their higher costs of production.

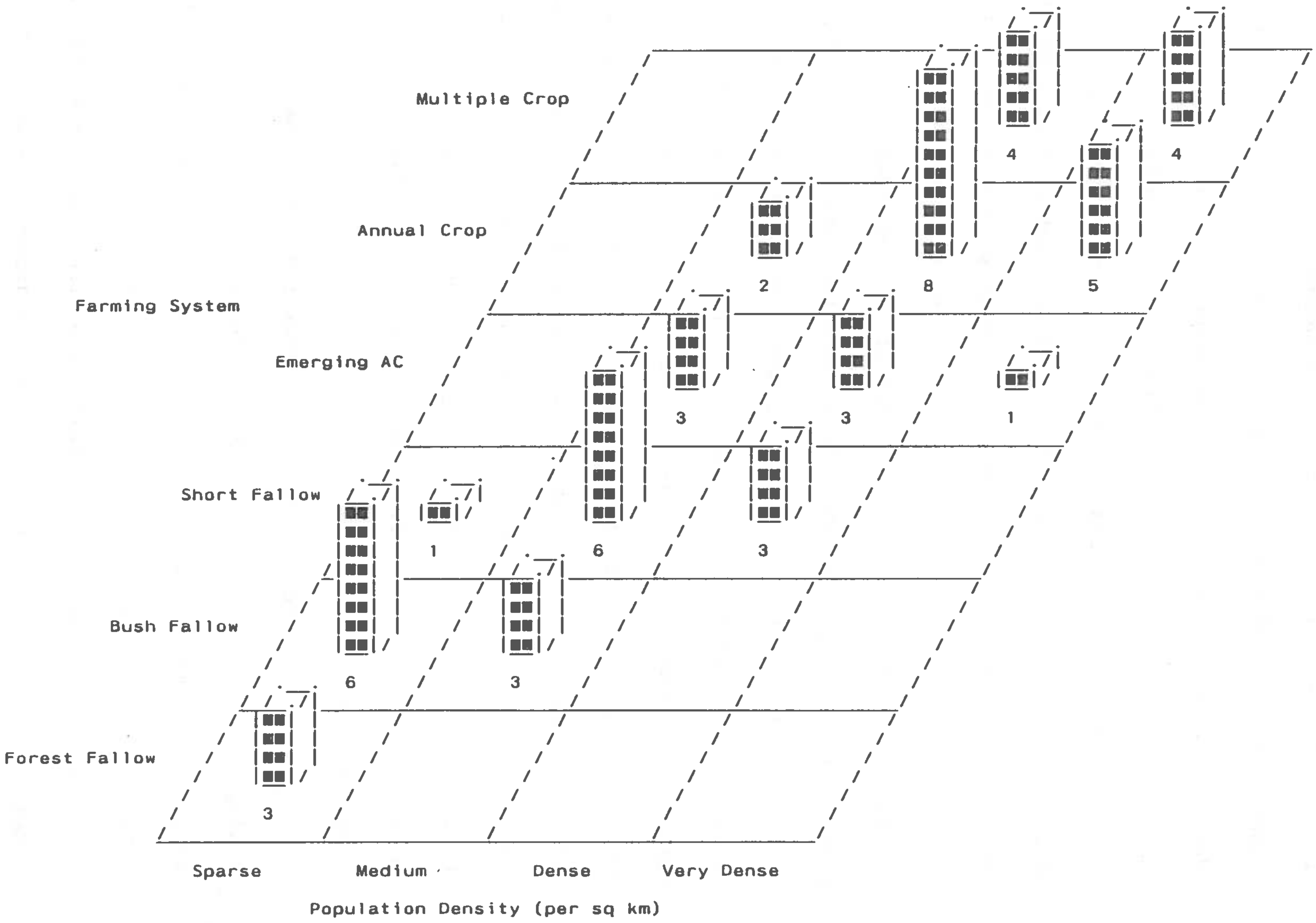
Other Causes

Finally, it should be noted that inter and intra-country variations in population densities, especially in Sub-Saharan Africa, have historically been caused by tribal warfare and slave trade resulting in population concentrations in relatively inaccessible highlands. Population concentration on the high plateau of Rwanda and Burundi was in response to the incursions of slave traders and for health reasons. Similar migrations from the lowlands to the Mandara Mountains in Cameroon, the Jos Plateau in Nigeria and the Rift Valley in Kenya and Tanzania have been based on the desire for personal security. Subsequent natural population growth has made many of these areas the most densely populated parts of Africa.

The above discussion leads to the broad generalization that for given agroclimatic conditions, increases in population density and/or improvements in market access will gradually move the agricultural system from forest fallow to annual cultivation and eventually to multi-cropping. Empirical support for these two determinants of agricultural intensification is provided by means of two-way frequency charts using our data set from Sub-Saharan Africa.

Graph 1 presents the positive relationship between population density and farming intensity. Forest and bush fallow systems are predominant under sparse population densities (less than 15 persons/km^2), nine of the ten sparsely populated areas in our sample practice these systems of farming, the remaining case is under short fallow. In the medium density

Graph 1: <u>Population Density and the Intensification of Farming Systems</u>

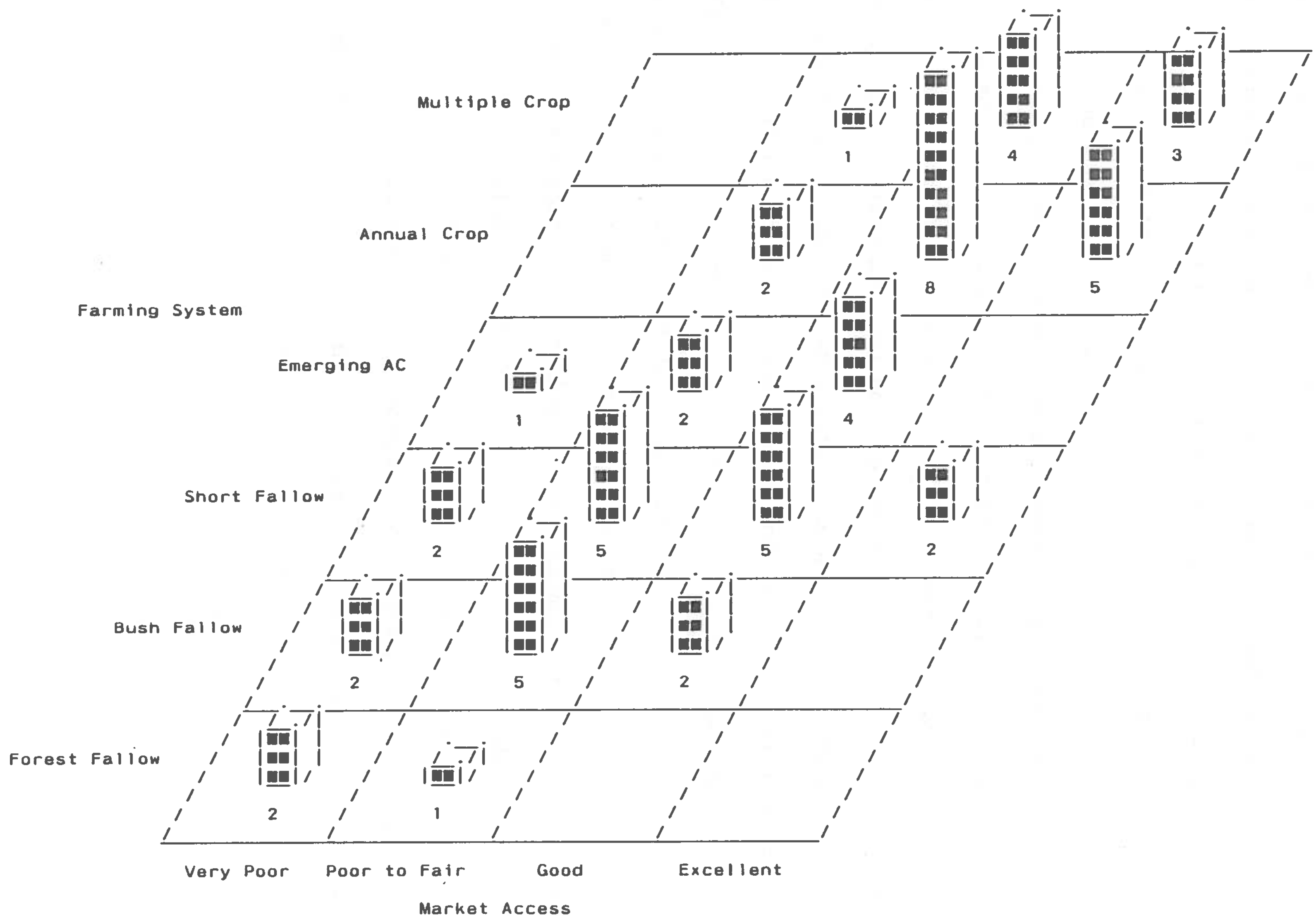


group (16-50 persons/km^2) one begins to observe the transition to more intensive systems of farming. Here the majority of the cases (9 of 14) fall in the short fallow and emerging annual cultivation categories, there are no forest fallow cases at this density level and bush fallow tapers off to three out of 14 cases. In the dense population group (51-100 persons/km^2) annual and multi-crop cultivation is well established with 12 of 18 cases in these systems and three cases emerging towards annual cultivation. There are three remaining short fallow cases presumably at the lower end of the population density group. Nine of the ten cases in the very dense population group (greater than 100 persons/km^2) practice annual or multi-crop cultivation, with the remaining case emerging towards annual cultivation. The classification of our cases shows a very definite trend towards agricultural intensification as population densities increase. Neither in our field visits nor during our literature survey have we come across any cases of sparsely populated areas under annual cultivation or cases of very densely populated areas under forest or bush fallow systems. Presumably, the former could occur under sparse population densities if market access is excellent, while the latter could not occur even under poor market access conditions.

define variables.

The positive relationship between the ease of market access and farming intensity is shown in Graph 2. For given population density an improvement in market access results in further intensification of the farming system. Under very poor market access mainly extensive forms of farming such as forest and bush fallow are practised. Under fair market access we observe nine of the 16 cases with intensities of short fallow and above. Among the cases where market access is good, 22 of the 24 cases are

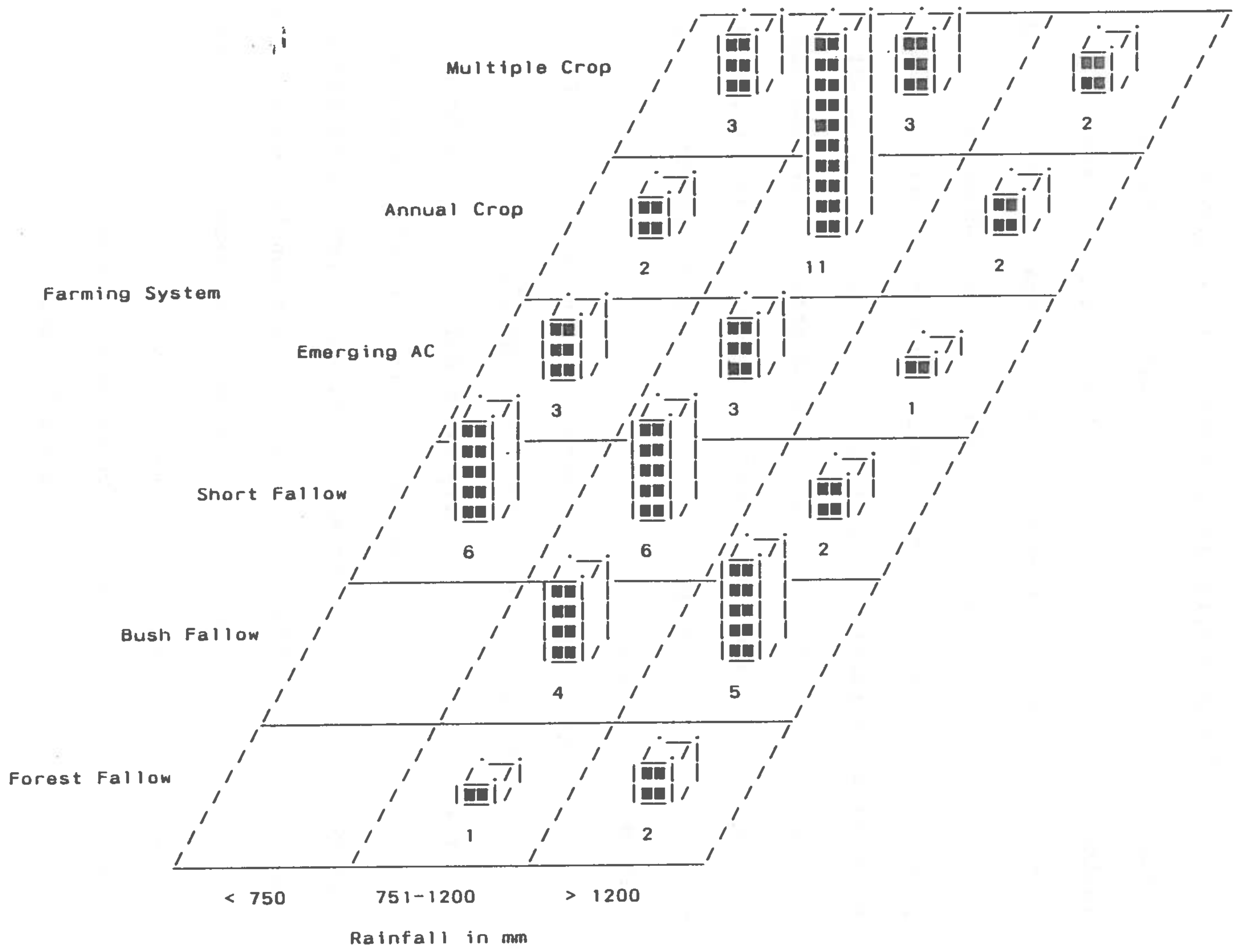
Graph 2: Market Access and the Intensification of Farming Systems



at intensities of short fallow and above. Where market access is excellent, nine of the ten cases are under annual or multi-crop cultivation and the remaining case approaching permanent cultivation.

Graph 3 presents the agroclimatic constraints on the process of intensification. At an annual average rainfall of less than 750 mm which includes the low rainfall semi-arid and the arid zones one does not see forest and bush fallow cultivation. This is due to: (a) the slow rate of vegetative regrowth under arid conditions which does not permit forest regeneration even at low densities, and (b) cultivation being concentrated mainly on the lower slopes and depressions which are relatively more responsive to intensification investments. Under high rainfall conditions such as the humid tropics (rainfall greater than 1,200 mm) one tends to observe a predominance of forest and bush fallow cultivation. Permanent cultivation of field crops under humid conditions is hard to sustain due to high levels of leeching and soil acidification problems. The exceptions in the graph are from the highlands of Kenya and Ethiopia which, of course, do not suffer from the same problems as the humid lowlands and therefore can be cultivated permanently. Sustained permanent cultivation of field crops is most feasible in the medium rainfall zones (751-1,200 mm), which is consistent with our empirical evidence.

Graph 3: Agroclimatic Zones and the Intensification of Farming Systems



II. The Consequences of Agricultural Intensification

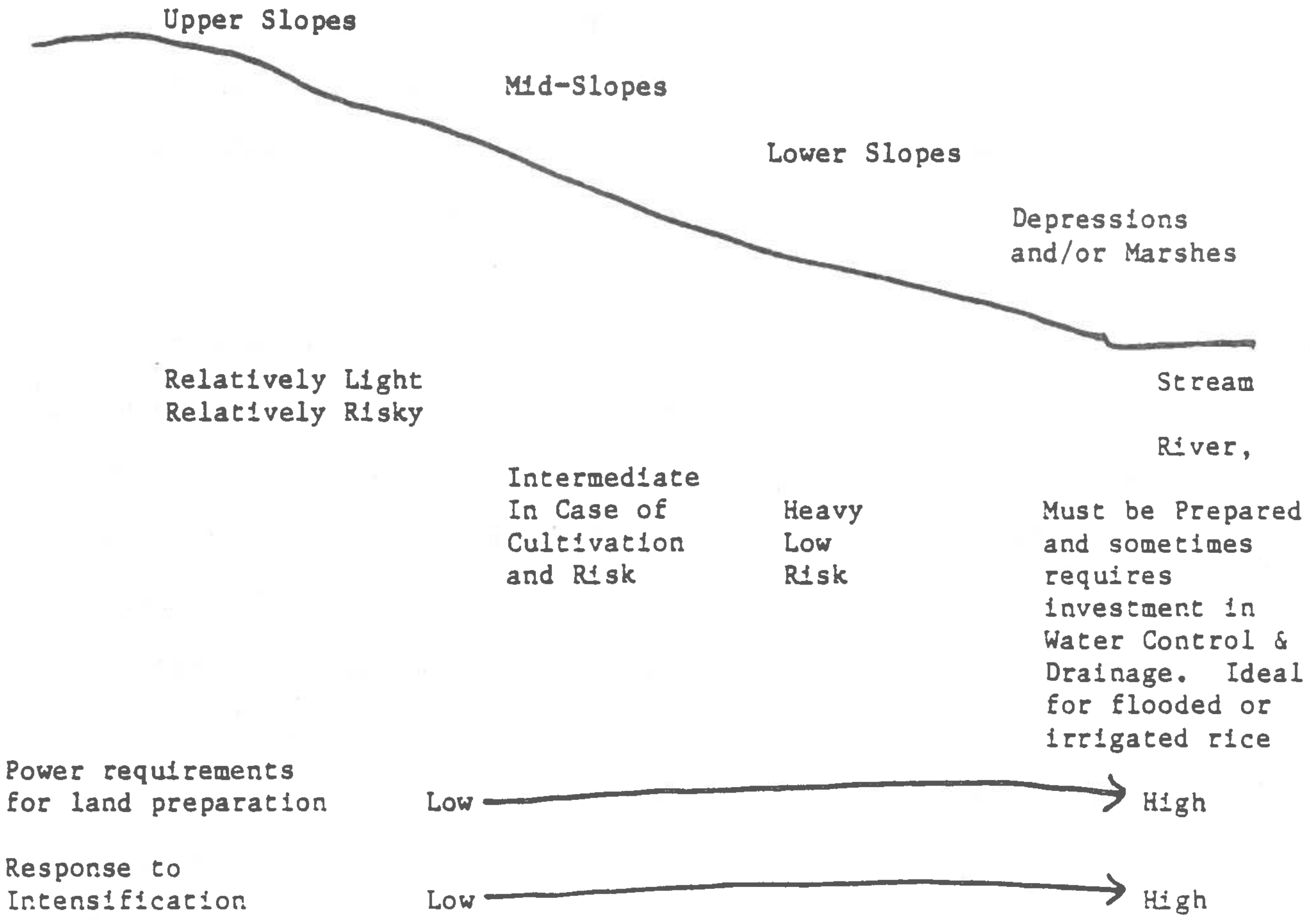
Agricultural Intensification and Soil Preferences

The intensification of agricultural systems is constrained by climatic and soil factors. Table 1 illustrates the impact of climatic factors on the intensification of the agricultural system. For given agroclimatic conditions the extent of intensification is conditional on the relative responsiveness of the soils to inputs associated with intensive production such as land improvements, manure and fertilizers. The responsiveness of intensification is generally higher on soils with higher water and nutrient holding capacity. This is primarily because higher water holding capacity reduces drought risk. Water holding capacity is higher the deeper the soils and the higher their clay content. It is low on shallow sandy soils.

Figure 1 presents a stylized picture of the differences in soil types across a toposequence for given agroclimatic conditions. Soils on the upper slopes are relatively light and easy to work by hand, tillage requirements are minimal on these soils. The clay content and hence the heaviness of the soils increase as one goes down the toposequence, consequently power requirements for land preparation increase. Movement down the slope also reduces yield risks due to increased water retention capacity of the soils. The soils are heaviest in the depressions and marshes at the bottom of the toposequence. These bottom lands or bas fonds are often extremely hard to prepare by hand and are often impossible to cultivate in the absence of investments in water control and drainage. The extremely high labor requirements for capital investments and land

Figure 1

Toposequence and Soil Type



preparation make the bottom lands the least preferred for cultivation under low population densities, and they are often found to be under fallow. As population densities increase, however, the bottom lands become intensively cultivated due to the relatively higher returns offered to labor and land investments, especially in rice cultivation. Also, as population densities increase labor supply increases, making it possible to undertake the labor intensive investments in irrigation, drainage, etc.

Soil type differences across a toposequence that are characterized here could be micro-variations limited to a few hundered meters or a few kilometers, or they could be macro-variations where entire regions are part of one level of the toposequence. For example, large parts of northeastern Thailand can be characterized as being the upper slopes, although there are, of course, depressions in northeast Thailand within micro toposequences. The central plains of Thailand are largely flood plains and have the characteristic of bottoms and marshes.

Preferences for cultivating different points of the toposequence is also dependent on the agroclimatic conditions. Table 3 presents soil preferences by farming intensity and agroclimatic zones. Under arid conditions lower slopes and depressions are the only lands which can be cultivated because only here is water retention capacity sufficient to sustain a crop at very low rainfall levels. This is the reason for the intensive cultivation systems of an oasis type one observes in arid areas even under low population densities. Pockets of arid farming in primarily pastoral areas of Botswana are a good example of this phenomenon.

Under semi-arid conditions the midslopes are the first to be cultivated. As population densities increase, cultivation replaces grazing

Table 3

Farming Intensity, Agroclimates and Soil Preferences

Agro-climates	Farming Intensity		
	Forest & Bush Fallow	Grass Fallow	Permanent Cultivation
Arid	Lower slopes & depressions only	Lower slopes & depressions only	Lower slopes & depressions only
Semi-arid	Mid-slopes	+ Lower slopes	+ Depressions
Sub-humid	Upper slopes	+ Mid & lower slopes	+ Depressions
Humid	Upper slopes	+ Mid & lower slopes	+ Depressions

in the lower slopes and eventually in the depressions. Power sources for tillage are first used in the bottom lands, generally around the time when population pressure makes these lands valuable for cultivation. The reversal of land preferences is quite dramatic. In the semi-arid zones of Africa where population density is low the lower slopes and depressions are left for grazing and contribute only minimally to food supply. In the semi-arid zones of India, on the other hand, the depressions are intensively cultivated usually with rice, using elaborate irrigation systems and animal traction.

Yield risks due to low water availability are not a major problem in the sub-humid and humid tropics, hence one finds cultivation starting at the upper slopes and gradually moving downwards as population pressure increases. At high population densities the swamp and depressions become the most important land sources for food production, often associated with extremely intensive rice production. One observes such labor intensive rice production in South and Southeast Asia and could expect the same for Africa as population densities increase.

Population pressure leads to a sharp reversal in preference (price) of different types of land in all but the arid zones. As population densities increase one observes the cultivation of land which requires substantially higher labor input but which at the same time also is more responsive to the extra inputs.

Cultivation Techniques and Labor-Use

As discussed by Boserup and Ruthenberg, the total labor input per hectare on a given crop is positively correlated with the intensity of farming, holding technology constant. Table 5 presents examples of labor-use with farming intensity in rice cultivation. The movement from forest fallow to annual cultivation in West Africa using the hoe results in an increase in total labor input per hectare from 770 hours in Liberia to 3,300 hours in Cameroon. The increase in labor input occurs due to an increase in intensity with which certain tasks have to be performed (for example, land preparation and weeding) and due to an increase in the number of operations performed (e.g., manuring, irrigation, etc.). A discussion of labor-use across intensities of farming is provided below. Table 4 presents the increase in operation performed with the intensification of the farming system.

In the forest and bush fallow systems of cultivation land clearing, planting and harvesting are the major tasks performed. Fire is the most prevalent technique used for land clearance. This form of land clearance in addition to regenerating the soil also removes weed growth. Land clearance by fire requires very low levels of labor input: 300 to 400 hours per hectare for forest fallow systems in Liberia and Ivory Coast. The ground being under tree cover is soft and hence no further land preparation is required prior to sowing with the help of a digging stick or a hand hoe. Such systems of cultivation require almost no weeding or interculture and the period between planting and harvesting is virtually task free.

Table 4

Comparision of Operations and Technology Across Farming Systems

Operations	SYSTEM				
	FF	BF	SF	AC	MC
Land clearance	Fire	Fire	None	None	None
Land preparation	No land preparation digging sticks used to plant roots and sow seeds	Land is loosened using hoes and diggind sticks	Use of plow for preparing land	Animal-drawn plows and tractors	Animal-drawn plows and and tractors
Manure use	- Ash - Household refuse for garden plots	Ash, burnt or unburnt leaves, other vegetable matter and turf brought from surrounding bushland	- Animal and human waste - Green manuring - Composts - Silt from canals	- Animal and human waste - Composting - Cultivation of green manure crops - Chemical fertilizer	- Animal and human waste - Composting - Cultivation of green manure - Chemical fertilizer
Weeding	Minimal	Required as the length of fallow decreases	Weeding required during the growing season	Intensive weeding required during the growing season	Intensive weeding required during the growing season
Use of animals in farming	None	As length of fallow decreases animal-drawn plows begin to appear	- Plowing - Transport - Interculture	- Plowing - Transport - Interculture - Post-harvest tasks - Irrigation	Plowing, transport, interculture, post-harvest tasks, irrigation
Seasonality of labor demand	None	None	Land preparation, weeding and harvesting	Acute seasonal labor demand concentrated around the rainy season and harvest period	Acute seasonal labor demand concentrated around land preparation, weeding, harvest and post-harvest tasks
Fodder supply	None	Emergence of grazing land	Abundant free grazing land	Free grazing during fallow period, crop residues	Intensive fodder management and fodder crop production

Table 5

Examples of Labor Use with Farming Intensity Rice Cultivation

COUNTRY	Liberia	Ivory Coast	Ghana	Cameroun	India	Java	Philippines
Region	Gbanga	Man	Begora	Bamunka	Ferozepore	Subang	Laguna
Intensity of Farming	11	24	40	100	121	200	180
Technique	Hoe	Hoe	Hoe	Hoe	Animal plow	Animal plow	tractor
Time/Operation (hours/hectare)							
Land clearing	418.4	300.8	665	--	--	--	--
Land Preparation	--	--	--	714	86.4	494.4	73.6
Sowing/Planting	107.2	142.4	207	536.8	129.6	146	80.0
Fertilizing & Manuring	--	--	--	--	12.8		
Weeding	36.8	292	276.8	113	57.6	218	213
Plant Protection	44	222	--	1,393			96
Harvesting	164	218.4	280	264	128.8	324.4	222.4
Threshing		84		280	76.8		
Other	--	--	--	--	136[1]	70	--
TOTAL	770	1,259.2	1,432	3,300	627.2	1,252	685

[1] Irrigation

As the fallow period becomes shorter and the land under fallow becomes grassy, fire can no longer be used for land clearance. Fire cannot get rid of grass roots, hence grasses persist through the growing season. The intensive use of a hoe for land preparation becomes essential to clear the grass roots. Land preparation and sowing take up almost 40% of the total labor input for the annual cultivation of rice in Cameroon. Under short fallow systems of cultivation early season weeding and plant protection become pronounced. Also manure use is required to complement fallow periods for maintaining soil fertility.

Permanent cultivation of land requires labor investments for irrigation, drainage, and leveling or terracing. It also requires the development of more evolved manuring techniques to restore soil fertility. Land preparation and interculture and weeding become much more important tasks.

Intensification therefore leads to both an increase in agricultural employment and an increase in yields per hectare. However, intensification of farming, in the absence of a change in tools used would probably lead to a decline in yield per man-hour. This can be deduced from the observation that the greater proportion of the additional labor input is used for maintaining soil fertility, weeding and plant protection. In other words, labor input per hectare may increase at a faster rate than yield per hectare in the movement to more intensive systems of farming. Pingali and Binswanger (1984) found a significant positive increase in labor-use with farming intensity using a data from 52 specific locations in Africa, Asia and Latin America. We also show a significant downward shift in labor-use when hand hoes are replaced by animal drawn plows and a further shift when animal draft is replaced by tractors.

The Evolution of Tool Systems

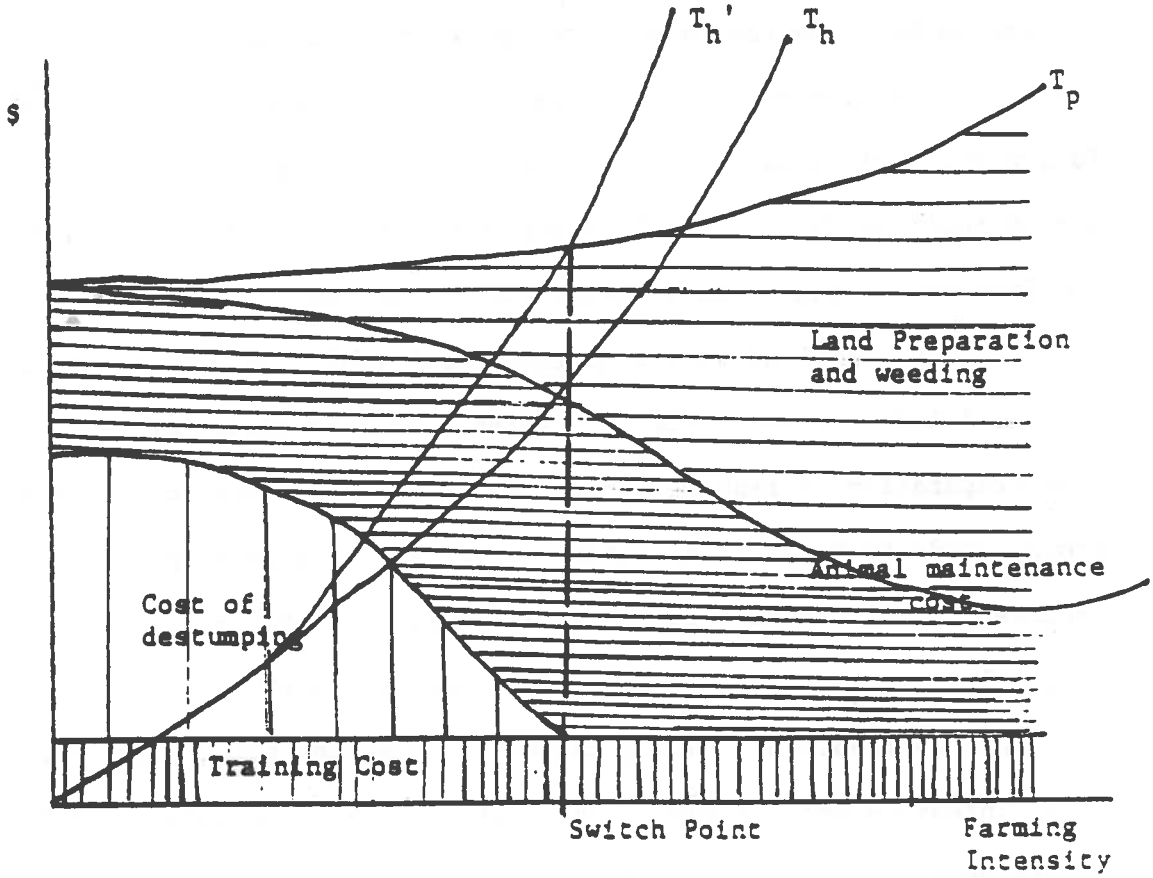
The transition from digging sticks and hand hoes to the plow is closely correlated with the evolution of the farming system and cannot be understood by using choice of techniques analysis familiar to economists. The emergence of mechanical tillage is generally observed at late bush fallow and early grass fallow stages and not before. The switch from one set of tools to the next would occur when the resulting labor-saving benefits exceed the costs of switching to new tools.

The simplest form of agricultural tool, the digging stick, is most useful in the very extensive forest and bush fallow systems where no land preparation is required. As the bush cover begins to recede the ground needs to be loosened before sowing and at this stage hand hoes replace digging sticks. Hand hoes are used for land preparation and weeding in the latter stages of bush fallow, grass fallow and even some instances of annual cultivation. Land preparation using the hoe becomes extremely labor intensive and tedious by the grass fallow stage because of the persistence of grass weeds. The use of a plow for land preparation becomes almost indispensible. A switch to the plow during grass fallow results in a substantial reduction in the amount of labor input required for land preparation. The net benefits of switching from the hoe to the plow are conditional on soil types and topography. The benefits are lower for sandy soils and for hilly terrain.

The above discussion on the evolution from hand hoes to animal drawn plows is formalized in Figure 2. This graph compares the labor costs under hand and animal powered cultivation systems and shows the point where animal traction is the dominant technology.

Figure 1

A Comparison of Labor Costs under Hand and Animal Powered Cultivation



T_p = Labor costs for land preparation, early season weeding and manuring using animal traction

T_h = Labor costs for land preparation and early season weeding using land hoes

T_h' = T_h plus labor costs for maintaining soil fertility without manure from draft animals

Switch Point = Farming intensity at which animal traction is the dominant technology.

The overhead labor costs in the transition from hand to animal power are: the cost of training animals, the cost of destumping and leveling the fields, and the cost of feeding and maintaining the animals on a year-round basis. The cost of training the animals is independent of the intensity of farming. The cost of destumping is extremely high under forest and early bush fallow system. As the length of fallow decreases the costs of destumping decline because of reduced tree and root density. Destumping requirements are minimal by the grass fallow stage. The costs of feeding and caretaking of draft animals is also very high during forest and early bush fallow, primarily due to the lack of grazing land and due to the prevalence of diseases such as trypanasomiasis. As the fallow becomes grassy, grazing land becomes prevalent and so does animal ownership; hence the costs of maintaining draft animals decline. By the annual cultivation stage, however, grazing land becomes a limiting factor, necessitating the production of fodder crops which in turn lead to an increase in the cost of feeding and maintaining draft animals. The total cost of using draft animals for land preparation, early season weeding and manuring is given by the curve, T_p. The curve T_h shows how total labor costs using hand hoes increases for land preparation and weeding, while T_h' adds in the cost of maintaining soil fertility. The shape of the T_h' curve depends on: (a) the ease of producing compost; (b) the rate of decay of organic matter; and (c) the cost of chemical fertilizer. In humid and sub-humid areas it is easier to produce compost and manure relative to semi-arid and arid areas due to an abundance of natural vegetation, hence the labor costs involved in the production of manure are lower and the T_h' curve is flatter. In hot tropical areas the very high temperatures cause the organic matter to decay at a faster rate relative to the more temperate highlands, and hence require additional compost and manure inputs making the T_h' curve steeper. The T_h' curve becomes flatter the cheaper chemical fertilizers are due to the substitution of fertilizers for labor intensive manure production.

Animal drawn plows become the dominant technology at the point where the costs of hand cultivation exceed the costs of transition to animal power. This switch point is shown in the figure. Before this point is reached the overall cost of production is simply lower the hand hoe and cultivators consistently reject the plow. This discussion illustrates the following conclusions:

a. The transition to animal-drawn plows would not be cost effective in forest and bush fallow systems due to the very high overhead labor required for destumping and animal maintenance.

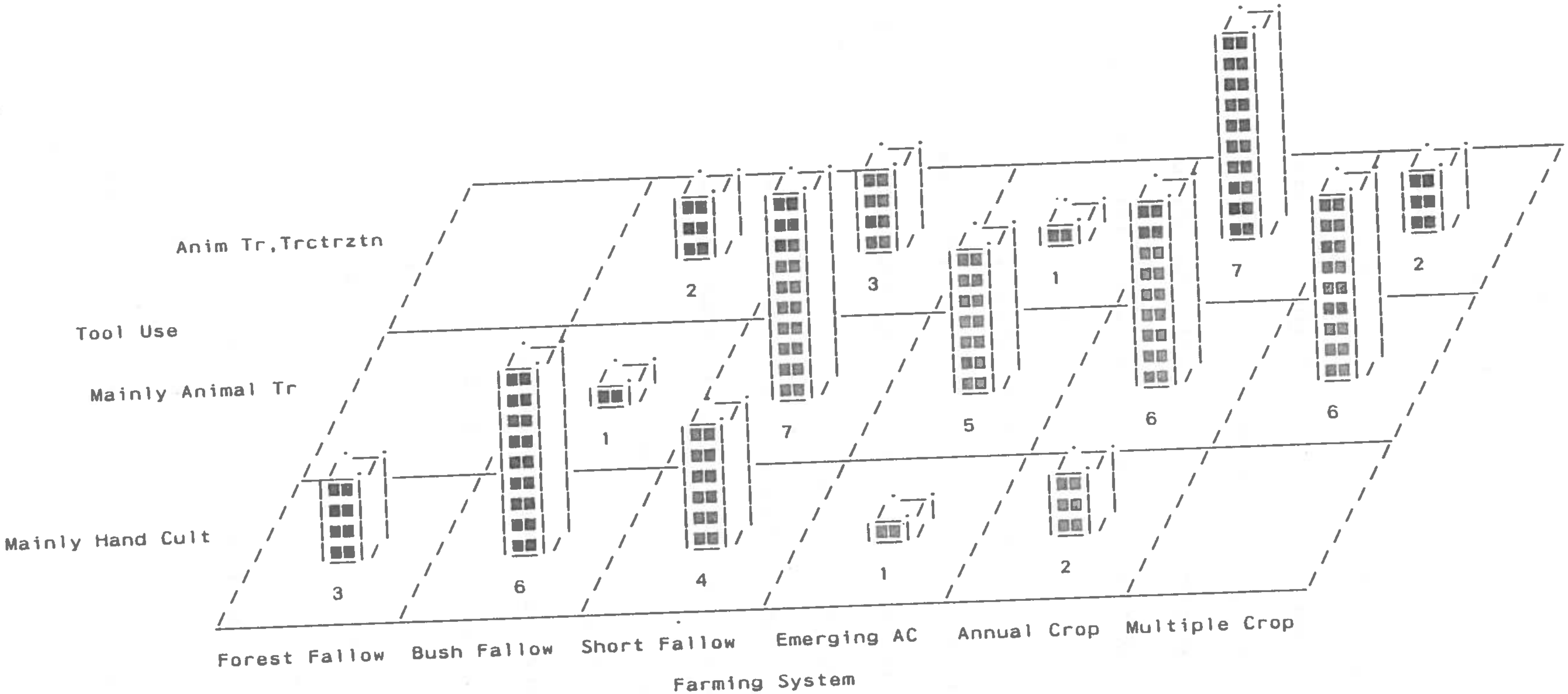
b. There is a distinct point in the evolution of agricultural systems where animal draft power becomes the economically dominant mode of land preparation.

c. This dominance point is conditional on soil types and soil fertility: the transition would occur sooner for hard to work soils (clays) and for soils which require high labor input for maintaining soil fertility.

Tractor drawn plows have not successfully been introduced into any systems prior to the grass fallow stage. Indeed, as we show in Pingali, Bigot and Binswanger, it is almost impossible to bypass the animal traction stage and move directly to tractors. This is because the quality and hence the cost of destumping is much higher for tractor operations than for animal drawn plows. Moreover, the societies concerned are usually characterized by extreme capital scarcity and cannot usually afford the substantially higher capital costs associated with tractors.

Once the stage of animal cultivation has been reached, however, tractors and animals become almost perfect substitutes for plowing. The choice of techniques analysis now finally becomes relevant. The factors involved are the relative costs of land, labor and capital, the seasonality of agricultural production and the cost of tractors.

Using the data set from Sub-Saharan Africa we provide a frequency chart of tool use with the evolution in farming systems in Graph 4. As discussed above hand cultivation is predominant in the forest and bush fallow systems, none of the forest fallow cases use any other form of tillage, while six of the nine bush fallow cases use hand tools. The majority of cases under short fallow use animal draft power (7 out of 14 cases), three locations use a combination of animal and tractor power, while the remaining four continue to use hand hoes. The dominance of mechanical tillage (both animal draft and 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 or a combination of animal draft and tractors for tillage. The exceptions where hand tillage persists are the hill slopes of Sukumaland, Graph 4: Evolution of Farming Systems and Tools Used



agricultural areas surrounding Kano city and Yatenga region of Burkina Faso. In the first two cases the light sandy soils are easy to work by hand and the last case, Yatenga, faces a severe plowing-sowing trade-off due to an extremely short growing season.

Development of Fertilizer Use

Under forest and bush fallow cultivation long-term soil fertility is maintained by periodic fallowing of land. Renewed vegetative growth on fallowed land helps to return fresh organic matter to the top soil and therefore re-charges it with nutrient supplies. Also, when fire is used for clearing vegetation prior to cultivation the burnt ashes return to the top soil the nutrients taken up by tree and bush cover. This closed cycle of nutrient supply is disrupted when long fallow periods are replaced by grass fallows.

The nutrient supply to the soil under grass fallow declines since grass cover cannot return the same amount of nutrients to the soil as tree and bush cover. Accordingly, at this stage the farmer starts complimenting fallow periods with additional organic waste and dung from cattle and livestock. At first these fertilization techniques are fairly rudimentary, often involving no more than a periodic transport of household refuse to the cultivated plots.

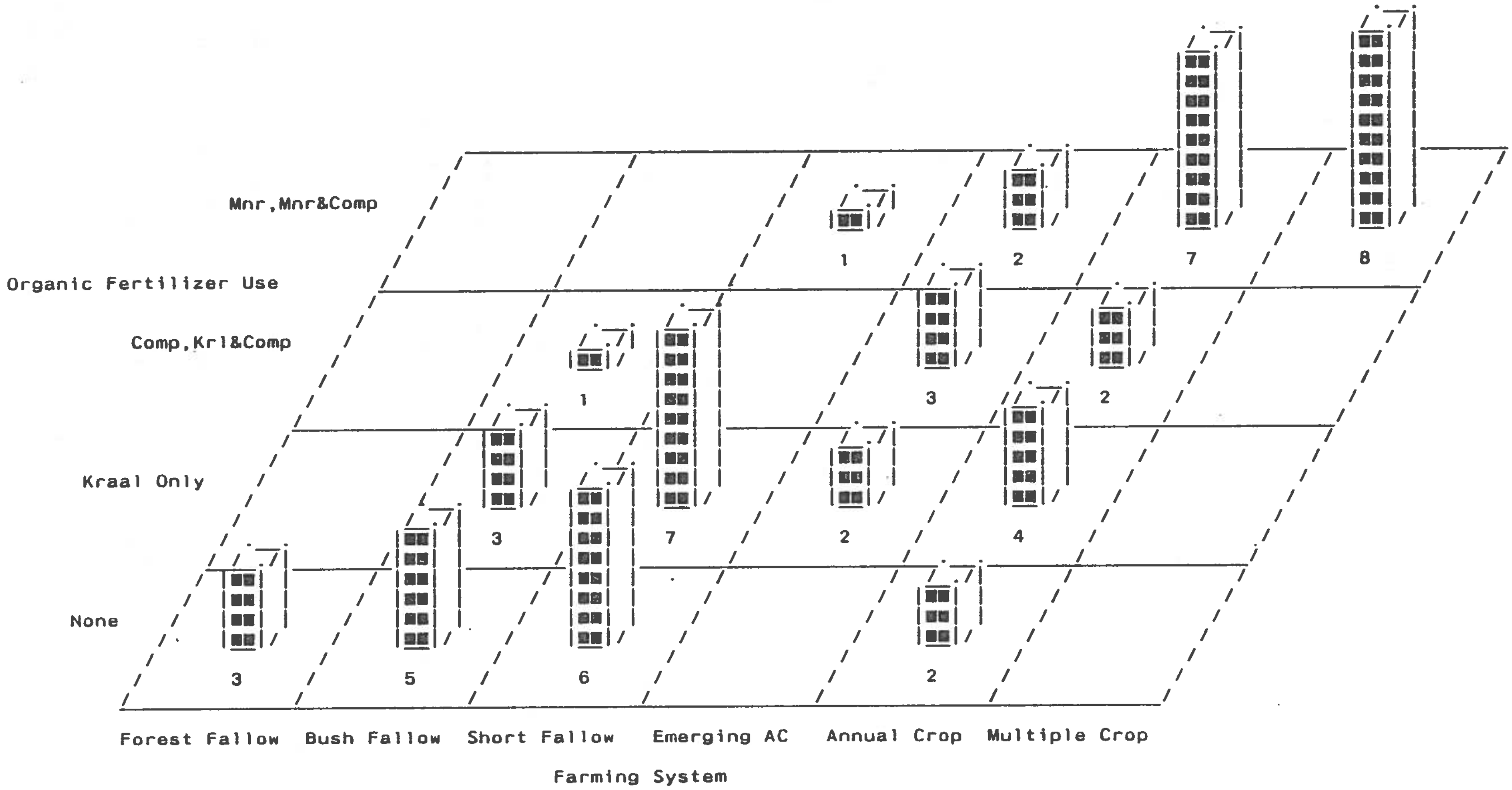
As farming intensities increase more labor intensive fertilizing techniques such as composting and then manuring evolve. The use of animal manure is common in most of the densely settled, intensively cultivated pockets of Sub-Saharan Africa. The inhabitants of Ukara Island in Lake Victoria, for instance, laboriously collect three tons of manure per year from each adult cattle and transport it by head load to the fields.

The final stage in the evolution of organic fertilizer use is the incorporation of legumes in a crop rotation cycle as green manuring. Green manuring along with other fertility restoring measuring is a common practise in several parts of India and China. The use of cowpeas in the rotation cycle is becoming increasingly common among the permanently cultivated areas of Africa.

At the multi-cropping stage one tends to observe increased use of chemical fertilizers as a substitute for the labor intensive manuring techniques. Such general use of chemical fertilizers is still very rare in Sub-Saharan Africa, although the use of fertilizers for select crops, such as cotton and groundnuts, which are produced for the market is becoming common.

Graph 5 shows the evolution in organic fertilizer use with an intensification of the farming system. Under the forest fallow system we observe no organic fertilizer use and under bush fallow there is a move towards the use of kraal dust and one case of compost use, although the majority of cases still do not use any organic fertilizer. By the grass fallow stage, however, there is a marked switch with the majority of cases (8 out of 14) using kraal dust or other more intensive techniques. Most of the cases under annual and multi-cropping use some form of organic soil fertility restoring techniques, with the majority using animal manure. The two exceptions are from Arusha region of Tanzania where the very fertile volcanic soils do not yet require fertility restoration.

Graph 5: <u>The Development of Organic Fertilizer Use</u>



The patterns of chemical fertilizer use are presented in Graph 6. The categories of chemical fertilizer use are: no use; use on select crops; and general use for all crops. The general use of chemical fertilizers is still not common, only 7 of the 56 cases report such use, of these five are under permanent cultivation systems. The use of chemical fertilizers for marketed crops is more generally prevalent, 34 of the 56 cases reported such use. It is interesting to note that there is no general relationship between farming intensity and chemical fertilizer use for select crops. This is perhaps because even under low intensities of farming some market crops are grown on small permanent plots of land. The cases of no chemical fertilizer use follow farming intensities more closely, 10 of the 13 cases of no fertilizer use practise forest, bush or short fallow cultivation. Of the three annual cultivation cases not using chemical fertilizers, two are from the volcanic soil locations of Arusha region, Tanzania and one is an exclusively subsistence crop production case in South Nyanza, Kenya.

Graph 7 highlights the complimentarity between organic and chemical fertilizer use. The striking feature here is the selective use of chemical fertilizers occuring in association with the general use of organic fertilizers. We have no cases of general chemical fertilizer use in the absence of organic fertilizers, although we have two cases of exclusive organic fertilizer use.

Changes in Land Rights

It is well known that the most prevalent organization of land rights under low population density is "communal property" where members of particular lineage groups have general cultivation rights,[1] i.e., they are

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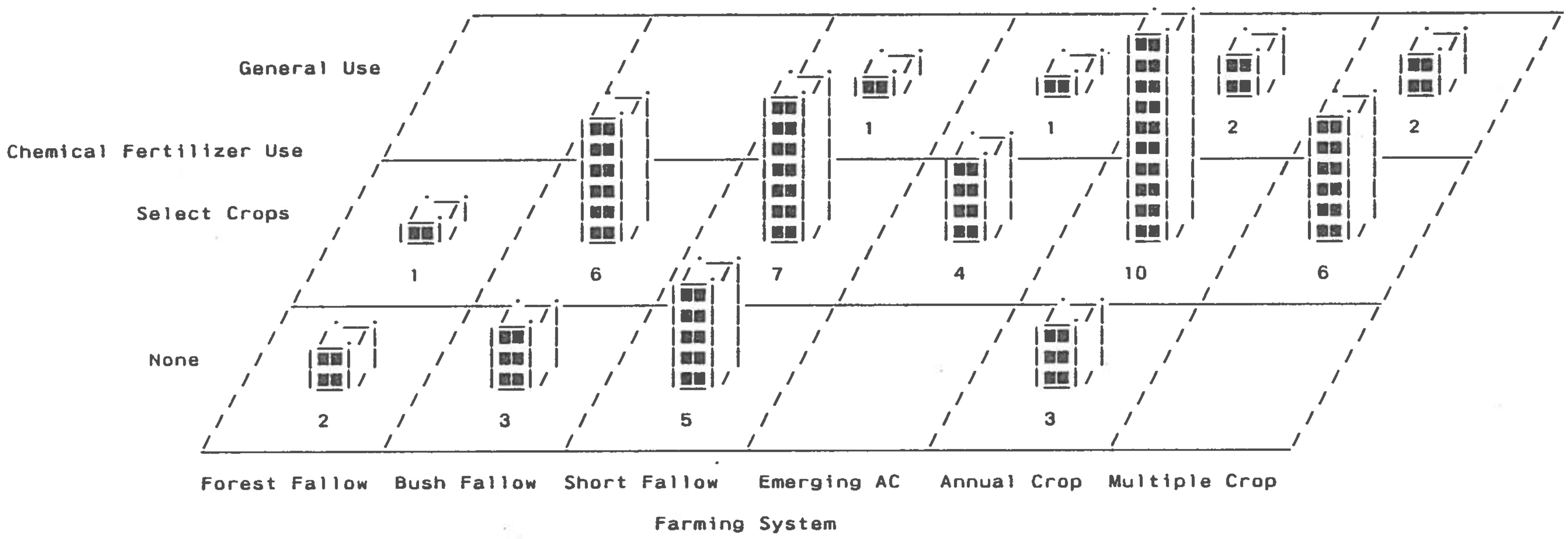
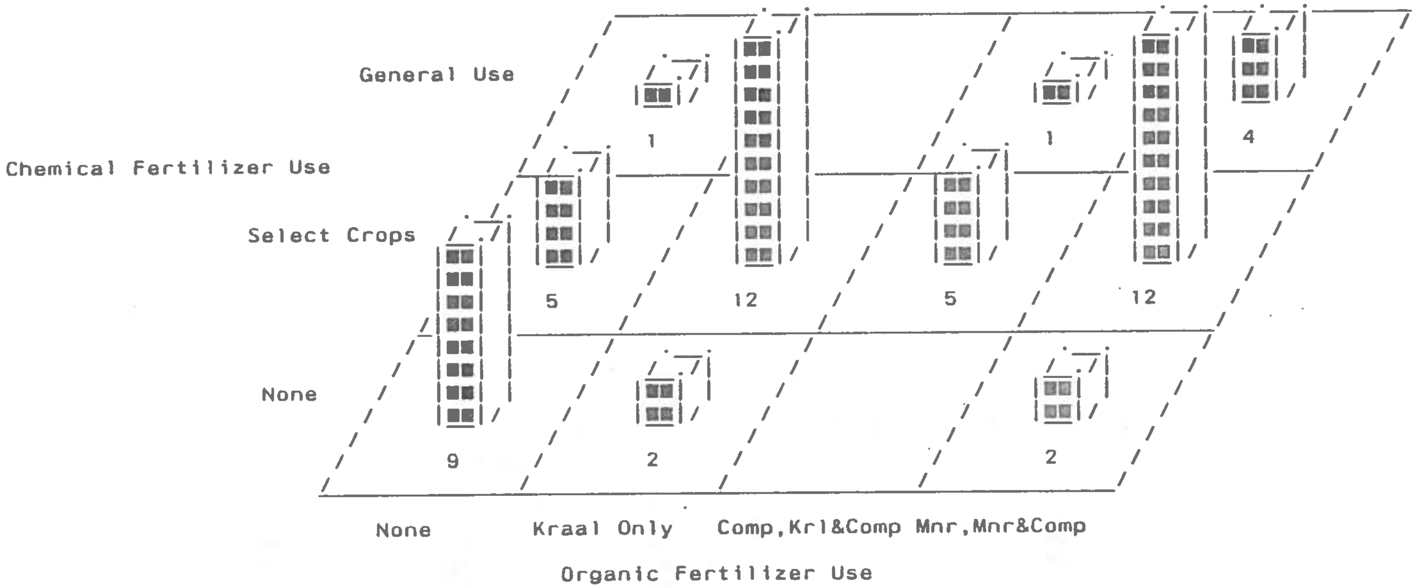
[1] Our discussion borrows heavily from Boserup, 1965, which is certainly the best brief discussion of the evolution of land rights we are aware of.

Graph 6: Farming Intensities and Chemical Fertilizer Use



Graph 7: Complimentarity Between Organic and Chemical Fertilizer Use



assured the right to cultivate a plot, but when they abandon it again to fallow, the cultivation right to that plot reverts to the lineage. On the other hand, intensive high population density areas typically have "private property" rights, i.e., cultivators have a large array of _rights to specific plots_. The distinction between communal and private property, however, is a rather harmful oversimplification, as it focuses on a simplistic legal codification of land rights rather than on the process "induced institutional innovation" by which societies move from general land rights to specific land rights by the gradual addition of one specific right after another. While there are enormous variations in how this process proceeds and while political powers have often interferred with it or speeded it up, the general tendencies are as follows:

With general land rights, cultivators typically own only the right to cultivate in a particular region. A lineage head assigns the right to use a specific plot to cultivators who retain this right as long as they actually cultivate the plot; when the current cultivator departs - usually to leave the plot fallow - the use right to the plot reverts to the lineage. In very land abundant environments outsiders are often welcome and general cultivation rights may thus be available to lineage groups which are very broadly defined to include almost everyone. When population densities increase the groups or lineages become more narrowly defined and more people are regarded as outsiders who are excluded from the general cultivation right.

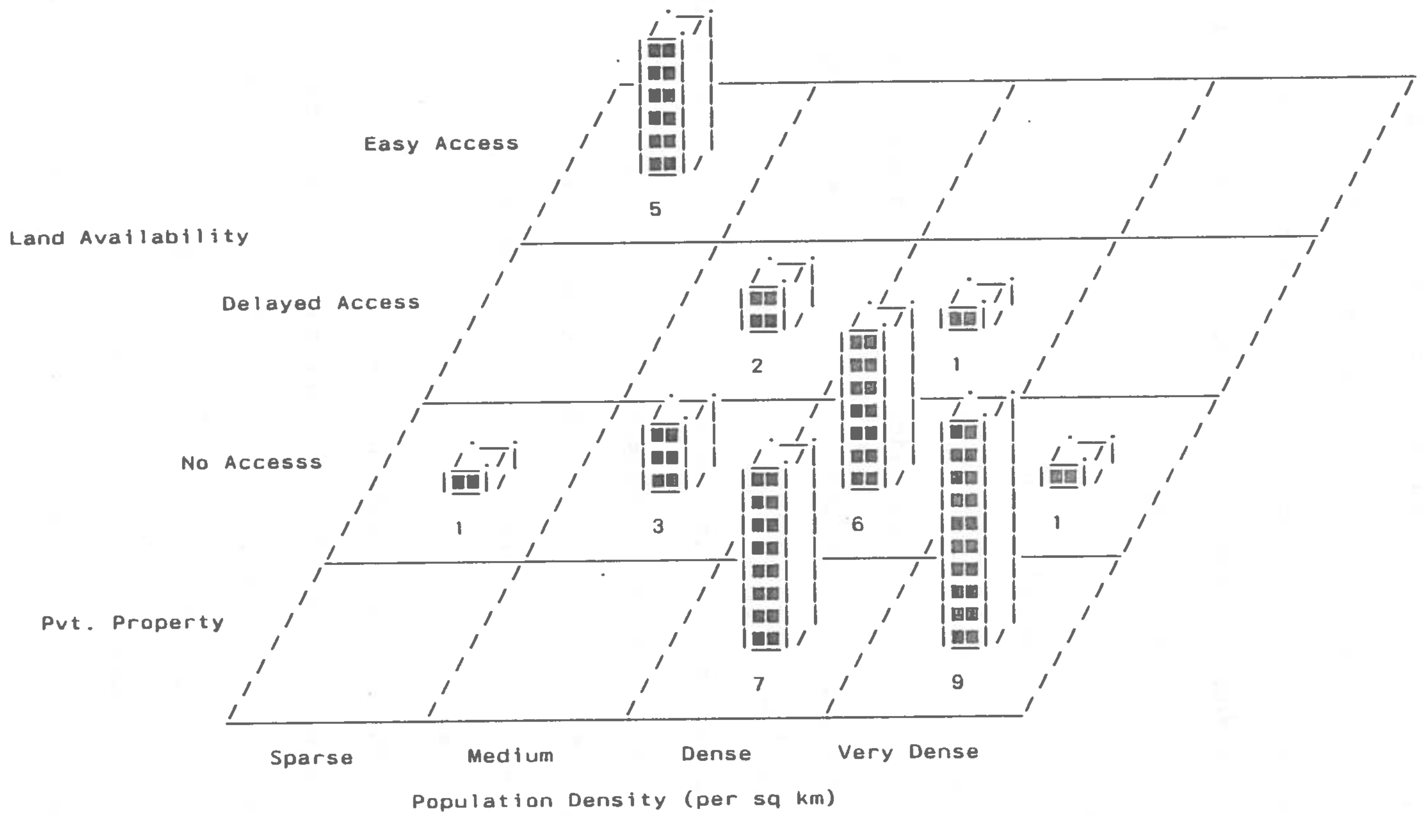
With the development of specific land rights the cultivator can begin to assert certain rights in specific plots, starting with the right to resume cultivation of the specific plot after a period of fallow. At a later stage he asserts, and will receive, the right to assign the plot to an heir or temporarily to another member of the same lineage; the use right in the plot does not revert to the lineage head anymore. Such changes often occur at different times in different regions or subregions of a country. Often systems are still described as "communal property rights system" when all land already is passed from generation to generation within individual families. With increasing population density, the rights assignable by the individual cultivator become more extensive and may include the right to rent out the land to other lineage members, or even to outsiders. Rights to graze cattle on fallow plots or stubble shift from all members of the community to the individual. Eventually individuals acquire the right to sell land to other lineage members and even to outsiders.

This transition to specific land rights improves incentives to undertake investments into specific plots, investments which are required for the intensification of production and preservation of fertility.

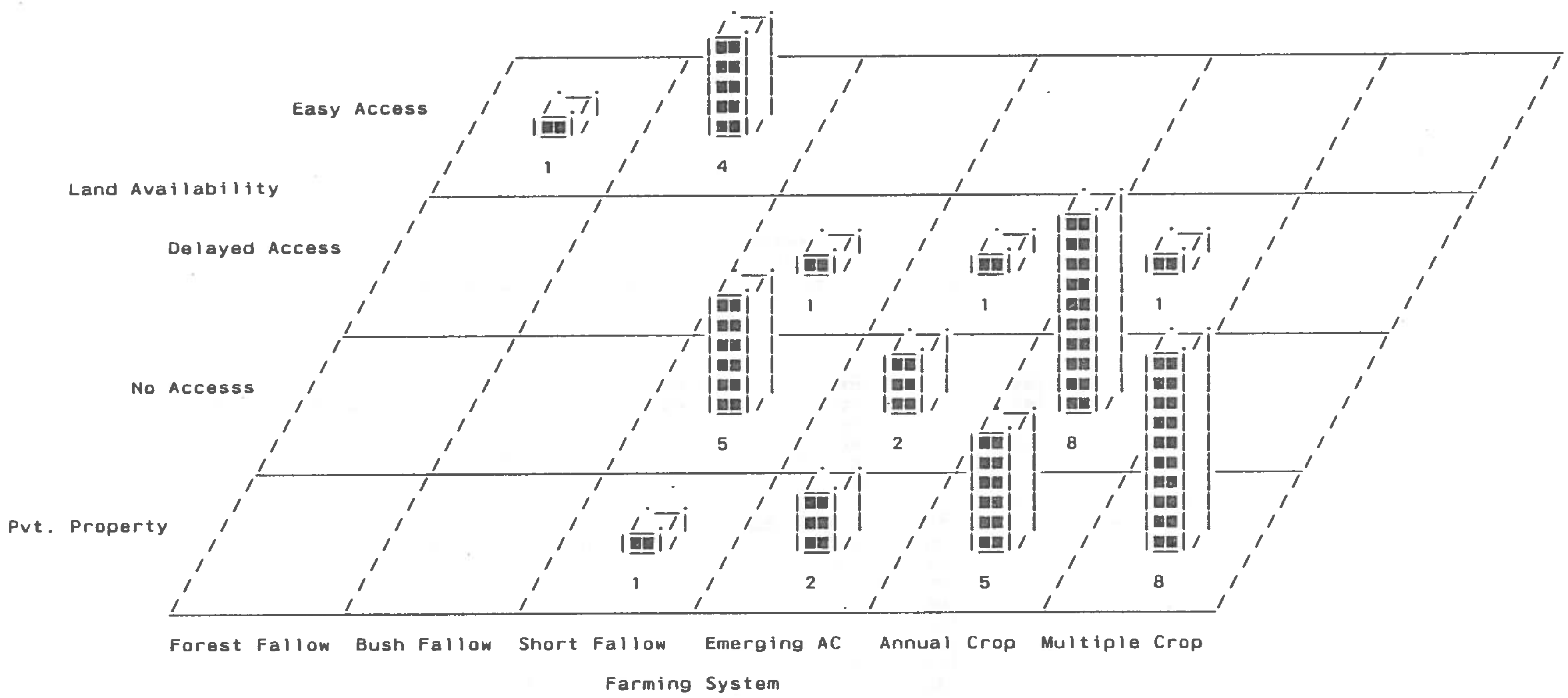
Population growth is not the only process which moves societies towards more specific land rights. Any of the other factors which cause intensification have the same effect. We therefore often see large variations in the number of specific rights allocated to individuals within different parts of the same country, depending on the degree of land fertility and market access.

During our field visits in Sub-Saharan Africa, we asked a series of questions that allowed us to determine if and how outsiders could acquire land in a particular society. For this paper we categorized land acquisition as follows: (1) easy access to land, where outsiders could obtain land merely by asking; (2) delayed access to land, where outsiders would have to work for a year or more as farm labor before acquiring the privilege to cultivate their own plots; (3) no access to land, where outsiders cannot acquire any land in the village but there are as yet no direct sales of land; (4) private property, where direct sales of land are possible and prevalent. The relationship between access to land and population density is presented in Graph 8. As expected it is relatively easy to acquire land in areas with sparse populations than in areas with very dense populations. Among the very densely populated locations direct sales of land is prevalent in nine of the ten cases, the remaining case has no access to land at all. Of the 14 cases under dense population, one observes the transition to codified private property: six locations have no access to land and seven have switched to private ownership of land. Moving to medium population locations, we find an absence of private ownership and a transition from delayed access to no access to land. It is only in the sparsely populated locations that we find easy access to land to be generally true. The relationship between access to land and the evolution of farming systems is presented in Graph 9. Since both the intensification of farming systems and the access to land are related to population density, the results match the ones in Graph 8. The movement from shifting to permanent cultivation is associated with a parallel movement towards privatization of agricultural land. Also, areas with better access to the market are more likely to deny outsiders access to land and move more rapidly towards codified private property. These results are presented in Graph 10. Of the 29 cases with good or excellent access to markets 14 reported direct sales of land, 12 reported no access to land for outsiders and two reported delayed access to land for outsiders.

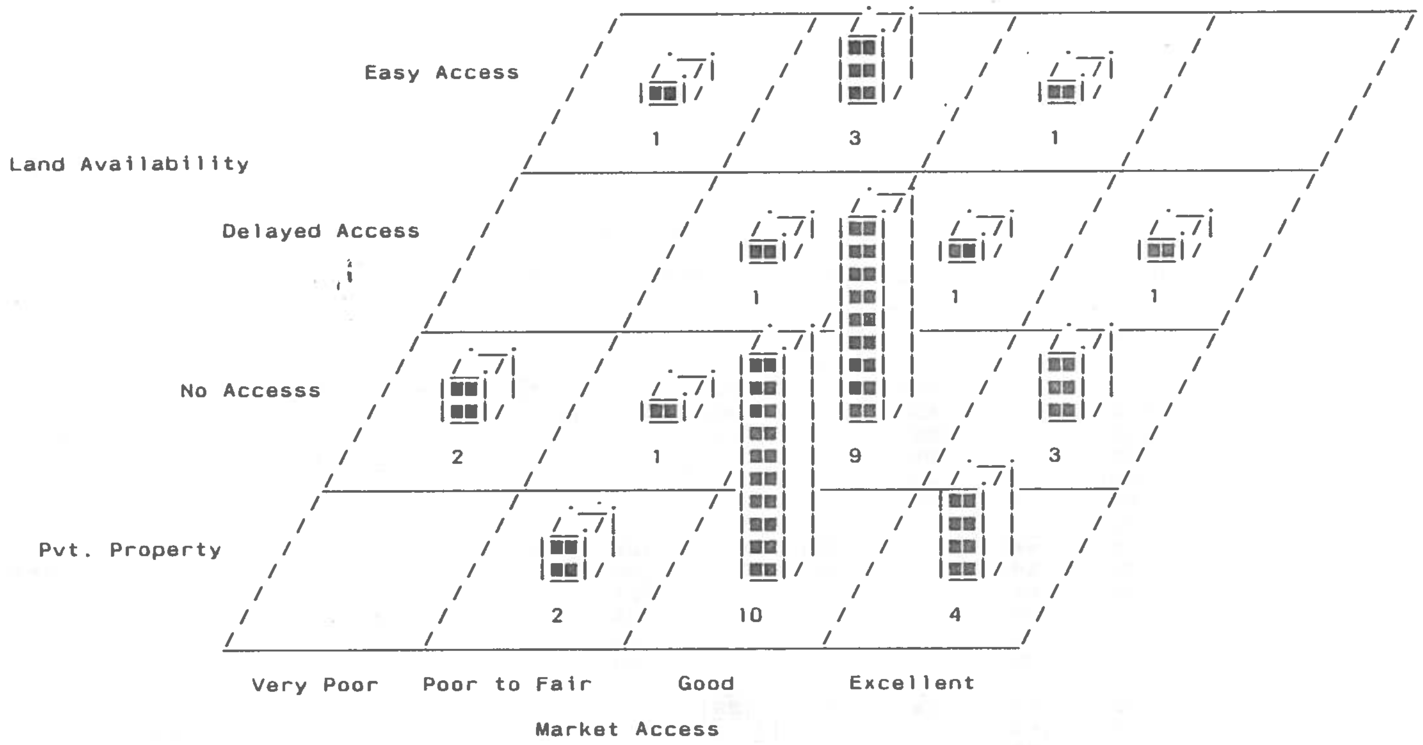
Graph 8: Population Density and Access to Land



Graph 9: <u>Farming Intensity and Access to Land</u>



Graph 10: Market Access and Access to Land



Conclusions

1. Far from being immobile and technologically stagnant "traditional" African societies have responded to changes in population densities and external markets with changes in farming systems, land-use patterns, technology and institutions along systematic and predictable patterns.

2. Using data collected through field visits to 56 locations spread across 10 countries in Sub-Saharan Africa and India, this paper provides additional empirical support to Boserup's thesis on the direct relationship between population growth and agricultural intensification. In addition to population growth we show that improvements in market access through better transport infrastructure have similar effects on intensification.

3. Intensification of agricultural systems is associated with a movement from easy to work soils to relatively hard to work soils which are more responsive to labor inputs, purchased inputs and to investments in land such as drainage, erosion control or irrigation. The responsiveness to intensification is higher on deep clayey soils which have higher water and nutrient holding capacity.

4. Intensification is generally associated with increased labor requirements per hectare of cultivated area. Increased labor is required not only for cultivation but also for land investments such as terracing and irrigation, for maintaining soil fertility through intensive manuring techniques, and where feasible for the maintenance of draft animals.

5. The switch from the hand hoe to animal drawn plows and later to tractors is closely associated with the evolution of farming systems. The switch to animal drawn plows occurs around the short fallow stage and not before because it is only at this stage that the overhead labor costs for

destumping and leveling fields and for training, feeding and maintaining animals are the lowest. At the stage of annual cultivation tractors and animals become almost perfect substitutes as it is here and not before that the choice of techniques analysis becomes relevant.

6. The substitution of fallowing first with simple and then with more evolved manuring techniques is likewise related to the evolution in farming systems. The general use of chemical fertilizers, although associated with intensification is not yet common in Sub-Saharan Africa. The select use of fertilizers for specific market oriented crops, however, is on the increase almost irrespective of farming intensity.

7. Finally, we show that the institutional arrangements for the acquisition of land by individuals within the group and by "outsiders" are not rigid but do change as increasing population densities or improved market access makes land scarce. Land acquisition which is extremely easy under shifting cultivation becomes more and more difficult as intensification leads to more narrowly defined groups or lineages and therefore results in the exclusion of large numbers of people from acquiring the rights to cultivate. The ultimate institutional change, and one which commonly occurs under high population densities is one of clearly defined private property rights with the ability to buy and sell land.

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