WORLD BANK REGIONAL AND SECTORAL STUDIES

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Introduction

This book is the result of a collaborative research effort between the World Bank and the International Livestock Centre for Africa (ILCA). It extends previous Bank-supported work on agricultural mechanization and the evolution of farming systems in Africa by seeking to answer a number of basic questions about the integration of crops and livestock in Sub-Saharan Africa. Those questions include the role of mixed farming in promoting agricultural growth, the appropriate points at which to encourage the use of animals as sources of farm power, the contribution of animals to improving the poor fertility of African soils, the efficacy of different methods to better livestock nutrition, and the economic returns to incorporating livestock production on small farms.

While many individual studies have analyzed such issues in the past, this book is the first comprehensive review of existing knowledge which offers general explanations of crop–livestock relations with respect to both economic and technical features of African agriculture. In doing so, experimental evidence is carefully synthesized and examined in light of field visits to thirty–three different sites throughout the major agroclimates of Sub–Saharan Africa. The detailed empirical nature of the book permits specific conclusions to be drawn for different farming systems, while its comparisons across those systems allow broad explanations of contrasting crop–livestock interactions.

The conclusions derived from this work will be important for the efforts of the Bank and associated institutions in meeting the major challenges of African agriculture. This includes not only the formulation of appropriate policies and development efforts in African agriculture, but the definition of agricultural research and extension priorities, areas in which the Bank maintains a strong interest. In the near future, the Bank will be working with ILCA and institutions like it at the national and international levels to implement the recommendations of this research.

Michel J. Petit
Director, Agriculture and Rural Development

1

Problems of Integrating Crops and Livestock in Sub-Saharan Africa

MANY HAVE ARGUED that crop and animal production are badly integrated in Sub-Saharan Africa. This lack of integration is contrasted to Asian or European farming systems, where the two activities have a long association. Failure to observe what are thought to be efficient interactions between crops and livestock has led development efforts to emphasize the significant benefits that closer integration could provide.

The benefits of crop-livestock interactions are several. Animal traction could improve the quality and timeliness of farming operations now done by hand, thus raising crop yields and incomes. Farm animals might furnish manure to improve soils. Livestock sales would generate cash to buy inputs. Keeping animals on the farm could also provide a use for other resources such as crop residue, which might be wasted in the absence of animals.

Crop-livestock relations are now highly variable across the subcontinent. Indeed, there are large expanses without significant interactions, including much of the forest zone where there is little animal production, and the arid pastoral zone, where raising livestock is practically the only activity. Elsewhere, interactions—defined as using crops in livestock production and vice versa—are common. Farmers throughout semi-arid Africa employ manure for crop production, save crop residue for feed, and use animals for cultivation and transport. In parts of the highlands, crop-livestock integration, defined as the merger of the two on one farm, is well established. The contrasting systems of crop-livestock relations suggest that the tenacious belief that the two are inefficiently integrated must sometimes be seriously wrong.

Two determinants of those varying relations are obvious: agroclimates and population density. Feed resources are an example of the effect of agroclimate. In arid, sparsely populated regions, feed is open pasture and browse, and there are few animal interactions with crops. In cooler, more densely populated regions, feeding consists of harvesting crop residue, growing forage crops, and cutting native grasses for feed. Soil fertility provides an example of the effect of population density. In zones with low population density, fallows are the principal means of maintaining fertility and give few opportunities for interactions. At higher population densities where there is no fallow, farmers produce manure to maintain soil fertility, thus requiring a close association of crops and animals.

While those determinants of interactions are evident, the apparently natural transition from separate, extensive crop and animal production to integrated, more intensive forms has been difficult to achieve via projects with crop–livestock components. An audit of 125 livestock and 'livestock–component' projects in Sub–Saharan Africa found that 71 percent of them had economic rates of return of less than 10 percent (World Bank 1985). A 1988 internal World Bank study by Hartwig Schafer showed many failures to adopt technologies proposed by such projects. The mixed record of projects with livestock components and crop–livestock components suggests that how to achieve greater interactions is not well understood.

In attempting to understand crop–livestock relations, three basic ideas are proposed.

First, contrasting crop–livestock interactions have been produced mainly by environmental differences, not by the availability of information or exogenous technologies. Where the two enterprises are separate, it is chiefly because some basic environmental conditions are not satisfied.

Second, crop and livestock production do, in fact, interact closely throughout much of Sub–Saharan Africa. In many areas closer integration has occurred as a process of factor and input substitution, induced largely by population growth. In rarer instances exogenous technical changes have promoted integration.

Third, whatever the type and degree of current interactions, many of the benefits of closer integration are small. Those benefits—in crop and animal productivity, and in improved soil fertility—are inherently limited by the low output response to such inputs as manure, crop residue, and animal power. Closer crop–livestock interactions therefore are unlikely to have a major impact on productivity unless they are associated with exogenous technical changes. Ignoring those ideas has been the main error of research and development projects, which have often promoted technologies and institutions inappropriate to target farming systems.

These arguments are expanded as follows:

- Key questions about crop–livestock interactions are posed in the section immediately following.
- Chapter 2 sketches the agricultural climates of the subcontinent as essential background for the reader.

- Chapter 3 sets out an evolutionary theory of crop–livestock interactions as a framework for analyzing resource competition and complementarity.
- In Chapters 4 through 7, four principal themes are analyzed in light of the main theory: animal traction, soil fertility maintenance, crop residue management, and animal production on the farm.
- Chapter 8 concludes with recommendations on policies, projects, and research programs.

Analytic Issues

Project and research design require answers to questions about the level and type of interactions as functions of agroclimate, population growth, and exogenous technical change. Those questions are organized around three topics: resource competition, mixed farming as a model, and the benefits of further integration.

Resource Competition

One argument is that resource competition between crop and animal production will inevitably reduce output in the absence of exogenous technical change. Short–term conflicts would occur over high quality land, such as when vegetable production impairs lowland grazing, or as irrigation investment displaces pasture. In the long–term, population growth would intensify competition of crops and livestock for both land and labor. Rising population would necessitate the expansion of cultivated area, replacing pasture and thereby reducing the grazing area for animals. As population growth aggravates land scarcity, it would lift labor requirements for the manure and fodder production necessary to substitute for disappearing fallow and pasture, thereby accentuating labor competition between crops and animals.

While the hypothesis of increasing competition between crops and livestock is accepted widely, it leaves unanswered numerous questions about the actual extent of such competition and its effects on the benefits of crop–livestock integration.

What is the extent of crop–livestock resource competition? How does it affect the benefits to be gained from interactions? Where is there a conflict between crops and animals for land—in which agroclimates, at which population densities, and for which land types? What have been farmer responses to such conflicts? Where there is a conflict for labor, how do farmers respond? How does labor competition affect the introduction of new techniques? How can projects help farmer responses to be more efficient?

Mixed Farming as a Model

A second argument concerns mixed farming as a model production system. Mixed farming is thought to be the natural, efficient outcome of changes in farming systems, and one which ought to be advanced in development projects. This argument is important for defining appropriate project sites and characteristics. If exogenous factors such as agroclimate determine integration, then projects have a narrower scope in which to promote efficient interactions.

Where does crop–livestock integration occur? Because integrating livestock on farms is often a major project component, it is important to understand where it occurs. Where is mixed farming seen in Sub-Saharan Africa? What forms does it take? Are there common trends in its evolution? Are there efficient methods to promote it?

How do specialized crop or animal production enterprises develop? Projects often promote specialized techniques, requiring more modern input use and greater skills than traditional techniques. The question of how specialization develops is essential for project evaluation. Do mixed farms develop to break up later into specialized enterprises? Will crop–livestock integration be replaced by specialized crop and animal production in Africa, as it has in much of Europe and the United States?

In which conditions do farmers adopt more labor–intensive techniques for crop and animal production? Three techniques—crop residue management, forage crop production, and manure production—are promoted both to capture the benefits of crop–livestock interactions and to intensify resource use under rising population pressure. Yet they use more labor per unit of output than do traditional techniques. Hence, it is essential to define the conditions in which more labor–intensive techniques have been adopted if benefits from using those inputs are to be had.

What is the role of modern inputs in crop–livestock interactions? Modern inputs—improved seeds, machines, fertilizer, sown forages, and concentrate feeds—are key elements in raising productivity, yet little is known about their relations to crop–livestock interactions. The case of fertilizer is particularly meaningful, if, for example, policies determining the price of chemical fertilizer affect incentives to own livestock in order to gain manure. Where chemical fertilizer, forage crops, and processed feeds are available, what are their effects on crop–livestock interactions? What are the effects of policies on input use and indirectly on interactions?

Should animal traction be a central theme in promoting crop–livestock integration? Many projects assume that animal traction is a central extension theme necessary to improve both crop and livestock production. This study tests that assumption by identifying barriers to the use of animal traction and by reviewing the relations among animal traction and such inputs as manure, crop residue, and forage crops.

Benefits of Further Integration

A third argument is that there is important unexploited complementarity between crops and animals. Complementarity is defined as one sector's supply of inputs to the other, such as using draft power and manure in crop production, or crop residue as feed. It has been argued repeatedly (for example, Norman, Newman, and Ouedraogo 1981) that failure to integrate wastes cheap inputs. Many rural development projects accept the argument that complementary inputs are allocated inefficiently, and insist on it in their extension work.

Are feasible interactions efficiently used? In some zones, certain interactions are not feasible, for example, using animal traction where livestock disease is prohibitive. Where interactions are feasible, it is still urgent to ask how they are employed. One key hypothesis is that some technically efficient activities—such as using manure in crop production—are not used because they are unprofitable.

What is the role of manuring in the farming system? It has long been argued that manuring is a basis of a stable, productive farming system. Although experiments have verified the benefits of manure to soil fertility, manuring has been notably difficult to extend. This study asks: What is the contribution of animals to soil fertility maintenance? What are the short-term yield effects of manure? Are they different from those of chemical fertilizer? What soil fertility practices are profitable? Can manuring maintain long-term soil fertility? Do resource conflicts on the farm prevent intensive soil fertility maintenance practices?

What is an appropriate sequence of feed development? Nutrition is recognized as the principal constraint to livestock production in Sub-Saharan Africa. In response, there have been many efforts to introduce new feeds, particularly specialized forage, on mixed farms. This study asks: What is the current pattern of feed production and use? Where have introduced feeds succeeded? Where should the emphasis be on forage crops? What is the appropriate locus for improvements in feed with respect to environment, species, and enterprise scale?

What is the role of crop residue in integrating animals on the farm? Crop residue provides a large share of feed in the subcontinent. At the same time, it can provide valuable organic matter to the soil. Many development projects promote both uses of the materials. For example, intensive residue management—cutting, storing, selective feeding—is often recommended to raise livestock productivity. Restoring crop residue to the soil, however, conflicts with using it for feed. The economic returns to different forms of crop residue management are a key issue in evaluating mixed farming.

What is an appropriate sequence of animal production development on farms? One project hypothesis is that animal production on farms allows a better use of underexploited resources such as crop residue, natural roughage, and dry season labor. A common project component is to fatten animals on the farm. Despite the apparent utility of the technique, many efforts have failed. This study asks: What is the scope for on–farm animal production using such apparently underexploited resources? What explains successes and failures in on–farm animal production initiatives?

Methodology

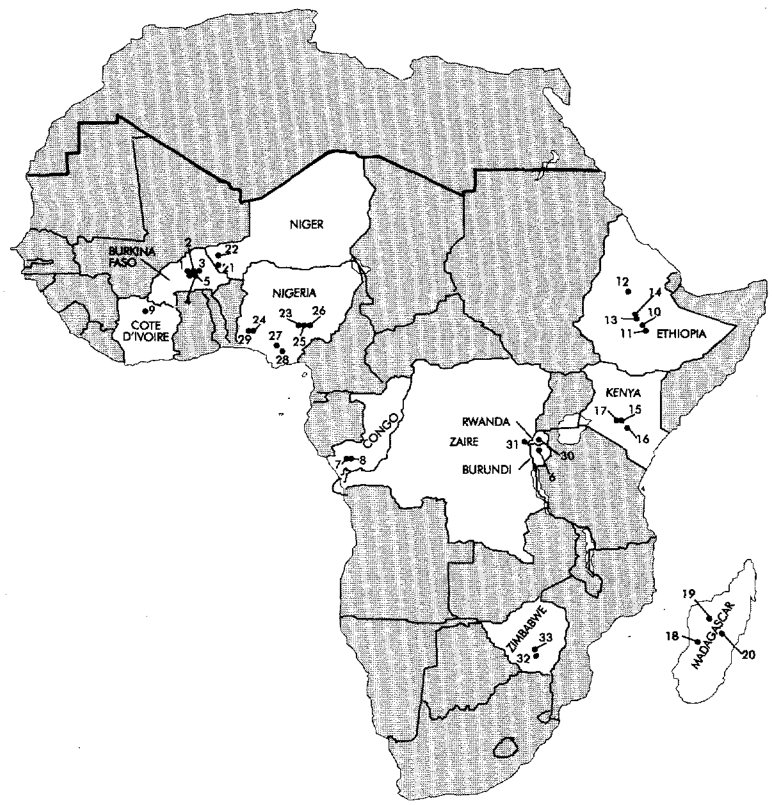
A rich literature exists in the work of ethnographers observing the interactions of herding and cultivating societies. This material was reviewed and used to describe historical and contemporary interactions. There is also a mine of related agricultural research, especially on soil fertility, forage production, and animal nutrition. This material was employed in cost–benefit analyses and in simple models of interactions.

During review of the literature, it became apparent that direct field observations were necessary to study current interactions. Field missions to assess crop–livestock interactions were made to thirty–three locations of Sub–Saharan Africa with different agroclimates, population densities, and market access (Table 1–1 and Figure 1–1). Group interviews were held with farmers and herders to elicit information on crops, livestock, soil fertility and crop residue management, forage production, mechanization, land tenure, and specific crop–livestock interactions. Given the rapidity of those visits, it was impossible to obtain information on labor use, crop yields, and other elements of cost–benefit analysis. Such information was obtained from primary surveys in Burkina Faso, Niger, Mali, Nigeria, and Ethiopia provided by the International Livestock Centre for Africa (ILCA) and the International Crops Research Institute for the Semi–Arid Tropics (ICRISAT), and from previously published research.

Definitions

Three key terms are used throughout this book. **Agroclimate** refers to the complex of factors that constitute the agricultural resource base and determine the potential productivity of farming: mainly the length of the growing season as determined by the amount and variability of rainfall, altitude, temperature, and soil characteristics. These factors determine the nature and productivity of agriculture: which crop and livestock commodities can be produced, their productivity and input requirements, and the incidence of insect pests and diseases.

The distinction between **extensive** and **intensive** agriculture refers to the amount and type of productive factors used in a given agroclimate. Pingali, Bigot, and Binswanger (1987, p. 26), following the definitions of Boserup (1965) and Ruthenberg (1983) summarized "agricultural



Note: The numbers refer to the list of locations visited given in table 1-1.

Figure 1–1. Locations Visited by Authors

Table 1–1. Field Site Characteristics

Environment and country	*Site*	*Annual rainfall (millimeters)*	*Population density (persons per square kilometer)*	*Farming system* [a]
Subhumid				
Côte d'Ivoire	Korhogo	1,300	45	Bush fallow
Nigeria	Abet	1,500	25	Bush fallow
Nigeria	Fashola	1,250	50	Bush fallow
Nigeria	Ganawuri	1,700	70	Grass fallow
Nigeria	Kufana	1,700	50	Bush fallow
Nigeria	Shaki	1,250	50	Bush fallow
Humid				
Congo	Koulila	1,550	5	Forest fallow
Congo	Les Saras	1,600	5	Forest fallow
Nigeria	Onitsha	2,000	200	Bush fallow, multistory
Nigeria	Owerri	2,200	300	Bush fallow, multistory
Semi–arid				
Burkina Faso	Bama	1,000	80	Grass, bush fallow
Burkina Faso	Bidi	500	60	Grass, bush fallow
Burkina Faso	Sabouna	500	60	Grass, bush fallow
Burkina Faso	Tondogosso	800	20	Bush fallow
Burkina Faso	Ziga	500	70	Grass, bush fallow
Kenya	Machakos	650	100	Grass fallow
Madagascar	Kianjasoa	1,500	10	Mixed
Niger	Boboye	450	50	Bush, grass fallow
Niger	Zarmaganda	300	15	Bush, grass fallow
Zimbabwe	Masvingo	650	50	Grass fallow
Zimbabwe	Mvuma	650	60	Grass fallow
Highland				
Burundi	Ngozi	1,250	350	Multiple cropping
Ethiopia	Debre Berhan	1,150	85	Grass fallow, annual

Environment and country	*Site*	*Annual rainfall (millimeters)*	*Population density (persons per square kilometer)*	*Farming system* [a]
Ethiopia	Debre Zeit	850	90	Grass fallow, annual
Ethiopia	Inewari	900	200	Multiple cropping
Ethiopia	Fogera	1,200	115	Grass fallow, annual
Ethiopia	Were Ilu	1,000	250	Grass fallow, annual
Kenya	Muranga	1,000	320	Multiple cropping
Kenya	Kiambu	600	390	Multiple cropping
Madagascar	Antsirabe	1,500	100	Multiple cropping
Madagascar	Manjankandriany	1,500	150	Multiple cropping
Rwanda	Bugasera	900	200	Multiple cropping
Zaire	Bukavu	1,100	150	Multiple cropping

a. Forest fallow is defined as one or two crops in fifteen to twenty years, bush fallow is roughly two crops in ten years, grass fallow is one or two crops in three or four years, annual cropping is one crop every year, multiple cropping is more than one crop each year, and mixed indicates the presence of several fallow types at a single site. Multistory cropping is the growth of useful crops and shrubs of varying heights on the same plot of land.

Source: Field visits by authors.

intensification [as] . . . an increase in the frequency with which plots of land are cultivated." Under extensive agriculture, more land and less labor are generally used per unit of output because the land lies fallow much of the time. When land is cultivated in extensive systems, it requires less rigorous methods, notably for preparation and weeding. As farming communities respond to land pressure and new market opportunities, agriculture becomes more intensive. More labor is used on less land, and typically more purchased inputs are used per unit of output because fallows become shorter. When land is cultivated under more intensive systems, its use imposes more demanding methods of preparation and weeding. Chapters 3 through 7 give many specific examples of the distinctions between extensive and intensive production methods.

2

Agricultural Environments in Sub–Saharan Africa

LAND USE is based on its comparative advantage in crop and animal production. Comparative advantage is influenced by what is loosely termed the 'agricultural environments' of Sub–Saharan Africa, as defined by agroclimate and population density. Soils, land form, market access, and incomes create diversity within and between environments, but the principal differences in agricultural systems are due first to agroclimate, and second, to population density within agroclimates.

Sub–Saharan Africa is normally divided into four major agroclimates. Although two classification systems are common (Table 2–1), the authors use that devised by Jahnke (1982, pp. 17 and 233) throughout this book.[1] The agroclimatic zones are distinguished by the amount and distribution of rainfall, and by altitude, principally as it affects temperature (Tables 2–2, 2–3, and 2–4). In the absence of irrigation, these parameters are the main determinants of the zonal balance among crops, livestock, and forestry. Agroclimate affects the types of crops which can be grown successfully and their agronomic characteristics, such as productivity, cycle length, ease of mechanization, and susceptibility to insect pests, diseases, and weeds. Agroclimate also influences livestock production in terms of species, breed, stocking capacity, susceptibility to diseases, and individual productivity.

The potential for livestock production is defined in terms of the carrying capacity, measured in tropical livestock units (TLU) per square kilometer.[2]

1. In contrast to Jahnke (1982, pp. 17 and 233), *The Atlas of African Agriculture* (FAO 1986, p. 49) describes six zones, five of which are included in Table 2–1. The FAO desert zone is not included. In this book, the humid and semi–arid are roughly the same as in the FAO *Atlas*, and the arid and desert are ignored. The authors' subhumid covers FAO's moist subhumid and dry subhumid, with the major exception that the FAO moist subhumid includes what is here called the highlands.

2. One tropical livestock unit (TLU) is defined as an animal of 250 kilograms liveweight.

Table 2–1. Two Agroclimatic Classifications of Sub–Saharan Africa

Source and zone	Area (thousands of square kilometers)	Growing period (days)	Rainfall range (millimeters)
Jahnke [a]			
Arid	7,673	0–90	<500
Semi–arid	3,915	90–180	500–1,000
Subhumid	4,834	180–270	1,000–1,500
Humid	4,137	270–365	>1,500
Highlands	934	Usually >180	1,000–2,000
Total	21,493 [b]		
FAO			
Arid	4,880	1–74	100–400
Semi–arid	2,330	75–119	400–600
Dry subhumid	3,140	120–179	600-1,200
Moist subhumid	5,840	180–270	1,200–1,500
Humid	4,090	>270	>1,500
Total	20,280 [b]		

a. Jahnke's data excludes Namibia, Djibouti, and Equatorial Guinea.

b. Totals are not equal because some of the desert area in FAO (8,220,000 square kilometers) is classified as arid by Jahnke.

Source: Jahnke 1982, pp. 17 and 233; FAO 1986, p. 49

In the driest semi–arid tropics with annual rainfall of 200 to 600 millimeters, the sustainable number of TLU is between 7 and 20. The highest carrying capacities are found in river basins, where they range from 150 to 350 TLU per square kilometer (Jahnke 1982).

Jahnke defined livestock production systems as range–livestock and crop–livestock (1982, p. 53). The former have low stocking rates and no associated cropping activity, and are further divided into pastoral and ranching subclasses. The pastoral is the main subclass; ranching is very rare, and exists in areas too arid for reliable crop production. Crop–livestock systems are closely linked to cropping activities, have higher stocking rates, are typical in wetter areas within the semi–arid tropics, and are more common than range–livestock systems.

Humid Zone

The humid zone stretches along the coast of West and central Africa and in the central Congo Basin. Moisture is rarely a constraint to crop production. Rainfall can vary from 1,500 millimeters to as much as 4,000 millimeters annually, and the growing season ranges from 7 to 12 months.

There are huge differences in population density within the humid zone. In parts of the Congo, Gabon, and Zaire, density is less than 10 persons per square kilometer, while it can exceed 500 in eastern Nigeria. In the sparsely settled subregions, urbanization and output demand are limited. In more densely settled regions, urbanization, commerce, and economic development are vibrant. An FAO study found that only 10 percent of the cultivable land in the humid countries of central Africa was under crops (FAO 1986, p. 53)

While farmers are largely smallholders, farming systems differ from those of drier zones. A wide variety of crops is grown, including tree crops not found in drier zones.[3] Complex mixes of food crops, tree crops, and natural vegetation are grown on the same plot of land. Farm sizes are typically very small because of high land productivity. Lagemann (1977, p. 59, for a densely populated part of eastern Nigeria) found crop yields to vary from 0.95 to 4.75 tons per hectare, with lower yields at higher population density. Mechanization is rare because of the fragility of humid tropical soils, the dominance of root crops, and the possibility of subsisting from the products of small cropped areas (Lagemann 1977). Farmers maintain soil fertility by shifting cultivation where population density is low, or where population density is high, by using non-crop vegetation and crop residue as mulch.

Trypanosomiasis and other diseases restrict livestock production, but where animal production is possible, it usually consists of dwarf trypanotolerant small stock. Cattle are only common where trypanotolerant breeds have been introduced in ranches (Shaw and Hoste 1987a, 1987b) or in the more elevated parts of the eastern Congo Basin. All countries in this zone are large net importers of both meat and milk. Crop-livestock interactions are weak or even totally absent. Improvements in housing, breed, or management of livestock are very rare. Feed consists of natural vegetation, which tends to be abundant but of poor nutritive quality.

Subhumid Zone

The subhumid zone extends through the center of West Africa, through parts of East and southern Africa, and has a somewhat better agricultural environment than the semi-arid tropics. It receives annual rainfall from 1,000 to 1,500 millimeters during a growing period of 6 to 9 months. Lower

3. Miracle (1967) is right to insist on the extreme complexity of agriculture in the Congo Basin and to warn against oversimplification. The main point is simply that there is little or no cattle production in most of the humid environment.

Table 2–2. Some Characteristics of the Main Environments

	Agricultural environment [a]					
Characteristic	*Humid* [b]	*Subhumid* [c]	*Semi-arid* [d]	*Highland* [e]	*Mixed* [f]	*Total*
Number of countries [g]	7	6	13	4	6	36
Per capita 1987 GNP (U.S. dollars)	415	404	309	208	318	–
Population, 1988 (millions)	68	41	96	84	170	459
Total area (thousands of square kilometers)	3,852	1,609	10,258	1,859	4,562	22,140
Rural population, 1988 (millions)	42	26	73	72	118	331
Rural population density (people per square kilometer) [h]	13.3	23.0	14.6	71.1	34.3	24.1

– Not applicable.
a. Countries categorized by environment have more than 50 percent of their rural population in that environment.
b. Humid: Cameroon, Congo, Gabon, Ghana, Liberia, Sierra Leone, Zaire.
c. Subhumid: Benin, Guinea, Côte d'Ivoire, Malawi, Togo, Zambia.
d. Semi-arid: Botswana, Burkina Faso, Chad, Gambia, Guinea Bissau, Mali, Mauritania, Mozambique, Niger, Senegal, Somalia, Sudan, Zimbabwe.
e. Highland: Burundi, Ethiopia, Kenya, Rwanda.
f. Mixed: Angola, Central African Republic, Madagascar, Nigeria, Tanzania, Uganda.
g. GDP estimates exclude Angola and Guinea.
h. Weighted by 1987 agricultural area.
Source: Jahnke (1982) for area, FAO (1988), World Bank (1989), and ILCA (1990).

rainfall variability makes the growing season less risky. Population density tends to be sparser, however, because of poor soils in West Africa, and stronger disease pressure which historically made the zone less well populated (von Kaufmann and Blench n.d., for a detailed study of central Nigeria). Substantial reserves of cultivable land exist in subhumid East and West Africa (FAO 1986, p. 53).

The cropping pattern in the subhumid zone is more varied than that of the semi-arid tropics, with more maize, rice, yams, cassava, fruits, and vegetables in addition to pearl millet, sorghum, groundnut, and cowpea. Irrigation is even rarer than in the semi-arid tropics. Farms are smaller than in drier zones, usually because a smaller area of the more productive land is required for subsistence. Actual crop yields are slightly higher than in the semi-arid tropics, but are also more reliable and potentially much higher (FAO 1986 and Norman, Simmons, and Hays 1982, pp. 57–61). Farmers are again mainly smallholders, and agricultural mechanization from engines or animals, while rarer than in the semi-arid or in the highlands, appears to be growing rapidly (Blench 1988, for central Nigeria).

While higher rainfall in the subhumid zone should create higher primary production and hence greater potential livestock output, the relation between humidity and stock carrying capacity is not as direct as it is in the semi-arid tropics (Jahnke 1982, pp. 119–123). The vegetative cover differs in composition and productivity from that of the semi-arid, and is less favorable for livestock. Livestock are also less numerous in the subhumid zone because of trypanosomiasis and other stock diseases, and hence countries in this zone are typically net importers of milk and meat. While livestock productivity may be inferior to that of the semi-arid zone, the longer subhumid rainy season allows more settled stock raising without the long migrations necessitated by the extended dry season in the semi-arid tropics. Mixes of crop–livestock production systems are the most common. Pastoralism and ranching are rare.

Semi–Arid Zone

The semi–arid tropics typically receive from 200 to 1,000 millimeters of rain in one growing season of 90 to 150 days (Cochemé and Franquin 1967). A dry season of 7 to 9 months follows. Without irrigation, agricultural productivity is limited by a lack of water for crops. Compounding the effects of the long dry season are sustained high temperatures which degrade soil organic matter, and poor moisture–holding capacity of the soil. The semi–arid zone's human support capacity at low levels of farming inputs per unit of land is the lowest of the four major environments (FAO 1986).

Despite the semi–arid zone's low theoretical support capacity, population density is often higher than in the subhumid and humid agroclimates.

Table 2-3. Agricultural Characteristics of the Main Environments

Characteristic	Agricultural environment [a]					
	Humid [b]	*Subhumid* [c]	*Semi-arid* [d]	*Highland* [e]	*Mixed* [f]	*Total*
Growing period (days)	270–365	180–270	90–180	Usually >180	–	–
Rainfall range (millimeters)	>1,500	1,000–1,500	500–1,000	1,000–2,000	–	–
Total agricultural area, 1987 (thousands of square kilometers) [g]	3,118	1,144	5,008	1,005	3,450	13,725
Arable land and permanent crops, 1987 (thousands of hectares)	19,858	16,073	38,520	18,802	51,892	145,145
Area under permanent pasture, 1987 (thousands of hectares)	38,065	43,482	318,086	50,102	126,980	576,715
Total irrigated area, 1987 (thousands of hectares)	79	179	2,731	278	1,890	5,157
Agricultural GDP, 1987 (percent of total GDP)	29	33	31	38	40	34
Main crops	Cassava, yam, rice, maize, plantain	Rice, sorghum, maize, yam, groundnut	Pearl millet, sorghum, maize, groundnut, cowpea	Wheat, maize, teff, beans, banana, potato	–	–
Maize, sorghum, pearl millet, and groundnuts (percent of total arable area and permanent crops area)	20	27	55	24	28	33
Roots and tuber crops (percent of roots, tubers, and cereals area harvested)	51	20	4	12	27	19

Tractors, 1987 (numbers)	10,020	9,865	52,515	12,599	46,630	131,629
Tsetse area, 1980 (percent of total area)	96	70	18	14	57	42
Tropical livestock units, 1988 (thousands) [h]	7,051	6,386	64,847	41,199	38,738	158,221
Livestock GDP, 1980 (percent of agricultural GDP) [i]	6	7	37	27	15	18
Value of net milk imports, 1985-87 average (millions of U.S. dollars)	56	78	145	33	123	435
Value of net meat imports, 1985-87 average (millions of U.S. dollars) [j]	138	40	-71	-3	70	174
Animal traction	Almost none	Beginning but still rare	Advanced in some areas, absent elsewhere	General in Ethiopia, common in Kenya and Madagascar, absent elsewhere	–	–

– Not applicable.
Note: Namibia, Djibouti, and Equatorial Guinea are excluded from the data in Jahnke (1982, p. 233)
a. Countries categorized by environment have more than 50 percent of their rural population in that environment.
b. Humid: Cameroon, Congo, Gabon, Ghana, Liberia, Sierra Leone, Zaire.
c. Subhumid: Benin, Guinea, Côte d'Ivoire, Malawi, Togo, Zambia.
d. Semi-arid: Botswana, Burkina Faso, Chad, Gambia, Guinea Bissau, Mali, Mauritania, Mozambique, Niger, Senegal, Somalia, Sudan, Zimbabwe.
e. Highland: Burundi, Ethiopia, Kenya, Rwanda.
f. Mixed: Angola, Central African Republic, Madagascar, Nigeria, Tanzania, Uganda.
g. Total agricultural area is the sum of arable, permanent crop, permanent pasture, forest, and woodland.
h. Tropical livestock units include only equines and ruminants. Pigs and chickens are excluded.
i. Does not include Botswana or Guinea Bissau.
j. Negative numbers denote exports.
Source: Jahnke (1982), FAO (1988), World Bank (1989), and ILCA (unpublished data).

Table 2–4. Field Site Characteristics

Zone and site	Main cattle breed	Tsetse pressure	Distance to annual trans–humance (km)	Main crops		Irrigation	Main types of mech-anization
				First	Second		
Humid							
Owerri	None	High	280	Cassava	Melon	None	None
Onitsha	None	High	240	Yam	Cassava	Lowlands	None
Koulila	None	Riverine	None	Cassava	Groundnut	None	None
Les Saras	None	Riverine	None	Cassava	Plaintain	None	None
Subhumid							
Shaki	Zebu × Keteku [a]	Low	140	Yam	Maize	None	None
Fashola	Bunaji [b]	Low	165	Yam	Sorghum	None	None
Abet	Bunaji [b]	Low	Close	Maize	Sorghum	None	None
Ganawuri	Bunaji [b]	Low	Close	Fonio	Finger millet	None	None
Kufana	Bunaji [b]	Low	Close	Sorghum	Maize	None	None
Korhogo	Zebu × trypanotolerant	Low	10	Maize	Groundnut	None	Oxen
Semi-arid							
Ziga	Peul Voltaic [b]	None	15	Sorghum	Pearl millet	None	Oxen
Sabouna	Peul Voltaic [b]	None	Close	Sorghum	Pearl millet	None	Oxen
Bidi	Peul Voltaic [b]	None	Close	Sorghum	Pearl millet	None	None

Bama	Zebu × Ndama [a]	High	5	Sorghum	Maize	None	Oxen
Tondogosso	Zebu × Ndama [a]	High	Unknown	Maize	Sorghum	None	Oxen
Machakos	Zebu	None	25	Maize	Beans	None	Oxen, tractor
Masvingo	Sangha [b]	None	Unknown	Maize	Pearl millet	None	Oxen
Mvuma	Sangha [b]	None	None	Maize	Finger millet	None	Oxen
Zarmaganda	Zebu	None	20	Pearl millet	Cowpea	None	None
Boboye	Zebu	None	20	Pearl millet	Cowpea	None	None
Kianjasoa	Malgache Zebu	None	100	Rice	Cassava	Lowlands	Oxen
Highlands							
Muranga	Friesan	None	None	Maize	Beans	Lowlands	None
Kiambu	Friesan	None	None	Maize	Beans	Lowlands	None
Ngozi	Ankole [b]	None	None	Beans	Banana	Lowlands	None
Bukavu	Ankole [b]	None	None	Beans	Cassava	Lowlands	None
Bugesera	Ankole [b]	Low	None	Beans	Sorghum	Lowlands	None
Antsirabe	Malgache Zebu	None	100	Maize	Rice	Diversion	Oxen
Manjankandriany	Malgache Zebu	None	200	Rice	Potato	Diversion	Other
Debre Zeit	Ethiopian Zebu	None	10	Teff	Chickpea	None	Oxen
Debre Berhan	Ethiopian Zebu	None	10	Barley	Faba	None	Oxen
Were Ilu	Ethiopian Zebu	None	None	Wheat	Teff	None	Oxen
Inewari	Ethiopian Zebu	None	None	Wheat	Faba	None	Oxen
Fogera	Ethiopian Zebu	None	None	Teff	Finger millet	Pump	Oxen

a. Half trypanotolerant breed, a cross between trypanotolerant Muturi and Bunaji, a race of Zebu.
b. Race of Zebu.
Source: Field visits by authors.

Densities on the order of 250 to 300 persons per square kilometer are found near the main river valleys such as the Senegal, Niger, and Logone/Chari in West Africa, and around the major cities of northern Nigeria. Such sites nearly always have good groundwater supplies and adequate water for livestock production. Very sparse settlement is typical of the zone's northern arid fringe.

About 8 percent of the semi-arid zone's agricultural area is cropped, although most of the best lands are used. Another 65 percent is devoted to permanent pasture. The dominant crops—pearl millet, sorghum, groundnut, maize, and cowpea—are those which can be grown without irrigation. These five cover approximately 55 percent of the arable land. Crop yields are from 300 to 600 kilograms per hectare with traditional farming techniques (Matlon and Fafchamps 1988, p. 35, for three regions of Burkina Faso). Irrigation is rare, except for a few large schemes in West Africa and the Sudan, where rice and cotton are grown. Root crops cover only 5 percent of the cropped area. Commercial tree crops are nearly absent. Smallholdings are the dominant farm type, on which peasant families cultivate a mix of food and cash crops.

Livestock have a strong comparative advantage and provide much of the value of agricultural output. The zone is a strong exporter of livestock, although milk imports are growing. A primary source of this comparative advantage is that trypanosomiasis and other stock diseases are weaker than in wetter zones. A second advantage is abundant pasture of good quality, despite the low pasture yields caused by aridity and poor soil fertility. A third is the complementarity between temporary rainy season pasture, such as those along the Sahara, and dry season pasture near river basins (de Leeuw, Wilson, and de Haan 1983, for central Mali).

Highland Zone

The highlands have cooler climates and longer growing seasons than the other three zones. They often have two growing seasons, and some parts of Rwanda and Burundi have three. The amount of rainfall is less crucial to agricultural productivity because of the cooler climate's effect on the rate of water lost to evaporation. Highland soils, which include many deep Vertisols and Nitrosols in East Africa, are also more productive.

The highlands have the highest population densities on the subcontinent. At the twelve highland field sites, population density varies from 80 to 350 persons per square kilometer.

Crops include wheat, maize, sorghum, beans, barley, and potatoes, as well as many tree and root crops. Yields tend to be higher than in other environments due to the temperate climate and better soils.

Agricultural mechanization in the highlands is varied. Animal traction is widespread in highland Ethiopia and in parts of Madagascar, while in

Rwanda, Burundi, and much of Kenya, there is none. Rolling topography and crops which are inherently difficult to mechanize (coffee, root crops) dissuade mechanization. Low wages and small farms make it unattractive to substitute tractors for human labor or animal traction.

Stocking rates are greatest in the highlands. Pressure from tsetse and other diseases is low, and two rainy seasons permit perennial pasture. This is in contrast to the semi–arid zone, where despite having similar rainfall, the long dry season does not allow annual livestock production (Pratt 1984, p. 22). The region is a net exporter of meat and live animals and only a small net importer of milk. Forage production is intensive and sometimes includes resources such as crop thinnings, weeds, and sown forages not used in the lowlands.

Summary: The Effect of Agroclimate on Land Allocation

Agroclimate defines the mix of crops and livestock among the zones via its effects on land productivity and on animal disease.

- If stock water is available, then the arid and semi–arid are the principal pastoral zones because they have lower disease pressure and higher pasture quality than more humid zones. In the medium rainfall semi–arid tropics, the agroclimate supports more arable farming and higher population densities; mixed farming is dominant and displaces pastoralism.
- The subhumid and humid zones have fewer animals because of stock diseases, notably trypanosomiasis. The humid zones have no pastoral systems, and the subhumid zones have them only seasonally. Both have more varied cropping patterns than the semi–arid tropics because of longer growing seasons and higher land productivity.
- The highlands are usually so densely populated that nomadic herding has vanished. Livestock remain important, stocking rates and land occupancy are high, and mixed farming is common.

These general observations permit some conclusions about the extent of mixed farming.

- The principal distinctions among farms across an agroclimate are the presence of livestock, cropping pattern, and farm mechanization. Differences of farm type—for example, smallholder versus estate, or ranching versus pastoral—are much less important. The distinction between smallholder and estate agriculture cannot explain differences in mixed farming because estate agriculture is so rare.
- By definition, stock numbers determine current crop–livestock interactions. They are strongest in the highlands and semi–arid tropics and

weakest in the humid and subhumid zones. Without dramatic changes in land use affecting animal disease or vice versa, agroclimatic differences demarcate the main crop–livestock interactions.

- In zones where both cereals and root crops are grown, the proportion of root crops increases with humidity. The crop mix affects mechanization and feed availability. Because cereals are more easily mechanized and provide more crop residue for feed, crop–livestock interactions are favored in cereal systems, all other things being equal. While the cropping pattern can change with irrigation or the introduction of novel species, it remains a powerful determinant of interactions.
- Agricultural mechanization is weakest in the humid zone, more advanced in the subhumid and semi-arid zones, and strongest in the highlands.
- Fodder for livestock in all agroclimates consists largely of roughage such as pasture, crop residue, and browse. Because such materials have low concentrations of digestible feed per unit of weight, they are costly to transport and hence are not often traded in markets.
- There is no consistent association between agroclimate and population density. Although the highlands are most densely settled, extreme densities can be found in other environments as well. Hence, it is possible to observe the effects of population density on farming systems with some independence from agroclimate, and to attribute variations in interactions to population density within agroclimate.
- Every zone is a net importer of milk, and most countries are also net importers of meat. Most countries have also exhibited increasing deficits in livestock products for at least a decade. Hence, it is unlikely that the aggregate African demand for livestock products is a general barrier to obtaining benefits from integrating livestock more closely with crop production.

3

Evolution of Crop–Livestock Interactions

THIS CHAPTER seeks to explain the evolution of crop–livestock interactions in Sub-Saharan Africa. In the context of the discussion in the previous chapter about the effects of agroclimate on zonal comparative advantage, population density influences farming systems toward characteristic types and levels of interactions. The evolution of interactions follows an inverted U form as population density increases: integration is very weak at the beginning, increases, and then decreases. At any point in the evolution there is a choice between specialized production of crops and livestock and some integration of the two. That choice can be further influenced by markets and exogenous technologies.

The seven arguments presented in this chapter can be summarized as follows:

At low population density, crop and animal production are 'extensive', that is, they use more land per unit of output than do 'intensive' techniques. Extensive agriculture creates few interactions, and those interactions which occur do so through markets or contracts among highly specialized producers of crops and livestock.

Second, with low population density and extensive production, there is a cost advantage to specializing in crop or animal production and interacting through markets and contracts.

Third, agriculture intensifies in response to population growth and changes in markets. Intensification means that farmers use more animal power, manure, and crop residue per unit of land and output. Where new markets or technologies create opportunities for growth, intensive agriculture is stimulated further.

Fourth, within agroclimates favorable to ruminant animal production, intensification of farming affects land allocation to crop or livestock production by location and season, stimulating further interactions between herders and farmers.

Fifth, greater interaction occurs in a progressive response to the main intensifying forces. Increasing constraints to obtaining inputs in markets or contracts are associated with closer interactions. Such constraints create a cost advantage in providing inputs directly on farm, thus encouraging crop–livestock integration. This movement to mixed farming occurs almost exclusively when extensive techniques of soil fertility maintenance cannot meet the crop production demands made by rising population.

Sixth, while population growth aggravates competition between crops and livestock, it does not begin to limit livestock production until fairly high human population densities. This is because the main constraint to livestock production is dry season feed, which is more binding than land competition from crops in the wet season. While the critical level of population density varies among agroclimates of differing productivity, the main constraint does not.

Finally, if markets and exogenous technologies develop, there can be a movement away from integration and a return to specialization. This movement is due to technical changes—fertilizer replacing manure, tractors supplanting animals, supplements replacing crop residue and pasture—which eliminate the cost advantage of a mixed enterprise providing its own inputs.

Low Population Density Restricts Interactions

The works of Boserup (1965), Ruthenberg (1983), and Pingali, Bigot, and Binswanger (1987) have established the basic arguments about the effects of population density on agricultural systems. Descriptions of farming systems in areas of low population density in arid Africa are found in Jahnke (1982), and de Leeuw, Wilson, and de Haan (1983). A comprehensive review of humid farming systems at low population density was made by Miracle (1967).

The top block of Table 3–1 summarizes the situation when modern technology is unavailable and markets are thin. In traditional farming systems with low population density, families use simple technology for cultivation or to raise animals near the subsistence level. Labor is the principal cost of production. Its price is high relative to that of land, which is abundant for pasture and crops, but yields are low. These systems are isolated, with inelastic local demand for their produce because there are few people and incomes are low. High transport costs promote farm self-sufficiency by depressing the prices of goods sold to the exterior and elevating the prices of goods bought from the exterior.

Other prominent characteristics of agricultural environments with low population density are:

- Fallow is the principal means of maintaining soil fertility and controlling weeds, and is preferred to manure because it requires less labor. By definition, modern fertilizer is not available.

- Farming intensity is expressed by the duration and species composition of fallow. Management of differing fallow systems affects the labor intensity of farming.
- In forest and bush fallow, even where land is available for expanded cropping, animal traction is not used because it has a higher cost per unit of output than hand tools.
- Open grazing of pasture and fallow is the principal source of livestock fodder. Crop residue is unimportant compared to pasture and fallow.
- Herding ranges over a wide area because land is cheap. Animal stocking rates and crop yields are low, hence expansion of crop or livestock output happens via land–using techniques.
- The demand for crop–livestock interactions is weak since there is little demand for animal power, manure, or crop residue for fodder.

Interactions First Occur Through Markets and Contracts

When population density and the incidence of animal disease are both low, specialized herding and cultivation are cheaper than integration.

Figure 3–1 sketches how the cost of producing one tropical livestock unit is a function of farming intensity for herding and farming groups. (A corresponding figure could be made for crop production costs). For a given animal type and breed, much of the production cost is pasture and other feeds, plus labor for animal care, minus the small value of manure. Costs of fodder, labor, and manure are identical for herders and farmers. However, information costs attributable to animal mobility are necessary for successful livestock production. Those information costs are positive to farmers, while they are zero to herders because they are incurred over many generations in ethnic groups which raise stock. Consequently, herders' total costs of livestock production are lower. When farming is sparse, therefore, crop and livestock production are specialized because herders can produce more cheaply.[1]

Other cost considerations encourage herders to stay specialized. Economies of scale in animal production favor larger herds. Because such herds require large pastures, and because arid zone pasture yields poorly, the herds have to be mobile. Sacrificing this mobility in order to settle and farm would cause herders to forgo livestock income. Where population

1. Information costs can also be seen as a tax paid by farmers, but not herders, on the price of livestock products. Information costs to farmers make the relative price of animal products so low that they find it efficient to specialize in crop production and exchange crop products for livestock products.

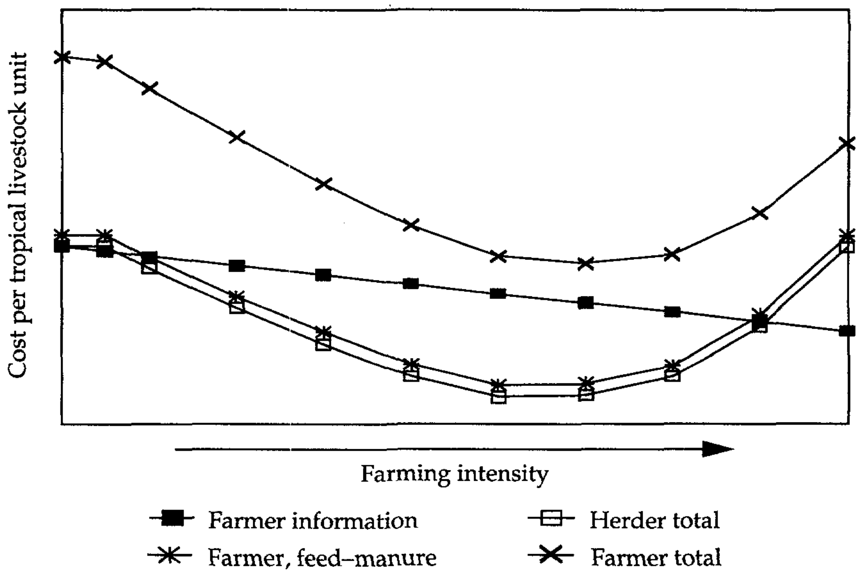
Table 3–1. Predicted Evolution of Crop–Livestock Interactions at Different Land Scarcities

Price of labor relative to land	*Crop cultivation*					
	Farming system	*Soil fertility*	*Tillage*	*Livestock feed systems*	*Demand for interactions*	*Institutions*
Modern technology unavailable and markets limited						
High	Forest fallow	Fallow	Hand hoe	None	None	Specialized cropping (shifting cultivators)
High	Bush fallow	Fallow	Hand hoe	Open grazing	Little	Specialized enterprises (with/without exchange relationships)
High/ medium	Grass fallow	Fallow, cattle manure	Hand hoe	Open grazing, stubble grazing	Moderate	Specialized enterprises with exchange (mobile herders)
High/ medium	Grass fallow	Fallow, compost	Animal draft	Open stubble grazing	Moderate to high	Emergence of mixed farming
Low	Annual cultivation	Manure	Animal draft	Stubble, crop residue, fodder crops	High	Mixed farming

Modern technology available or markets developed						
High	Ranches or pastoralism	None	None	Pasture, supplements	None	Specialized ranches
High	Annual cultivation	Fertilizer	Tractors	Pasture, grain	None	Specialized ranches, dairy farms, and grain farmers
Low	Annual cultivation	Fertilizer	Power tiller, tractors	Pasture, crop residue	None	Specialized enterprises: controlled feeding, beef and dairy, grain farmers
Low	Highland milk	Manure, fertilizer for forage	None in highlands	Cut forage, supplements	Manure on permanent crops	Mixed farming with dairy and permanent crops

Source: Synthesis by authors from field visits and literature review.

Figure 3–1. Livestock Production Costs as a Function of Farming Intensity



density is low and access to pasture and water is open, these scale and mobility considerations dominate. If herders have enough animals to support themselves, exchanging livestock products for crops provides higher income than a mix of cultivation and stock raising.[2]

Farmers remain specialized for cost reasons in addition to the cost of information. Economies of scale in animal production make it unprofitable for farmers to raise small numbers of animals because they would have to sacrifice disproportionate amounts of crop output to do so. Other reasons concern crop production costs. At low population density, fallowing is cheaper than manuring and hand tools are cheaper than animal traction, meaning that there is little demand for animal inputs on the farm. Hence the value of manure and power from livestock does not change a farmer's livestock cost function at this point.

This reasoning does not mean that farmers are totally specialized in cropping. Many farmers with no experience at cattle production do raise other stock, such as sheep, goats, poultry, and pigs. The key difference between those species and cattle is that they require less land, and can be managed directly by farmers without mobility and its associated information costs.

2. Herders use various strategies to insure against risk, including diversification of pasture, species, and breeds, so a mix of crop and livestock production is unnecessary as a response to risk.

Product Interactions Between Specialized Farmers and Herders

Existing literature and field visits confirm the segregation of crop and animal production. In the arid pastoral zone, physical and ethnic separation of cultivators and herders is typical, there are few interactions on the farm, and no mixed farming occurs (Table 3–2 and the pastoral cases reviewed by Monod 1975). Where there is a demand for interactions, they typically occur as products or services exchanged through contracts or markets.

While pastoralists generally live in the most arid areas, they do move across agroclimatic zones in search of seasonal water and pasture, giving rise to product exchanges. Baier (1980) found product interactions to have a long history in the West African Sahel. The main exchanges between farming and herding communities still typically occur in the barter of milk for grain (Burnham 1980). Milk/grain barters have been observed in Burkina Faso (Delgado 1979), central Mali (Swift, Winter, and Fowler 1985) Niger (Eddy 1979, Bernus 1974), East Africa (Schneider 1979), and throughout West Africa (Swift 1980). Pearl millet and other vegetable products form 50 to 70 percent of the total diet of most pastoral groups, even the ones relying most on herding (Jahnke 1982). Negussie Tilahun (1984) found that Ethiopian pastoralists obtained 93 percent of their income from the sale of cattle, butter, and milk, while purchases of cereals and other foods accounted for 40 percent of their expenditures. Solomon Bekure and others (1991) reported similar market transactions among the Kenyan Masai.[3]

The authors' field visits showed the importance of manuring and grain interactions (Table 3–3) in the subhumid and semi–arid tropics most like traditional pastoral areas. In the subhumid zone, cultivators obtain manure and labor to care for animals in return for cash and crop residue given to herders. In the semi–arid tropics, cultivators receive manure, labor, and less importantly, milk in return for cash, grain, and water rights traded to pastoralists.

Investment Interactions Between Specialized Farmers and Herders

Farmers invest in livestock as insurance against crop failure (Horowitz 1975, for Niger; Swift, Winter, and Fowler 1985, for Mali), or as a productive asset. They do not need to manage livestock to invest in them if it is possible to employ herders. Farmers contract herders by two interactions: by entrusting animals to herders or hiring labor, or both (Morgan and

3. Storage costs and seasonal supply and demand determine the nature of these interactions. Grain can be stored, but not by herders because of their mobility, so they need to obtain it regularly in the market. Because most milk is produced in the short rainy season and cannot be stored, it is sold for cash or bartered for grain.

Table 3–2. Summary of Earlier Studies of Crop–Livestock Systems by Population Density

Area and reference	*Institutions*	*Interhousehold transactions*	*Market transactions*	*Direction of change*
Sparsely populated areas				
Northern Kenya (Dahl 1979)	Specialized herding	Negligible	Meat–milk for grain	Herding labor and off–farm labor
Northern Senegal (Sutter 1983)	Specialized herding and cultivation	Milk–pearl millet	Negligible	Herding labor and off–farm labor
Pastoral zone of Niger (Eddy 1979)	Specialized herding and cultivation	Milk–pearl millet and investment	Negligible	Herding labor and off–farm labor
Ethiopian range-lands (Negussie Tilahun 1984)	Specialized herding	Negligible	Meat, buttermilk for grain other food and clothes	Little change
Congo basin (Miracle 1967)	No cattle herding	None	Meat, fish purchased	Little change
Moderate density areas				
Niger (Horowitz 1975)	Specialized cultivation and herding	Manure–water, investment–milk	Negligible	Herding labor, off–farm labor, herders are settling
Western Sudan (Gibbon and Harvey 1977)	Mixed farmers and specialized herders	Investment	Grain	Herders are settling

Central Mali (Toulmin 1983; Swift, Winter, and Fowler 1985)	Mixed farmers and specialized herders	Manure–water, milk–pearl millet	Grain and crop residue–milk	Herding labor, farm labor, herders are settling
Abet, Nigeria (Powell 1986)	Specialized units and emerging mixed farming	Manure–crop residue and grain	Milk, livestock products, grain	Pastoralists settling down and further mixed farming
Batagarawa, Nigeria (Hill 1972)	Mixed farming and specialized herders	Grain–manure and investment	Compound sweeping	Mixed farming
High density areas				
Ukara Island, Uganda (Ruthenberg 1983)	Mixed farming	Unknown	Labor and all major crop and livestock products	Further intensification
Maradi, Niger (Nicolas 1967)	Mixed farming	Grain and crop residue–manure	Labor and all major crop and livestock products	Further intensification, including fodder and manure markets
Kano City, Nigeria (Mortimore and Wilson 1965)	Mixed farming	Grain and crop residue–manure	Labor and all major crop and livestock products	Further intensification, including fodder and manure markets
Jos Plateau, Nigeria (Netting 1968)	Mixed farming	Cash and/or labor for manure	Labor and all major crop and livestock products	Further intensification
Ethiopian highlands (Gryseels and Anderson 1983)	Mixed farming	Livestock products, coffee, tea, and other goods	Labor and all major crop and livestock products	Further intensification, active fodder markets

Source: Authors' review of cited studies.

Table 3–3. Principal Interactions at the Field Sites, by Environment

Sites and interactions	*Humid*	*Subhumid*	*Semi–arid*	*Highlands*
Number of sites	4	6	11	12
Principal interaction [a]				
Received by cultivators				
Animal care labor	–	3	1	–
Crop labor	–	–	1	–
Manure	–	3	7	10
Cash	–	–	–	2
Received by animal owners or managers				
Cash	–	3	3	3
Crop residue grazing	–	2	–	–
Cut crop residue	–	–	1	7
Fallow	–	1	–	–
Grain	–	–	4	–
Water	–	–	1	2
Second interaction [a]				
Received by cultivators				
No interaction	–	–	1	–
Animal care labor	–	4	–	–
Animals	–	–	1	–
Cash	–	–	1	5
Crop labor	–	–	1	–
Manure	–	2	5	4
Milk	–	–	–	3
Received by animal owners or managers				
No interaction	–	–	1	–
Cash	–	1	3	4
Crop residue grazing	–	2	1	–
Cut crop residue	–	–	–	3
Water	–	1	3	3
Young animals	–	2	1	2
Third interaction [a]				
Received by cultivators				
No interaction	–	–	2	–
Animal care labor	–	4	1	–
Crop labor	–	1	–	–
Animals	–	–	1	4
Cash	–	–	–	5
Manure	–	1	2	–
Milk	–	–	3	–
Draft power	–	–	–	3

Sites and interactions	*Humid*	*Subhumid*	*Semi–arid*	*Highlands*
Received by animal owners or managers				
No interaction	–	–	2	–
Cash	–	1	3	2
Crop residue grazing	–	1	–	–
Cut crop residue	–	2	1	5
Grain	–	–	2	–
Salt or water	–	–	1	4
Young animals	–	2	–	1

– No interactions

a. Information about interactions at two semi–arid sites could not be clearly ranked and is therefore missing from the table.

Source: Field visits by authors.

Pugh 1969, Delgado 1977, for Burkina Faso; Hill 1972, for Nigeria; Eddy 1979, Bernus 1974, for Niger; McCown, Haaland, and de Haan 1979, for Ethiopia and Senegal). Such interactions take advantage of economies of scale and of herders' experience, without requiring crop–livestock integration on the farm.

Entrustment also allows numerous exchanges of products, inputs, and primary factors among producers specialized to some degree. A typical contract is described by Delgado (1977) in Burkina Faso, in which a herder manages an owner's cattle and receives milk plus a share of the offspring. Toulmin (1983) shows how Bambara farmers in central Mali entrust cattle to herders who get cash, crop land, labor for the crop land, and a share of the milk produced. In central Nigeria, Waters–Bayer and Taylor–Powell (1986) found settled Fulani farmers hiring herding labor in the cropping season, while in a proximate site, Fricke (1979) found them hiring cropping labor.[4]

Interactions Increase With Farming Intensity

The principal effect of population growth is to inflate the price of land relative to that of labor. This change in relative factor prices stimulates

4. There are many other examples. Farmers in the tsetse–infested Kilombero valley of Tanzania entrust cattle to herders in neighboring tsetse–free areas (Jatzold and Baum 1968). Similar tsetse–induced entrustment has been observed in Mumbwa district, Zambia (Pingali, Bigot, and Binswanger 1987). Mixed farmers in Ethiopia make entrustment contracts with herders (McCown, Haaland, and de Haan 1979, for Harerghe province, Ethiopia), who pasture the animals at different altitudes.

farmers and herders to enhance land use. Specific aspects of the intensification wrought by population growth are again well known from the books of Boserup (1965) and Ruthenberg (1983). The authors' field results, summarized by population density in Table 3–4, are consistent with earlier research.

First, population growth expands crop land and contracts fallow and pasture. In Table 3–1, lack of modern technology is reflected in shorter fallows—systems move from longer forest and bush fallow cycles to grass fallows, and then to annual cultivation and multiple cropping. Field results in Table 3–4 show less fallow at higher population densities.

Table 3–4. Principal Interactions at the Field Sites, by Population Density

	Persons per square kilometer			
Sites and interactions	*≦20*	*21–80*	*81–160*	*>160*
Number of sites	5	13	7	8
Extent of fallow (percent of arable land in fallow)	66	43	24	17
Fallow substitutes (number of sites)				
Manuring	3	11	7	8
Paddocking animals	3	13	–	–
Crop residue use (number of sites)				
Grazing mainly	1	11	–	–
Mulching	2	–	1	6
Grazing, cutting, and storing	3	11	7	8
Main power source (number of sites)				
Hand	3	9	1	6
Use of animals for				
Transport only	1	1	–	1
Cultivation only	–	–	–	–
Transport and cultivation	2	7	6	2
Tractors	–	–	1	–

– None observed at these sites.
Note: There is double counting of sites at which several practices are common.
Source: Field visits by authors.

Second, farmers seek substitutes for fallow to maintain soil fertility. In dry environments favorable to animal production, they paddock animals or otherwise collect and use manure (Norman, Newman, and Ouedraogo 1981, for the semi–arid tropics). In more humid environments unfavorable to animal production, farmers develop intricate systems of mulching vegetation (Lagemann 1977, Lal and Greenland 1979, for Nigeria).

Third, farmers raise labor use per unit of land and per unit of output. Pingali, Bigot, and Binswanger (1987, p. 107) showed statistically significant increases in labor use per hectare and per unit of output with higher farming intensity. This occurred as better soil preparation, more intensive manuring, and construction of water control structures, among others. Manuring shifts from paddocking to collection, spreading, and incorporating (Tables 3–4 and 5–5).

Fourth, cultivators use bottomlands more intensively. In dry agroclimates, such lands are more productive because they retain moisture better, but are difficult to cultivate because soils are heavier. In rainy environments, these lands may be too wet to cultivate without investments in water control, which can only be justified by growing water–responsive crops such as rice. The special problem of these lands for crop–livestock interactions is discussed in the following section of this chapter.

Fifth, farmers feed more crop residue because of the growing limits on pasture and fallow. Associated with the more plentiful crop residue is intensive management, including cutting, storing, feeding, and restricting access to outsiders. In Table 3–4 this is shown as a shift from animal production systems involving mainly, and sometimes exclusively, field grazing of crop residue to systems in which greater and greater shares of crop residue are harvested and stored for later feeding. This point is elaborated in Chapter 6.

Sixth, farmers replace labor with animal traction and engine mechanization. Pingali, Bigot, and Binswanger (1987) explained the genesis of mechanization in terms of the cost per unit of crop output at different farming intensities. At low intensity, the costs of mechanization are greater than those of hand cultivation because of the costs of land clearing necessary for mechanization. As cultivation spreads, those costs are incurred and gradually become small at the margin. When the annual sum of land clearing, animal maintenance, and farming costs with animal traction falls to less than the sum with hand cultivation, then it is profitable to adopt mechanization.

Effects of Interactions on Crop–Livestock Competition

The developments mentioned above impose closer crop–livestock interactions at higher farming intensities. As interactions become closer, the unit cost of livestock production declines with changes in its components of feed, manure, and learning costs. This allows higher stocking rates in a given land area, and for a time, attenuates competition between crop and animal production.

The impact of farming intensity can be shown by the seasonal changes in feed availability and cost. Figure 3–2 shows how feed is most plentiful during and at the end of the rains because natural pasture and crop residue are available.[5] The difference in the temporal patterns of crop residue and pasture mean that the former are more abundant late in the rainy season and in part of the dry season. Crop residue therefore makes a net positive contribution to feed supply in the post–harvest and dry seasons, even if crop land replaces pasture in the wet season. Up to a certain point in the evolution of farming intensity, therefore, feed becomes cheaper as more crop residue becomes available even if there is a net displacement of pasture.

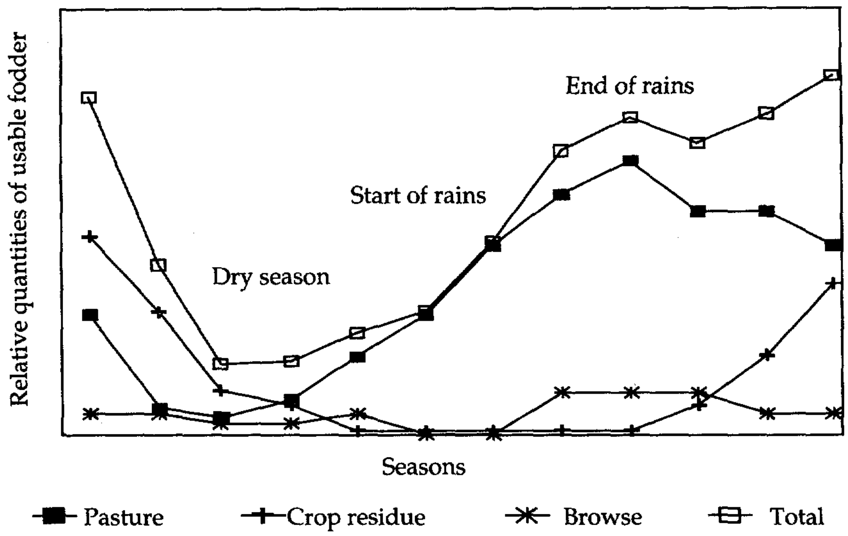
Rising farming intensity also changes the value of manure. If chemical fertilizer is unavailable, the growing demand for manure lowers the costs of animal production to herders because the value of manure is an additional benefit to owning livestock. At the same time, farmers' learning costs drop slowly as they acquire information about managing livestock. The sum of the three cost effects—feed to herders and farmers, manure to herders, and learning to farmers—diminishes the cost of a unit of animal product at higher farming intensities and makes it more profitable to hold stock. This attenuates crop–livestock competition, at least temporarily.

Effect of Rising Population Density on Land Allocation Within Agroclimates

Within an agroclimate, soil depth, moisture holding capacity, and the seasonal distribution of moisture influence the allocation of land between crops and livestock, and the production techniques employed. The key aspect of soil quality is moisture retention as affected by position on the slope. In moving from a summit to a valley, soils change in moisture holding capacity, and thus in ease of work and riskiness. Soils on the upper slopes are lighter and easier to work by hand, but have higher drought risks. Soils become deeper and hold more water with the progression down the slope, but as they become less risky they are also harder to work. Soils on the valley bottom are heaviest and most difficult to work, but are the least risky along the toposequence. In choosing where to cultivate, therefore, the farmer balances lower labor requirements and higher risk of drought on the summit against higher labor requirements and lower risk of drought in the valley.

5. Ruthenberg (1983) showed how farming system evolution affected total dry matter production at a medium altitude site in Kenya.

Figure 3–2. Relative Fodder Supply by Season



The trade off between higher labor input and lower risk varies by agroclimatic zone, and becomes more severe as aridity increases. In the most arid conditions lower slopes and depressions are the only lands cultivated because only there does water holding capacity allow cropping. Saharan oases and pockets of farming in northeastern Botswana are examples.

In semi–arid conditions the mid–slopes are the first to be cultivated. Ridges are unacceptably risky. The lower slopes are grazed because they remain green longer into the dry season and because they are difficult to cultivate by hand in the wet season. As population densities increase, cultivation replaces grazing on the lower slopes and in the depressions. As densities increase further, the returns to investments in drainage and irrigation in the bottom lands also increase.

In more humid areas where the drought risk is less acute, the choice of where to farm depends almost totally on ease of cultivation. There is little incentive to crop bottomlands. Animal disease limits the stocking rate so that the bottomlands are unnecessary for fodder production, as they would be in more heavily stocked zones. Hence the specific conflict between the two activities does not occur in low–lying areas.

For all but the most arid areas, the discussion can be summarized thus: as population densities increase, people can intensify production on the mid– to upper slopes, move to marginal lands on the upper slopes, or move down the slope. Each option implies some investment in erosion or water control. Typically, the payoff to these investments is highest on the lower slopes and valley bottoms of the semi-arid zones. Therefore, where lower slopes and valley bottoms are available, population growth induces intensification on these lands.[6]

Movement to the lower slopes and depressions in response to population pressure has major implications for crop–livestock interactions. One is that herders lose some dry season grazing on lower slopes. While they gain in total fodder availability because crop residue complements pasture, they may lose in the critical dry season. The net gain or loss depends on the extent of bottomlands. Next, farmers begin to restrict access to crop residue. Finally, higher power requirements for cultivating the bottom lands stimulate the demand for power and encourage the direct integration of animals within the farming system.

Several sources of evidence support these propositions on movement down the toposequence and on the choice between cultivation and grazing. Examples from the literature are Norman, Newman, and Ouedraogo (1981) for semi-arid West Africa; Waters-Bayer and Taylor-Powell (1986) and von Kaufmann and Blench (n. d.) for Nigeria; Rounce (1949), McLoughlin (1970), and Collinson (1972) for Tanzania; Berg (1981) for Madagascar; and Jones and Egli (1984) for Rwanda, Burundi, and eastern Zaire. Field evidence showed the same patterns in Niger, Burkina Faso, and central Nigeria.

The Transition to Crop–Livestock Integration

Crop–livestock integration is an extension of the cost forces creating more intensive interactions. As farming becomes very difficult, manure becomes more and more valuable. The cost of feed grows as the expansion of crop land no longer produces enough crop residue to compensate for the displaced pasture. In response to the greater value of manure, farmers begin to raise their own stock in order to gain manure without paying herders for the costs of transport, water access, grain, or crop residue. Herders settle to obtain the land rights necessary to produce grain and crop residue without foregoing animal production and manure output. As population density rises, livestock mobility for both seasonal movements and annual transhumance becomes restricted (Table 3–5). As shown near the right end of the horizontal axis of Figure 3–1, the gap in animal production costs between herders and farmers tends to disappear. At that

6. Norman, Simmons, and Hays (1982, pp. 136–137) report instances in northern Nigeria in which lowland cultivation is chosen, not because of population pressure, but because it allows more profitable sugar cane cropping. Contrary cases have also been observed in many areas of highland Ethiopia, where bottomlands are not cropped because of the risk of frost damage to crops.

Table 3–5. Cattle Herd Mobility at Different Population Densities

	Persons per square kilometer			
Sites and mobility	*≦20*	*21–80*	*81–160*	*>160*
Number of sites	4 [a]	12 [a]	7	8
Cattle mobility				
Annual transhumance				
None	2	1	4	6
≦100 kilometers	1	9	1	–
>100 kilometers	1	2	2	2
Seasonal movements				
None	2	1	3	8
≦100 kilometers	2	9	4	–
>100 kilometers	–	2	–	–

– No observations

Note: Annual transhumance is the distance to the nearest major transhumance routes, whether there are cattle at the field site or not. A seasonal movement is the distance typically traveled by herds from the field site during the dry season.

a. Information missing at one site.

Source: Field visits by authors.

point the distinction between herders and farmers blurs, and both become mixed entrepreneurs.

At every point in the transition to greater farming intensity, the choice for farmers is between continued interactions via markets or contracts and integration. This choice depends on two sets of conditions.

- For integration to be cheaper than crop–livestock interaction, there must be a constraint to the interaction through contracts or markets. One fundamental constraint is the high transport cost per unit of useful input in draft power, manure, and crop residue. As demands for those inputs rise with population density, transport costs block their profitable exchange among specialized producers. Another constraint is the market scarcity of some high quality inputs, such as chemical fertilizer and processed feeds.
- For integration to be selected, households must also have slack resources to incorporate the new activity in the production process. Even if such techniques as animal traction and manure production are profitable in the partial equilibrium sense, they will not be adopted if they require

incremental land and labor which are not available on the farm or in markets.

Detailed analysis of the choices among contracts, markets, and integration is presented in the thematic chapters. What follows is a summary of the main factors affecting those choices.

When animal traction becomes cheaper than hand cultivation, then the choice for farmers is to acquire it in a market or to own it. That choice depends on the transaction costs of acquiring draft power in a market. Costs to the owner include uninsurable risks to draft animals doing custom work. The owner therefore chooses not to rent out, or to do the work himself with a premium for the opportunity cost of his own labor in the rental cost. Costs to the renter are for transporting animals, supervising contract work, losing yield because of low standing in the work schedule, and foregoing manure production. These costs to sellers and buyers make market acquisition more costly than ownership. Farmers therefore prefer to own draft power rather than to acquire it in a market.[7]

When manuring is necessary to replace fallows, the choice between contracts and integration depends on farming intensity, transaction costs, and the costs of other soil fertility inputs. At low intensity, farmers use manure via paddocking contracts in which herders' cattle are stabled in rotation on fields. In such areas, herders have small crop farms or none at all, so their own demand for manure is weak. In a mid–intensity area of Côte d'Ivoire, Bernardet (1984) found that farmers paddocked animals to gain manure supplies at low marginal transport and labor costs. Similar observations were made by Pelissier (1977) for Senegal, Ruthenberg (1983) throughout tropical Africa, and Norman, Newman, and Ouedraogo (1981) for semi–arid West Africa.

As farming intensity rises, herders begin to settle, cultivate, and use manure on their own fields. The market supply of manure to farmers becomes restricted at the same time as it has become more valuable to them. The restricted supply imposes a market cost on farmers, who then need to raise animals to gain manure. In an intensively cropped area around Batagarawa, Nigeria, Hill (1972) noted that farmers adopted mixed farming in order to ensure an adequate manure supply which had become unavailable through traditional contracts. The constraints to obtaining fertility inputs in markets were that chemical fertilizer was not available at all, and manure, which had become more scarce locally, could not be transported from further away.

Crop residue becomes more important because pasture declines with the expansion of crop land. In a relatively sparsely populated subhumid

7. This is not to say that animal draft power rental markets never exist. They are described in Chapter 4.

site in central Nigeria, Powell (1986b) found that crop residue was 30 percent of animal intake in the post–harvest season. In a more heavily stocked region of semi–arid northern Nigeria, van Raay and de Leeuw (1971) found crop residue to be 70 to 90 percent of grazing in the post–harvest season and about 20 percent annually. In the highlands of Ethiopia, where stocking rates are among the highest in Africa, crop residue can be as much as 50 percent of annual grazing time (Gryseels and Anderson 1983).

Because feed markets are so underdeveloped, herders must choose between grazing contracts with farmers or producing crops themselves. In traditional contracts, animals graze residue belonging to or managed by farmers, and farmers ceding the residue receive manure deposited in their fields. This contract is characteristic of less intensively farmed environments in which discrete groups of herders still exist. To obtain residue in more intensively farmed environments, mixed farmers need to produce it directly. While grazing contracts still occur, most farmers choose to harvest and store their own residue (Tables 3–2, 3–3, and 3–4).

Mixed farming occurs in the most densely populated highlands. Nearly all land is cropped at some time during the year. Farmers have assimilated the knowledge to raise stock, so the cost differential of information between farmers and herders no longer exists. Transhumance has disappeared and pasture grazing is diminished, crop residue has been privatized and is a major share of feed intake, and use of draft power is widespread. Stabling livestock replaces seasonal or permanent entrustment, partly in order to acquire all the available manure. Examples of such farming systems are in the Ethiopian highlands (Gryseels and Anderson 1983), Sukumaland and Arusha regions of Tanzania (Collinson 1972), most of Rwanda and Burundi (Jones and Egli 1984), the plateaux of Madagascar (authors' field visits), the densely populated Mandara mountains of northern Cameroon (Holtzmann 1986), and western Sudan (Gibbon and Harvey 1977).

Crop–Livestock Interactions and the Competition for Land

The progressive intensification of farming systems sometimes leads to land conflicts between crops and livestock. In a previous section, it was concluded that specific competition for lowlands would develop. Is this true of land in general?

Land competition between crops and livestock varies across agroclimates. It is weakest in the humid zones where disease raises the costs of ruminant livestock production and hence suppresses stocking rates. Impending crop–livestock competition appears greatest in the semi–arid tropics and might affect that zone's comparative advantage in livestock. Competition is strongest in the highlands because population density and stocking rates are already high.

While such general tendencies in competition are seen easily, there remain important questions about the point at which competition occurs. That point is a function of population density and its effects on the demand for food, land productivity in terms of crop and fodder yields, animal feed demand at a given stocking rate, and the seasonal distribution of feed supplies and its impact on carrying capacity.

A simple model of land competition between crops and animals was developed to examine these issues.[8] Its logic is that population density, the food demand necessary to support that population, and the land's productive capacity determine how much land is needed for cultivation. The cultivated area in turn determines the area available for pasture. Pasture area and its environmentally influenced fodder yield, plus the contributions of crop residue and browse to fodder supplies, determine the number of animals which can be supported. Obviously there are possibilities for trade and technical change affecting cultivated area, yields, and the stocking rate, but these are mentioned later.

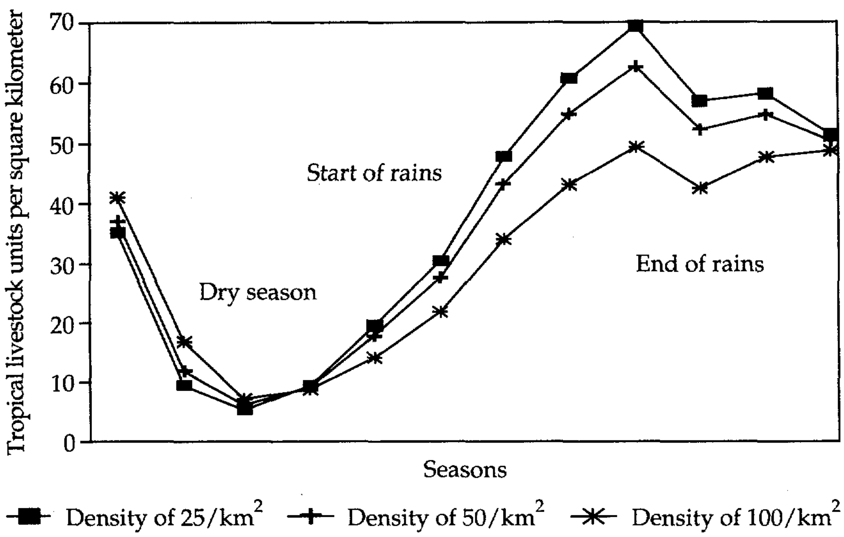
The key issue is the minimum feasible stocking rate, measured in tropical livestock units per unit of land. The minimum feasible stocking rate is defined as the rate attainable during the season in which fodder is scarcest. If the lowest feasible rate occurs in the cropping season, then land competition with crops can be said to limit livestock production. The only way to expand livestock production would be to increase the area in fodder and to reduce the area in crops in the absence of technical change or external trade. If the lowest feasible rate occurs in the dry season when there is no crop, then the stock carrying capacity of the land is the constraint to livestock production, not land competition with the standing crop.

Simulated monthly stocking rates are shown in Figure 3–3 for a semi–arid or subhumid farming system with one rainy season. The stocking rate is lowest in the dry season because of the extreme seasonality of forage production. There is ample evidence for this (Penning de Vries and Djiteye 1982, Chapters 1 and 4 for semi–arid Mali, and von Kaufmann and Blench n.d., for subhumid Nigeria). If population density doubles from 25 to 50 persons per square kilometer, the highest rainy season stocking rates fall by about 10 percent. If population density doubles again, from 50 to 100, the fall in the highest rainy season rate is roughly 25 percent. Only at population densities well above 100 persons per square kilometer does the rainy season stocking rate restrict animal production. In the semi–arid and subhumid environments, such population densities are generally found in river basins.

A second issue is the effect of population density on the feasible rate in different environments. Figure 3–4 depicts feasible rates for three environments, each with a corresponding level of pasture productivity. In each

8. See Appendix for details.

Figure 3–3. Feasible Stocking Rates by Season and Population Density

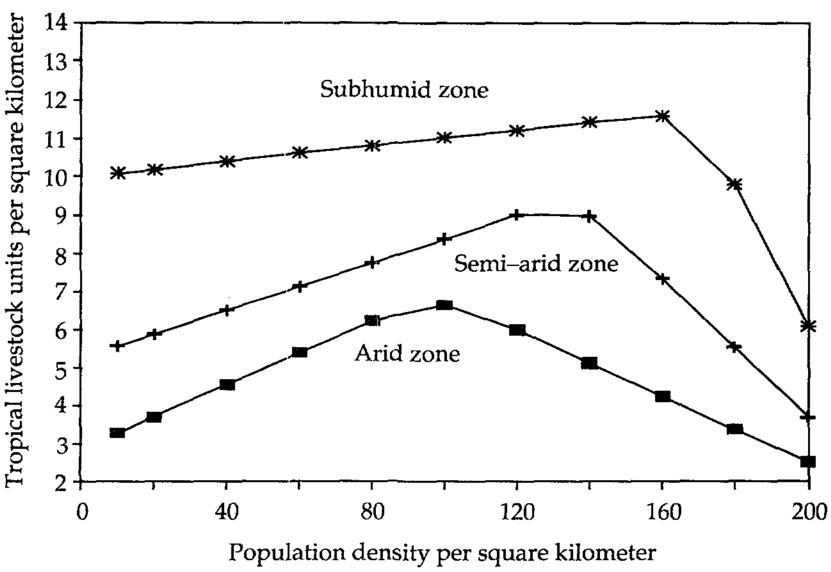


case, the feasible rate first rises as the expansion of crop land produces more crop residue than the quantity of pasture replaced. The feasible rate later falls when the area necessary for crops displaces pasture in the rainy season, shifting the time of competition from the dry to the wet season. In all zones, there is a wide range of population densities at which similar stocking rates are possible.

A number of factors relieve this competition and move comparative advantage in favor of livestock. The relative prices of crops and livestock can shift with greater penetration of foreign trade. Where livestock prices are high, feasible stocking rates will expand as farmers adopt more intensive forage production methods. An illustration, in terms of Figure 3–3, would be if better prices gave farmers incentives to produce supplementary feed for the dry season, or to harvest wet–season fodder and store it for later use. The authors' field visits provided many relevant examples of fodder production, conservation, and storage for dry season use (Chapter 6).

Herders can move animals to seek pasture and other sources of fodder. This is again a well–known strategy in arid areas. In wetter areas with longer cropping cycles, herdsmen adopt a complex strategy of cropping, mobility, and forage production. Farmers grow crops in overlapping cycles to allow animals to consume crop residue while other crops are standing (Powell 1986). They harvest such feed resources as weeds, crop thinnings, and leaves which would not otherwise be used (field visits to Inewari, Ethiopia). Technical changes to reduce the unit cost of production—new livestock breeds or species, new forage crops, or new crop

Figure 3–4. Feasible Stocking Rates by Agroclimate and Population Density



husbandry methods—would also attenuate competition, so the result of this modeling should not be interpreted mechanistically.

Return to Specialized Crop and Animal Production

Specialized farming and herding tend to disappear under the pressure of human population growth. As agriculturalists require manure and draft power which cannot be obtained in markets or via contracts, they begin to manage their own cattle. Something similar occurs with herders as they require more crop residue which cannot be obtained via exchange: they start to cultivate in order to gain crop residue and other products of stable land rights.

Changes in markets and exogenous techniques can also induce a reversion to specialized animal and crop production to replace crop–livestock integration. Specialization may return when constraints to contracts or market interactions disappear. The best example is falling transport costs, which make it profitable to specialize in one type of crop or animal production rather than to maintain a mix. In urban areas, where transport costs of inputs and products are lower than in rural areas, specialized animal production is common.

New technologies may also encourage specialization. For example, where crossbred milk production is possible, it is usually so profitable that

Table 3–6. Modern Technologies and Specialization at Field Sites, by Environment

Sites and technologies	*Humid*	*Subhumid*	*Semi-arid*	*Highlands*
Number of sites	4	6	11	12
Chemical fertilizer				
Cash crops	1	1	2	2
Food crops	–	6	5	8
Livestock feeds				
Grain	–	1	–	–
Other processed supplements	1	2	7	4
Treated crop residue	–	–	–	–
Mechanization				
Animals for transport only	–	–	2	1
Animals for cultivation only	–	–	–	–
Animals for transport and cultivation	–	1	9	7
Tractors	–	–	1	–
Specialized production using modern inputs				
Food crops	–	–	1	–
Cash crops	–	1	2	2
Beef	–	–	–	–
Milk	–	–	–	3
Small ruminants	–	–	–	–

– None observed at these sites.
Source: Field visits by authors.

it displaces other activities (Stotz 1979, for Kenya). This is the main example of specialized ruminant livestock production found in the field visits (Table 3–6).[9] Specialized crop production with new technology was found with cotton in Burkina Faso and Zimbabwe, and with tea and coffee in Rwanda and Kenya.

Shifts in product demand can induce specialization. Behnke (1985) studied commercial fodder production around the city of Nyala, Sudan. Nyala has numerous milk cows, horses, and donkeys for transport, and other animals held for slaughter or shipment. Agricultural areas around the city specialize in fodder crop production for the Nyala market.

9. There is also industrial pig or poultry production in West Africa.

Declines in fertilizer prices encourage substituting for manure and accelerate a return to specialization. While no examples of this were found in tropical Africa, it is well known in Asia. In Japan after World War II, the growing supply of chemical fertilizer and the rising opportunity cost of labor largely eliminated the practice of green manuring (IRRI 1988).

4

The Role of Animal Traction

Is Animal Traction Central to Crop–Livestock Integration?

A COMMON ASSUMPTION about African farming is that animal traction is the centerpiece of crop–livestock integration. In the model of an integrated crop–livestock farm, farm animals would provide power, manure, and sometimes milk. Use of animal power could extend cultivated area, raise yields by relieving the burden of hand labor and improving the quality of tillage and weeding, and allow farmers to grow a more lucrative crop mix. Draft animals could be maintained cheaply with crop residue, which in their absence was assumed to have been more or less wasted. Such benefits ought to have encouraged farmers to adopt animal traction rapidly.

Development with animal traction, however, has been less successful than expected. Many efforts to introduce it in the humid and subhumid zones failed. Farmers refused the technology or reverted to hand cultivation after a brief try with mechanization. Related failures include projects to develop a specialized draft animal, improve local tools, grow forage for draft animals, and refine a multipurpose toolbar. In Ethiopia and Madagascar where animal traction has a long history, external research and development efforts have added nothing to its progress. Even where animal traction has grown rapidly, as in the semi–arid tropics since World War II, many programs have washed out or have only partially succeeded (Starkey 1988).

Pingali, Bigot, and Binswanger (1987) showed why mechanization has proceeded slowly in Sub–Saharan Africa. They concluded that agroclimate and population density were the main forces driving the change from hand to mechanized farming. They wrote that attempts to induce mechanized farming in regions which did not satisfy some basic conditions of agroclimate, population density, and market access were unlikely to succeed.

The inability to find general crop–livestock integration with animal traction as a unifying theme suggests that the role of draft power is poorly understood. During the authors' field visits, no sweeping association between animal traction and other activities was observed. Animal traction is not typically associated with specific techniques for soil fertility management and animal feeding. In parts of the East African highlands with little or no mechanization, there are many crop–livestock interactions, including manuring and forage production. In parts of the Ethiopian highlands where animal traction has an ancient history, other interactions, especially manuring, have not developed or have even disappeared. Throughout the semi–arid and subhumid tropics, sophisticated systems of animal management have no connection to the presence or type of agricultural mechanization.

This chapter considers the determinants of animal traction and its relations to soil fertility and crop residue management, and competition for feed and other resources. Several broad questions are asked: What are the constraints to agricultural mechanization? What is the effect of feed competition on the use of draft power? What are the effects of animal traction and how do they in turn affect other interactions? What are the relations between draft power and such collateral techniques as manuring and crop residue management? What are the relations between the agroclimatic factors promoting or blocking animal traction and the extension of other techniques? Should animal traction be a central element in promoting mixed farming because it is a necessary complement to the other components of mixed farming?

Constraints to Mechanization

Five potential constraints to mechanization are considered in this section: farming intensity and market access, agroclimate, feed competition, rental markets as a substitute for ownership, and inadequate research. Evaluation of these constraints would indicate barriers to diffusion of mechanization, and might suggest ways to overcome those barriers in the context of mixed farming.

Farming Intensity and Market Access

The broad theses of Boserup (1965) and Pingali, Bigot, and Binswanger (1987) about the profitability of mechanization can be summarized narrowly. Mechanization is a response to growing population density, and to changes in output and factor prices. A growing population density shortens fallow periods and raises annual labor input per area. Shorter fallow periods encourage weed infestation, and increased labor demands from shorter fallows induce mechanization to save labor. Increases in output prices, wages, or both would stimulate agricultural production or encourage the use of labor–saving techniques. Thus, certain levels of population density and market access would almost always be required for successful mechanization.

If the theses of Boserup and Pingali, Bigot, and Binswanger hold, then constraints to animal traction can be studied by asking these questions:

- Are the basic conditions for mechanization satisfied? If they are not, then mechanization will probably be unsuccessful.
- If the basic conditions are satisfied, does mechanization succeed? If mechanization fails, were there barriers in addition to the basic ones?

Table 4–1 summarizes field evidence about the basic conditions. Labor and product market access are proxies for changes in wages and output prices. If labor market access is good, then the opportunity cost of farm labor is almost certainly higher than where access is poor. Better wages off–farm would encourage laborers to leave farming, and subsequently induce mechanization to replace them. If product market access is better, then there is reason to expand cropping, which again promotes mechanization. All sites with animal traction satisfy the population density and product market access conditions with the exception of Kianjasoa, Madagascar.[1]

Even where the basic conditions of mechanization are satisfied, there are other barriers to its development. These barriers were found at the seven sites which satisfied the basic conditions, but remained unmechanized: the two Nigerian humid sites, Korhogo and Kufana in the subhumid zone, and Kiambu, Muranga, and Bukavu in the highlands (Table 1–1). Of those seven, only Korhogo and Kufana present any reasonable prospects for mechanization. Soil fragility in the humid sites and small farm sizes and steep slopes in the highlands discourage field mechanization in the remaining five sites.

Pingali, Bigot, and Binswanger identified the apparently trivial fact of the presence of cattle as an important condition for animal traction. This is a necessary condition, but not a sufficient one. Field evidence showed no relation between the presence of cattle and animal traction (Table 4–2). None of the humid sites has cattle, and none is mechanized. All the subhumid sites have cattle, and none has widespread mechanization. The number of cattle, as shown by the semi–arid and highland sites in Table 4–2, affects only the type of mechanization, not its presence. If disease prevents cattle raising but the farming system is otherwise propitious for mechanization, farmers can mechanize with engines. If animal diseases were controlled to allow cattle raising, then animal traction and engines would both be alternatives.

A further argument made by Pingali, Bigot, and Binswanger (1987) is that absence of mechanization has little to do with absence of knowledge

1. The special case of Kianjasoa is discussed below.

Table 4–1. Number of Sites Satisfying Conditions for Mechanization, by Environment

Sites and conditions	*Humid*	*Subhumid*	*Semi–arid*	*Highlands*
Number of sites	4	6	11	12
Population density (persons per square kilometer)				
0–40	2	2	3	–
40–80	–	4	7	–
>80	2	–	1	12
Labor market access				
Poor	2	4	8	7
Fair	–	–	2	–
Good	2	2	1	5
Product market access				
Poor	2	1	–	7
Fair	–	3	8	–
Good	2	2	3	5
Basic conditions by site				
Population density	2	3	5	12
Labor market access	2	2	3	5
Product market access	2	5	11	5
All conditions	2	2	3	5
No conditions	2	1	–	–
Main power source				
Sites where all basic conditions are satisfied				
Hand [a]	2	2	–	3
Animal traction	–	–	3	2
Engines	–	–	–	–
All sites				
Hand	4	6	5	5
Animal traction	–	–	6	7
Engines	–	–	–	–

– No sites found which satisfied condition.

a. The humid sites are in Nigeria; the subhumid ones are Korhogo, Côte d'Ivoire and Kufana, Nigeria; the highland sites are Kiambu and Muranga, Kenya and Bukavu, Zaire.

Source: Field visits by authors.

Table 4–2. Number of Sites Using Different Types of Mechanization, by Environment

Sites and characteristics	*Humid*	*Subhumid*	*Semi–arid*	*Highlands*
Number of sites	4	6	11	12
Sites with no cattle	4	–	–	–
Main power source				
Hand	4	6	5	5
Animal traction	–	–	6	7
Engines	–	–	–	–
Main operations mechanized				
With animals	None	None	Soil preparation, transport	Soil preparation
With engines	Processing, transport	Processing, transport	Processing, transport	Transport
Feeding systems for draft animals				
Pasture only	–	–	–	–
Pasture and crop residue	–	–	11	7
Zero grazing	–	–	–	–
Feed purchased	–	–	4	7

– No sites found which satisfied condition.
Note: There can be double counting of feeding systems for draft animals, if, for example, animals receive purchased feed in addition to pasture and crop residue.
Source: Field visits by authors.

about machines, animal husbandry, or cropping techniques. This argument is partly supported by examples of such knowledge existing where there is no mechanization, or where mechanization has proceeded slowly. There are cases where lack of information about animal traction itself might be a serious barrier. These cases are discussed below for the humid, subhumid, and semi–arid sites.

These results confirm the basic arguments of Pingali, Bigot and Binswanger, as well as those of Boserup (1965) and Ruthenberg (1983). They suggest that there are firm conditions for success with mechanization, and even where such conditions are broadly met, other factors can impair the use of animals for power. Hence, where the basic conditions for mechanization are not met or where other impediments exist, animal traction cannot always serve as the vehicle for bringing other interactions into the farming system because it is so difficult to introduce itself.

Agroclimate

Field results from different agroclimates indicate specific barriers to animal traction. These are compared in the following sections, noting farmer adaptations of mechanized techniques and their associations with other farming practices as substitutes or complements to mechanization.

HUMID ZONE. At the humid sites, there are marked contrasts in the population density and market access conditions. The Congo and Nigeria have radically different population densities and market access, but farming is uniformly manual (Table 4–2). This is characteristic of humid Africa (Miracle 1967, Lagemann 1977).

Southeastern Nigeria illustrates the effect of the humid agroclimate. The basic conditions of high population density and market access are satisfied and there is mechanization everywhere, except in cropping operations. Transport is fully mechanized: many farmers have vehicles, and taxis are regular. There are mills for grinding maize, pounding yams, grating manioc, and pressing oil palm. Despite those examples, the only field mechanization is the occasional tractor, the import of which was stimulated by a severely overvalued exchange rate in Nigeria before late 1986. The barriers to field mechanization are: dense crop covers, necessary to prevent erosion, but unfavorable to field mechanization; semi–perennial root crops, requiring little labor and thus giving weak incentive for labor–saving innovations; the physical barriers posed by yams to animal traction; and epizootics, which reduce stock numbers.

Given the high costs of mechanization, farmers in southeastern Nigeria have made other adaptations to the labor demands of population density. One is continuous multistory cropping. This technique reduces labor demands for crop weeding and soil fertility management. Another adaptation is to grow cassava, which is a response to both population density and the rising opportunity cost of labor. Cassava is less labor intensive than the traditional staple of yams, and less demanding of soil fertility (Lagemann 1977).

SUBHUMID ZONE. The subhumid zones present an intermediate situation between the humid tropics, where mechanization is rare and not growing, and the semi–arid tropics where mechanization is common and growing rapidly. The subhumid field sites partly satisfied the basic conditions of high population density and market access. In central Nigeria, Abet and

Ganawuri met the conditions; all other sites did not. Mechanization was rare, although all sites had the beginnings of animal traction, tractor mechanization, or both (Table 4–3).

Although the subhumid zone of central Nigeria offers potential for animal traction to cultivate unused land, one problem has been the slow progress of animal traction despite apparent land abundance.

In a 1988 study, Roger Blench tried to show why animal traction has grown slowly in the Nigerian subhumid zone (all quoted text in this section is from his work). Blench identified several factors which ought to have promoted animal traction there: abundant cattle, low trypanosomiasis challenge, strong product demand, flat terrain, and the proximity to northern Nigeria where the use of animals for transport and cultivation is widespread. If cattle are common in the farming system, then their use for power would not immediately increase overall resource competition between crops and animals. Reduced trypanosomiasis challenge would eliminate the hypothetical negative interaction between disease and work, and strong product demand would allow farmers to extend cultivated areas.[2]

Blench's hypotheses were:

- Soil hardness makes it difficult to till with animals and breaks tools.
- Work stress aggravates the effects of trypanosomiasis and other diseases, and makes it unprofitable to harness animals.
- The "sparse population of the subhumid zone (relative to the humid and semi–arid zones of Nigeria)" discourages market crop production and hence mechanization.
- The southern limit of animal traction "appears to correspond to the southern limit of Hausa settlement, which is also the southern limit of Islam in many places." This might affect the willingness of farmers to use the technique.
- Mounded yams impair field mechanization and reduce the availability of crop residue to feed draft animals.

Blench studied villages on a west–east line through central Nigeria, roughly on the expected boundary of the extension of animal cultivation southwards from northern Nigeria. He interviewed farmers who had never used animal power, those who had used and abandoned it, and

2. The same reasoning applies to a subhumid site near Korhogo, Côte d'Ivoire, which has the additional stimulant of extension for mechanized cotton cultivation (Bigot 1977).

Table 4–3. *Mechanization at the Subhumid Sites*

Extent of mechanization	Nigeria					Côte d'Ivoire
	Abet	*Fashola*	*Ganawuri*	*Kufana*	*Shaki*	*Korhogo*
Introduction of mechanization among						
Cultivators	None	Public tractors	Tractors, animals	Unknown	Public tractors	Tractors, animals
Herders	None	None	None	Unknown	None	Unknown
Other machines						
Carts	Rare	None	Rare	None	None	Occasional
Grain mills	Occasional	Rare	Common	Common	Rare	Occasional

Source: Field visits by authors.

those who were using it at the time of the interviews. His general conclusions were:

- The southern limit of animal traction does not correspond to the border of the semi–arid and subhumid zones. Animal traction extends "well south into the [subhumid] zone in eastern Nigeria."
- "Lack of knowledge is a major cause of the failure of animal traction to spread farther south."
- Yam–based cropping patterns are a constraint only in western Gongola state.
- Soil hardness is probably not a problem because farmers cited it only once as a constraint to animal traction.
- Trypanosomiasis is not a general constraint to keeping cattle and hence would not have indirectly stopped the advance of animal traction.[3]

SEMI–ARID ZONE. Most of the conditions for animal traction are satisfied at the semi–arid sites. The distinction between the mechanized and unmechanized regions of the semi–arid tropics visited by the authors was generally not in satisfying the basic conditions of high population density and market access. The distinction was, however, in the growing season and soil conditions which made mechanization more or less attractive to producers.

The sandy soils and low rainfall (less than 600 millimeters in 90 to 120 days) at sites in Niger and Burkina Faso bar mechanization. Although sandy soils can be planted without much preparation, the time for preparation is short because the soil cannot be worked during the long dry season, but rather must be prepared when the rains begin. At that time, there is a sharp conflict between preparing the soil and planting the crop. In economic terms, the benefits from using animals to prepare the soil—cultivated area, yield per area, and labor saved—are less than the costs of delayed planting and labor spent on the increased area. Therefore, on sandy soils where the planting period and growing season are short, farmers often prefer zero tillage or light hand tillage over mechanization.

The heavier soils, higher and more well–distributed rainfall, and complex cropping patterns of sites in Kenya, Madagascar, and Zimbabwe

3. While the interaction between trypanosomiasis and work stress is not well understood, other animal production indices do not differ much between the Nigerian semi–arid and subhumid zones. Therefore, if trypanosomiasis does not affect cattle productivity differently between the two zones, it can only affect the use of animals for draft if there is a strong interaction between trypanosomiasis and work stress. This interaction has not been proven.

contrast with the Niger and Burkina Faso sites, and spur mechanization. The site at Machakos, Kenya has bimodal rainfall, the Zimbabwean sites are more southerly and cooler, and the Kianjasoa (Madagascar) site has very high rainfall. The soil preparation periods are long enough to reduce competition between preparing the soil and planting the crop. Heavier soils raise tillage demand, especially on lowland rice at Kianjasoa. Higher rainfall, a longer growing season, and more soil variability allow a more varied cropping pattern. To grow a more complex cropping pattern, mechanization is necessary to reduce labor conflicts in soil preparation and weeding.

For at least one site in the semi–arid tropics, wages affect the source of power. Near Machakos, Kenya, where pull from the urban labor market is strong and there is some absentee farming, private tractor rentals compete with animal traction. The sites in Madagascar, Burkina Faso, and Zimbabwe are further from urban labor markets and have lower labor costs. The substitution of engines for labor and animal draft power is therefore less profitable and does not occur, in contrast to Machakos, where such substitution is beginning.

HIGHLANDS. The highlands ought to favor field mechanization most strongly. They have high population density, continuous cultivation, and relatively heavy soils, all of which should increase the demand for tillage. Every site satisfies the population density condition, and five of twelve satisfy the market access conditions. Despite the presence of these conditions, sharp differences between mechanized and unmechanized sites are exposed in the highlands.

The highlands of Ethiopia and Madagascar have long and well studied histories of mechanization (Goe 1987, for Ethiopia; Munzinger 1982, for Madagascar). The main stimuli to mechanization are heavy soils which remain productive in continuous use, and crops which respond to cultivation, such as teff and rice. The plateaux of Ethiopia and the rice growing valleys of Madagascar, while not always fulfilling the market access conditions for mechanization, show best the importance of agroclimate in the choice of techniques.

The unmechanized highlands also fulfill the basic conditions. These zones have many characteristics—high population density, relatively high rainfall, long growing period, and heavy soils compared to the humid and semi–arid tropics—similar to those of the mechanized highlands, so these features cannot explain the differences in mechanization. Topography, and its induced cropping pattern response, create the difference between the mechanized and unmechanized highlands. The steep slopes of Rwanda, Burundi, and eastern Zaire make it difficult or impossible to cultivate with machines. Such slopes impose a cropping pattern which reduces erosion risks (SEAS 1987). This cropping pattern, dominated by bananas, coffee, and other semiperennial crops, further discourages mechanization.[4] Another reason is that mechanization presents no cultivation speed or farm size advantage on very small farms.

Feed Competition

Designers of research and development projects have often insisted that the poor quality and scant quantity of feed are a hindrance to animal power. In the semi–arid tropics, feed quantity is held to be a significant limitation at the end of the long dry season. Draft animals are thought to be in poor condition at that time and hence unable to work effectively, thus preventing their full use and the expansion of cultivated area. In humid areas, where feed quantity is greater, the argument holds that poor quality herbage weakens the working capacity of draft animals.

The argument that poor nutrition impedes animal traction has two variants. The more common is that feed scarcity makes using draft animals costly; this would help explain the apparent paradox that oxen are not always used for power even where they abound in a given farming system where fodder seems to be adequate. If feed costs were a constraint to the introduction of animal traction, then a comparison of mechanized to unmechanized areas in the same agroclimate should reveal differences between feeding practices for draft animals and those for other stock. Farmers adopting animal traction would have been able to do so by virtue of feeding their stock better.

The field evidence suggests that special feeding of oxen is not associated with their use as sources of power. Two intensive practices for draft animals, zero grazing and concentrate feeding, are absent from the mechanized sites (Table 4–2). Intensive feeding does exist in those areas, but usually only for feeder stock. Farmers use animal traction at Machakos, Kenya, but reserve intensive feeding for dairy cattle. One exception is at Inewari, Ethiopia, an extremely land scarce and isolated spot. Farmers feed crop thinnings and weeds to work oxen early in the rainy season when pastures have not yet regrown. At Inewari, there is no substitute for animals to work the heavy soils. Because Inewari is poor and isolated, there is little market demand for milk, so feed competition is resolved in favor of draft animals.

A better test would be to compare feeding on farms with and without animal traction in the same place, or better yet, on farms before and after adoption. This was not possible from the field data except by looking for differences in feeding practices between different cattle herds at the same

4. Farming systems of the unmechanized highlands have other adaptations to save labor. One is to grow permanent crops, such as bananas, cassava, and coffee, which call for little labor to prepare land.

sites. No major differences were found in favor of draft animals, notably at Machakos, which is the best case because it has a mix of dairy and draft cattle.

The second variant of the poor nutrition argument is that feed competition between power and other animal products prevents feeding to upgrade working capacity. This competition would not so much restrict the introduction of animal traction, but rather its full employment where it is already used. At sites satisfying the basic conditions for mechanization, if feed for draft animals gives a lower return than feed for milk or for fattening, then profitability is a constraint in the sense that feed for draft is an inefficient resource use.

Use of high quality feed for fattening and milk production, but not for power, suggests that selective feeding for draft provides a lower rate of return than the alternatives. Field sites in Kenya and Madagascar illustrate how the feed competition between work and milk can be resolved in favor of the latter. The Kenyan highlands have a very successful smallholder dairy development program (Stotz 1979), so lack of experience with livestock cannot be the reason for the absence of animal traction. In addition, those highlands have high population density, deep soils, and good market access, all of which ought to favor animal traction. The site at Manjankandriany, Madagascar is evolving similarly to the Kenyan highlands. Feed competition from dairying has suppressed animal traction. Many former owners of draft animals sold them, invested in milk cows, and now rent oxen for mechanized field operations. In both cases, feeding for dairy production was superior to feeding for power.

In the unmechanized semi–arid and subhumid zones, competing forms of animal production include extensive grazing and short–term fattening. In the unmechanized highlands, they include short–term fattening and dairy production. While there is no strict test of the effect of feeding on animal traction, field evidence shows no strong relation between draft animal feeding and the success of animal traction.[5] It does suggest that where improved milk production is feasible, then it can reduce the importance of animal power in the farming system simply by offering farmers a better return on their investments.

Benefits from feeding residue and by–products do not derive exclusively from animal traction. In central Nigeria near Kufana, young cattle thrive on maize by–products, grasses, and crop residue. Proximity to a major road and access to young stock purchases from neighboring herders confer other cost advantages. Those advantages—feed, transport, and young stock—could all be put to use in animal traction, but are not because they are more profitable in fattening.

5. Evidence about economic returns to animal feeding is discussed in Chapter 7. An exception to this argument was found by Ingawa (1987) in north central Nigeria.

Rental Markets as Substitutes for Ownership

Chapter 3 discussed rising transaction costs, which make markets and contracts inferior to ownership of draft power. These costs would encourage farmers to own animals for power and not rely on rentals or other forms of markets and contracts.

Field studies show variable ownership of animal traction despite the transaction costs of rentals and other exchanges. There are active rental markets even where animal traction has been widely adopted for many years (Table 4–4). The best example is from the Ethiopian highlands, where many rentals and exchanges occur (Gryseels and Anderson 1983). Another is from the ICRISAT farm management studies in Burkina Faso. In six villages in three agroclimatic subzones of the country, the population proportions of traction ownership were 8 to 10 percent in the driest zone, 7 to 17 percent in an intermediate rainfall area, and 15 to 24 percent in the wettest zone (Matlon and Fafchamps 1988). There were numerous animal traction exchanges among farmers in those zones (McIntire 1982). Norman, Newman, and Ouedraogo (1981) mention rentals at several places in the West African semi–arid tropics.

If transaction costs make rentals inferior to ownership, why is ownership not more general where draft power is feasible? Where animal power has a long history, the main reason is inability to purchase and maintain animals. Those who cannot afford to buy animals rely on rental markets. Where draft power is comparatively new, as in much of West Africa, rental markets further reduce learning costs for new users. A third reason is that rental markets involving animal power allow payment in kind, usually with fodder for the animals themselves. At the eleven field sites where rental terms could be observed, all transactions had some in–kind element, of which crop residue or grazing rights were a part.[6]

The flexibility of rental markets and the speed with which they develop suggest that they promote efficient crop–livestock interactions. Two constraints to efficient interactions would be low capacity utilization of animal traction and the high transport costs of using manure and crop residue. Surveys have shown that because working animals are used for only a few days during the year, their fixed costs of purchase, housing, and veterinary care are not always fully amortized. One clear effect of rentals would be to raise capacity use, thereby lowering the average fixed costs per animal. Second, while it has been argued (Norman, Newman, and Ouedraogo 1981) that draft power transactions are nascent forms of exploitation, they

6. Tied transactions with tractors are uncommon; because the tractor owner has no use for crop residue, he insists on cash payments. At Machakos, the one site with tractor rentals, only cash payments were accepted.

Table 4–4. Number of Sites with Access to Animal Traction, by Environment

Sites and interactions	*Humid*	*Subhumid*	*Semi–arid*	*Highlands*
Number of sites	4	6	11	12
Animal traction ownership				
None	4	5	–	5
Rare	–	–	3	–
Occasional	–	1	2	–
Frequent	–	–	2	2
General	–	–	4	5
Access to animal traction exchanges among non–owners				
None	4	5	2	5
Rare	–	–	5	–
Occasional	–	–	–	2
Frequent	–	1	4	–
General	–	–	–	5
Terms of animal traction access among non–owners				
No access possible	4	5	2	5
Access for				
Unknown terms	–	–	5	–
Cash only	–	–	–	–
Cash plus in–kind	–	1	–	2
Cash plus labor	–	–	–	–
Cash, in–kind, labor	–	–	3	–
In–kind, labor	–	–	1	5

– No sites found which satisfied condition.
Source: Field visits by authors.

actually promote efficient use of such bulky, low value inputs as manure and crop residue via exchanges tied to draft power.

Inadequate Research

A repeated justification for more research on animal traction is that it has been ignored in previous studies. That would imply a failure to generate appropriate animal traction technologies for Sub–Saharan Africa, and hence would have been a cause of the lag in adopting them.

DRAFT ANIMAL RESEARCH. Draft animal research within Africa has received less attention than other topics, notably animal health and reproduction. Even in Zimbabwe, Sudan, and Nigeria, where agricultural research is well developed, there is little or nothing on draft animal power (ILCA 1986, ILCA 1982, Gefu and others 1988). This emphasis would be fully consistent with the priorities in transferring livestock production technologies, because mechanized practices could be more cheaply transferred from abroad without local research than could biological ones. The deficiency in mechanical research is remedied by the ample work in Europe, North America, and Asia, some of which is applicable to African conditions.

ZONAL EMPHASIS. Most animal power work has been where it should have been—in the semi-arid tropics and the highlands. To the great credit of scientists in the humid zone, they realized early that mechanization would fail there because of its destructive effects on the vegetation and soil complex (Muller and de Bilderling 1953, Dumont 1957). Given the physical limitations of this agroclimate, it is unlikely that animal traction research has much to offer without a substantial expansion of lowland rice cultivation, a crop which is a better candidate for mechanization of field operations.

WORK OUTPUT. Experiments to improve the work output of draft animals would appear to be appropriate because they would attack the common problem of working speed. An emphasis on expanding cropped area via working speed would be congruent with the main benefits from draft animals. Examples of such studies would include measures of factors determining work output, such as animal nutrition, animal health, and tool characteristics. Examples are Goe (1987) for highland Ethiopia, and Aw and Traoré (1971), Meda (1972), and Coulibaly (1983) for the semi-arid zone of Mali. There are almost no studies of work animal physiology, feed intake, or disease × work interactions. Such experiments are numerous in India, Japan, the United States, and eastern Europe (Goe and Michael Hailu 1983), however, and many of the results from those sites could be applied to Africa.

OTHER TECHNICAL CHANGES. Work to improve animal traction typically comprises tool design, animal selection and management, and new operations. This work has failed. The main tools used were introduced during the colonial era and have changed little or not at all since then. Efforts to select animals for better working characteristics have washed out. Programs to raise the capacity utilization of working animals by adding new operations (for example, water lifting) have had little impact (Starkey 1988).

A prominent failure of draft animal research has been the assumption that plowing is the only mechanized field operation. This error has been especially serious in the francophone countries, where much effort has been expended on deep plowing with little practical impact (Charreau and Nicou 1971). Such work assumed that primary tillage would be the main mechanized task, and ignored surveys showing weeding to use as much as 80 percent of total labor per hectare. A variant of this error is a study of oxen and donkey power for soil preparation in western Niger (Dicko 1986). In that experiment, soil preparation with animal traction used significantly less labor than did hand labor. Because there is no soil preparation by hand or by any other means in the region, however, the control and the resulting treatment comparison are meaningless.

EXPERIMENTAL BIAS. A major bias is inadequate experimental controls. For example, many cropping practice experiments use the same type of mechanization. It would not be possible to study interactions between cropping practices, power source, and crop yields in such experiments. Experiments may also be biased because they use healthier and better-fed animals than farmers do. If there are interactions among health, nutritional status, and work output, then the experiment is biased with respect to farmer conditions and might not be a reliable basis for making extension recommendations.

Experiments are incomplete in that they have often looked only at the feed response of draft animals, and not at the feed response of other animals in the same environment. It is legitimate to say that supplementation with legume hay and cottonseed cake would increase working capacity relative to an unsupplemented control (Aw and Traoré 1971, Meda 1972). It is not legitimate to say that this is the best feed use, because the experiment failed to prove that the feed could not have been used more profitably in milk or meat production (Goe 1983).

Interactions Between Mechanization and Other Production Techniques

If there is a general association between mechanization and other production techniques, it ought to be evident across zones, and hence would serve as a factor in using animal traction to benefit from closer interactions. Among the benefits would be labor savings in such cropping practices as using animals to incorporate manure or crop residue into the soil, and forming land for cultivation.

Subhumid Zone

The subhumid zones prove that crop–livestock integration is possible without animal traction. Integration there has little relation to animal traction: cropping techniques do not depend on it, nor does selective feeding. Some aspects of integration, including use of manure and crop residue feeding, developed before animal traction or after introduction of animal traction had failed.

If animal traction bore any necessary relation to the use of other animal inputs, notably manure, more consistent relations would appear at the same level of mechanization. Yet in Nigeria, there are sharp contrasts in interactions between the Abet/Ganawuri/Kufana area and the Shaki/Fashola area, at the same level of mechanization. Observations in Abet/Ganawuri/Kufana, and research summarized by von Kaufmann and Blench (n. d.), show well-developed systems of manure and crop residue interactions within and between cultivating and herding groups. Cultivators exchange crop residue grazing rights for manure with Fulani herders to whom they entrust animals, yet neither group employs animal traction.

Field observations around Shaki/Fashola show no manure use, indifferent crop residue use, and little contact between farmers and herders. Yoruba cultivators also entrust animals to the Fulani, but do not receive manure and exercise no control over their crop residue grazing. Those systems have existed for many years with no relation to mechanization.

Comparisons between the subhumid and semi-arid zones of Nigeria demonstrate that animal traction is not a condition for some cropping techniques. In Abet/Ganawuri/Kufana, ridging is common without mechanization, just as it is common with mechanization in the semi-arid zone. While the quality and durability of ridges in the semi-arid might be superior, animal traction is not a condition for them, nor is animal traction a condition for cultivating lowlands. Subhumid zone farmers grow rice and vegetables in lowlands without mechanical tillage, just as is done in the semi-arid zone.

Semi-Arid Zone

A general association between animal traction and collateral techniques ought to be most evident in this zone. The semi-arid sites do present contrasting crop-livestock interactions which are at least partly determined by the presence of animal traction (Table 4-5).

In Niger, with no animal traction, intensification of animal production is manifested in a shorter grazing ambit, disruption of traditional entrustment contracts, more selective feeding of small ruminants, and crop residue exchanges. In Kenya, where animal traction has dominated for at least 30 years, intensification of animal production is manifested in similar ways, including privatization of pasture grazing, restricted access to crop residue by outsiders, and manure production from confined animals.

The ICRISAT studies of semi-arid agriculture in Burkina Faso revealed sharp contrasts in manure use between households owning animal

Table 4–5. Contrasting Crop–Livestock Interactions at Semi–Arid Sites

	Mechanized sites			*Unmechanized sites*	
Interaction	*Machakos, Kenya*	*Kianjasoa, Madagascar*	*Masvingo and Mvuma Zimbabwe*	*Zarmaganda and Boboye, Niger*	*Ziga, Burkina Faso*
Grazing	Private pastures	Common	Common	Shorter grazing ambit	Shorter grazing ambit
Crop residue use	Restricted access, market terms	Restricted access, no market	Restricted access, emerging market	Restricted access, emerging market	Restricted access
Manuring	By–product of stall feeding	By–product of stall feeding	By–product of stall feeding	Exchanges	Exchanges
Species and breed mix	Crossbred milk draft oxen	Draft oxen	Draft oxen	Small ruminants, beef cattle	Small ruminants, beef cattle

Source: Field visits by authors.

traction and those not owning it. Such differences were also found by Norman, Simmons, and Hays (1982, p. 188) in northern Nigeria. These contrasts are due mainly to difference in cattle numbers among households. Those without draft animals had few cattle; those with draft animals had more cattle and more manure. This tends to confirm the argument in Chapter 3 that constraints to gaining manure via markets or contracts—in this case, the constraint is the use of manure by cattle-owning households—sometimes encourage farmers to adopt mixed farming in order to maintain soil fertility. However, this does not show that animal traction is a condition for greater manuring.

Highland Zone

Sites in Madagascar and Rwanda allowed comparisons of the effects of migration within those countries on mechanization and its associations with collateral techniques (Table 4–6). In Rwanda, migration produced no change in mechanization. Field work is exclusively by hand in the regions of origin and of settlement. Several potential roadblocks are not responsible for stopping mechanization: unfamiliarity with cattle, trypanosomiasis, or lack of feed. Migrants raised cattle in their regions of origin and in their regions of settlement. The region of settlement had cattle after tsetse was eradicated around 1970. Lack of feed is not a problem because natural vegetation is abundant, residue is available from cereal crops, and forage grasses are widely grown in both regions.

In Madagascar, migration changed mechanization. Farmers moved from the plateaux, shifted their cropping patterns, and increased their farm sizes. The adoption of animal traction took place very quickly with the help of a rental market; respondents said that they learned the technique in less than a full year. Unfamiliarity with cattle and trypanosomiasis had nothing to do with the presence or absence of animal traction.

In both Rwanda and Madagascar, collateral techniques existed without animal traction. These include manure production, erosion control works, and valley cultivation, all of which are done by hand. Animal traction in Madagascar did allow manure incorporation, but did not stimulate crop residue incorporation.

Effects of Animal Traction on Crop–Livestock Competition

In terms of the competition model of Chapter 3, benefits to animal traction can be seen as decreases in livestock production costs. Such cost savings would create more incentive to own cattle and shift the mix of activities from crops to livestock. In principle, the benefits of mechanization are in cultivated area, better yield per unit of land, more profitable cropping patterns, and labor productivity. Draft animals may further affect the

Table 4–6. Cropping Changes Following Resettlement within Rwanda and Madagascar

Region	*Madagascar*	*Rwanda*
Old region	Central plateaux	Biyumba, Ruhengeri
Major crops	Sweet potato, taro, coffee, rice	Potato, wheat, pigeon pea
Soil fertility management	Collected manure, compost, rare fertilizer. Incorporate manure by hand or ox trampling	Direct manuring, paddocking, little composting, no fertilizer
Soil fertility transactions	Occasional manure transactions	No manure exchanges
Power source	Hand	Hand, rare animal traction
Lowland grazing	Little or none	Little or none
New region	Kianjasoa	Bugasera
Time of settlement	10–15 years	15 years

Major crops	Rice, cassava, maize, groundnut, bambara groundnut	Beans, sorghum, Cassava, banana, coffee
New crops tried	Unknown	Soybean, cassava, yam, groundnut
Soil fertility management	Direct manuring, no compost, no produced manure, rare fertilizer. Incorporate manure with ox traction, burn straw in field without incorporation	Compost with manure, coffee mulch, no fertilizer, no direct manuring, no paddocking. Spread manure in field
Soil fertility transactions	Rare manure exchanges	Manure barter, manure sales
Power source	Oxen	Hand
Lowland cropping	Long–standing, conflicts with rice production	Began in 1976, has now replaced grazing

Source: Field visits by authors.

overall stocking rate and the methods of fodder production. The balance of this chapter reviews the possible cost savings from animal traction.

AREA INCREASES. Mechanization might increase cropped area by allowing faster work per unit of land. In a review of nineteen studies, Pingali, Bigot, and Binswanger (1987, pp. 98–102) found that area cultivated per family member was 25 percent greater where animals were used for cropping. The area effect in 'favorable' regions (more than 750 millimeters annual rainfall) was not different from that in 'unfavorable' (less than 750 millimeters). The papers reviewed do not indicate if the expansion in cropped area came from fallow, pasture, or other cropped areas excluded from the survey samples, but given the nature of much of African land tenure, the expansion likely came from fallow or pasture.

YIELD INCREASES. In principle, animal traction creates better yields by upgrading the quality and timeliness of farming operations. Measuring the crop yield effect of mechanization has been difficult, however, because it is often confounded with other changes. Because many studies are done in association with development projects providing fertilizer, credit, extension, or seeds, it is sometimes impossible to separate the effect of animal traction from that of other inputs.

The pure yield effects of mechanization, as estimated from field studies, are typically small. There were few marked effects on the quality and timeliness of cropping operations. The yield effects alone did not appear sufficient to justify investment in animal traction without area increases or labor savings (Pingali, Bigot, and Binswanger 1987, pp. 102–103). The failure to find a major yield effect independent of other inputs suggests that draft animals by themselves would not affect livestock production costs by promoting higher crop yields.

CROPPING PATTERN. Mechanization might save labor and allow farmers to employ a more remunerative cropping pattern. More than area or yield effects, this cropping pattern effect would depend on new crops, irrigation, improved cultivars, and fertilizer. To simplify greatly, most of African agriculture—rainfed, with local cultivars, and no fertilizer—presents few unexploited opportunities with traditional technology. While Pingali, Bigot, and Binswanger (1987) found cropping pattern effects in two-thirds of the papers they reviewed, those effects were small. This is to be expected because most of the studies were done in the semi-arid tropics where the agroclimate imposes a simpler cropping pattern. The main effect was associated with cash crops, such as cotton, groundnut, and rice.

LABOR PRODUCTIVITY. Mechanization ought to reduce labor costs per unit of area. It would thereby release labor from field operations for manuring, incorporating crop residue, and other operations too arduous to be performed easily by hand. Pingali, Bigot, and Binswanger did indeed find that the labor savings per unit of area were consistent, but small. Despite labor savings per unit of land, however, labor use per farm apparently rose. Because the positive area effect on total labor use was greater than the negative effect on labor per unit of area, mechanization would not release labor for other activities (Pingali, Bigot, and Binswanger 1987).

Mechanization's labor effects can also be seen in the history of adoption of new cropping activities. If animal traction saved labor, then it would be expected to be associated with new cropping operations. For example, many of the French experiments (summarized for central Senegal by Charreau and Nicou 1971) with deep plowing, basal fertilization, and residue incorporation assumed that animal traction would release labor and thus permit those new operations. However, even with rapid growth of animal traction, those operations were never widely employed.

STOCKING RATES. If animal traction provided few benefits in terms of area, yields, cropping pattern, or labor economies, then it ought not to affect the general stocking rate because it would not change livestock production costs independently of other factors. The one study of a shift from extensive cattle production to a more intensive one with animal traction is that of Philippe Lhoste (1989) in central Senegal. Lhoste found that animal traction itself did not seem to have caused major changes in the stocking rate, independent of the general intensification of the farming system.

Without such a change in the general level of stocking, animal traction would not have provided greater incentives to grow forage crops. Existing feeds—natural pasture, browse, and crop residue—would be sufficient. Animal traction has been associated with changed feed management, notably privatization, harvesting, and storing crop residue, but these were the results of intensification, which could have occurred without mechanization.[7]

LAND COMPETITION. How does animal traction affect overall land competition between crops and animals? This issue can be studied with the land competition model of Chapter 3, using some assumptions about the effects of draft power. First, the independent yield effects of draft power are small, so it would not appear to relieve land pressure by raising productivity per unit of land. Accordingly, yield effects are assumed to be zero. Second, cropping pattern effects appear to create some shift toward

7. At a given stocking rate, better quality draft animals might also fetch higher prices in the live animal and meat markets, thus shifting comparative advantage toward livestock.

cash crops, more so in 'favorable' areas. Therefore, using draft power would raise total incomes and might permit greater purchases of food from outside the region adopting animal traction. This effect is not modeled, but is useful to keep in mind. Third, using animals for power is assumed to have no impact on feed intake per animal.

The effect on cropped area is the primary effect modeled. This is assumed to be 25 percent, a value consistent with some empirical studies. At a given population density, cropped area would expand by 25 percent with animal traction compared to the previous situation. The impact of animal traction on feasible monthly stocking rates at different levels of population density is shown in Figure 4–1. At a population density of 40 persons per square kilometer, draft power had no effect on the dry season stocking rate and reduced the maximum rainy season stocking rate by about 5 percent. At population densities of 80 and 160 persons per square kilometer, the rainy season effects were about 11 and 44 percent, respectively. The dry season effects were roughly zero.

Summary

The role of animal traction in crop–livestock interaction can be summarized under three general topics: why it should not be an organizing theme for projects, and the introduction and improvement of animal traction.

Animal Traction Should Not Be an Organizing Theme for Projects

In humid environments, animal traction will not be competitive with hand–tool cultivation in cost per unit of output without a major change in the farming system to one in which the lowlands are much more intensively exploited.

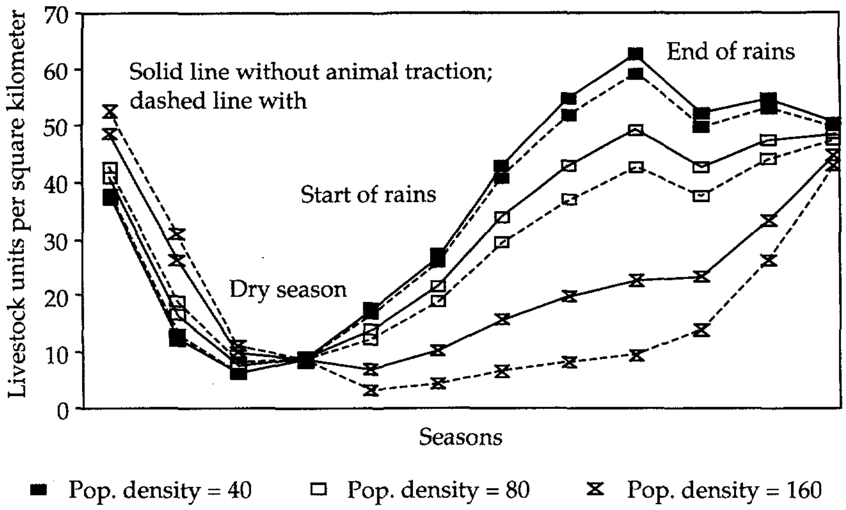
In other environments, animal traction will be competitive, but is retarded by specific barriers, such as the effects of trypanosomiasis and other livestock diseases, hilly topography which makes mechanized cultivation difficult, and lack of knowledge about animal production among farmers.

Introducing Animal Traction

The first step is to establish that the base conditions of population density and market access favor mechanized cultivation. Without those conditions it is much more difficult to shift from hand–tool cultivation to any form of mechanization.

A cash crop is a nearly universal condition for rapid introduction of animal traction into an area where it had not previously existed. A cash crop can catalyze the shift from hand tools to animal traction even without research and extension beyond adaptation of existing tools and methods.

Figure 4–1. Feasible Stocking Rates With and Without Animal Traction at Varying Population Densities



Better nutrition of draft animals is not likely to facilitate the entry of animal traction into a farming system because the economics of supplementary feeding to such animals are unfavorable. The authors did not observe farmers practicing selective feeding of draft animals at early stages of adoption, but rather only where animal traction was well established.

There has been enough research carried out under African conditions that much of the knowledge needed for introduction of animal traction is already available. Moreover, other knowledge, especially of techniques for using and maintaining agricultural machinery, is available from outside Africa. However, further research is needed on some topics which do not appear to have been studied enough, such as interactions between livestock disease and work output, and animal nutrition and work output.

Public credit is a legitimate substitute for private credit to facilitate the entry of animal traction for reasons discussed in Pingali, Bigot, and Binswanger (1987), but only if the cost of animal traction cultivation, including the costs of credit, is less than that of hand cultivation.

Improving Animal Traction

Working efficiency is a major constraint to lowering the costs of cultivation with animals, but improving it faces a number of obstacles which are discussed below.

Supplementary feeding is likely to be unfavorable economically because the value of output from feeding draft animals is typically less than that of animal fattening or milk production. The feeding period for draft animals is short, so the fixed costs of forage production are quite high in comparison to the use of crop residue, browse, and other fodder for draft animals.

The redesign of experiments with supplementary feeding and sown forages to consider resource competition between work and other inputs would be beneficial because more specific extension recommendations to farmers would be available.

Although it may be necessary to study alternative means of reducing the feed cost of draft animals, including tractor rentals, cow traction, reducing the numbers of animals in the span, mechanization with engines, or new tools, many of these alternatives have been tried and failed. Proposals to try these options again should always be preceded with an adequate literature review.

Disease × work interactions have not been generally studied because of the complexity of the problem. They should be a priority, especially in the subhumid zones.

5

The Pattern of Soil Fertility Maintenance

Low soil fertility is a critical constraint to African agriculture.[1] Typical recommendations to amend fertility include increasing the nutrient supply by adding fertilizer and raising soil organic matter with manure applications. Improved crop–livestock integration would achieve the latter, and as Hartwig Schafer pointed out in a 1988 internal World Bank document, this presumed benefit has always been a strong selling point for many projects.

Manure can indeed be a major benefit of crop–livestock integration. Research demonstrates that it provides soil nutrients, raises soil pH, and might permit stable intensified cropping systems (Padwick 1983, Mokwunye 1980, Pieri 1986). Studies from many African sites verify that manure raises yields and improves soil organic matter content (Jones 1971, for Nigeria; McWalter and Wimble 1976, for Uganda; Pichot and others 1981, for Burkina Faso).

Despite such positive research results, the authors' field visits confirmed the findings of many farm management studies, which demonstrate that manure is often employed only on small areas, and sometimes not used at all (examples from three zones of Burkina Faso are found in Matlon and Fafchamps 1988; examples from the Ethiopian highlands are in Gryseels and Anderson 1983). Where it is employed, manure is used in an agronomically inefficient way: it is rarely stored, mixed with litter, composted, or incorporated into the soil. Failure to adopt those practices exacerbates the loss of organic matter and nutrients contained in manure to leaching, evaporation, and microbial action, thus curtailing the technical efficiency of manure use.

Unfavorable economics explain the failure to use more soil fertility inputs. Fertilizer use per hectare is much lower in Africa than in other

1. For several zones in Africa, see the papers in Mellor, Delgado, and Blackie (1988); for the West African subhumid and semi–arid zones, see Kowal and Kassam (1978), pp. 21-27.

regions of the world (McIntire 1986). The demand for soil fertility inputs is weak in some African farming systems because a fallow period is available. The high labor and transport costs per unit of manure make it expensive per unit of nutrient. Weak crop responses to fertilizer—due in part to sparse rainfall, poor soil quality, an absence of irrigation, and lack of improved crop cultivars—mean that it is profitable only at relatively small doses. Supply restrictions and other government policies sometimes depress the use of fertilizer.

A commonly proposed remedy for soil fertility problems is crop–livestock integration, but as this chapter shows, integration as a model for intensified soil fertility management is not always necessary. Markets and contracts can sometimes provide fertility inputs more efficiently than mixed–farming. Even where fallow has disappeared and crop–livestock integration is more advanced, land competition between crops and livestock causes the cost of manure to rise, hence compromising a benefit of mixed farming. Because closer integration will often do nothing to resolve the problems of soil fertility management in many African farming situations, it is less attractive as a general resource management system.

Productivity Effects of Organic Inputs

A basic issue in analyzing the profitability of crop–livestock integration to promote better soil fertility management is whether organic inputs raise crop yields and soil quality. The following discussion reviews animals as both a source of fertility through use of manure and as competing users of crop residue which can be fed to stock or mulched.

Crop Yields

The primary concern is the relative efficiency of organic materials compared to chemical fertilizer. If animal manure and vegetative mulch give better production responses, or if they have better long–term responses in terms of yields or soil quality, then they ought to have more weight in extension programs because they would be more efficient compared to other sources of fertility.

MANURE. Soil fertility studies (summarized in Tables 5–1 and 5–2) have been carried out in all agroclimates, including efforts at Samaru, Nigeria (Jones 1971, 1976); Bambey, Senegal (Charreau and Nicou 1971, Ganry and Bideau 1974); Saria, Burkina Faso (Pichot and others 1981); M'Pesoba, Mali (Pieri 1973); Tarna, Niger (Pichot and others 1974); Serere, Uganda (McWalter and Wimble 1976); and at the International Institute for Tropical Agriculture (IITA) in Ibadan, Nigeria (Okigbo and others 1980, Lal and Greenland 1979). They prove the nutrient concentration in organic materials to be dilute.[2] In Burkina Faso, Pichot and others (1981) found manure to contain 1.5 to 2.5 percent N, about 0.2 percent P_2O_5, and 1.6 to 4.5 percent K_2O. In Ghana, Kwakye (1980) found N contents from 0.7 to 1.5 percent, P_2O_5 from 0.5 to 0.6 percent, K_2O from 1.3 to 2.1 percent, and dry matter from 22 to 27 percent. McWalter and Wimble (1976) reported values in Uganda of 1.9 percent N, 0.9 percent P_2O_5, 3.6 percent K, and 36.1 percent dry matter.

SPECIFIC EFFECTS OF MANURE. The idea that manure gives different responses from fertilizer at equal quantities of nutrients is called the 'specific effect' hypothesis. Experiments tabulated in Tables 5–1 and 5–2 indicate that manure produces output responses, when expressed in weights of grain produced per weight of plant nutrient, which are similar to expected responses from chemical fertilizer. In other words, manure does not produce responses different from fertilizer at equal concentrations when applied with similar methods and in similar conditions. This is consistent with Padwick's (1983) review of African soil research, which found no specific effect.

LONG-TERM EFFECTS OF MANURE. The contention has been made that manure would have a stronger cumulative effect, thus permitting it to replace fallows or chemical fertilizer. McWalter and Wimble (1976) examined this hypothesis in Uganda. An experiment beginning in 1933 and continuing until 1964 investigated the effects of type of fallow, length of fallow, and manure, on yields of cotton, sorghum, finger millet (*Eleusine coracana*), sweet potato, and groundnut over six 5-year cycles at three manure levels. All treatments on sorghum, finger millet, and sweet potatoes had a declining yield trend. A ton of manure produced 19 to 23 kilograms of sorghum in cycles II and III, and 31 to 39 kilograms in cycles IV and V. These increased responses did not prevent long-term yields from decreasing from cycles II to V. While the marginal product of manure rose in later cycles, manure did not prevent yields from declining over the course of the experiment, and hence could not completely replace fallow and chemical fertilizer.

MULCH. In the humid zone (Table 5–3), IITA scientists at Ibadan found significant responses in grain and cassava to applications of maize stover and cassava stems, as well as to many other organic and inorganic mulches (Okigbo and others 1980, Lal and Greenland 1979). Positive responses have also been observed with crop residue and grasses in drier

2. Padwick's review (1983) of the maintenance of soil fertility in tropical Africa noted the lack of information on manure in some experiments. For this reason, it has not been possible to include information here from all fertility experiments.

Table 5–1. Summary of Eight Soil Fertility Experiments in Sub-Saharan Africa

Experimental factor	*Ganry and Bideau 1974*	*Pieri 1973*	*Pichot and others 1981*	*Pichot and others 1974*	*Jones 1971, 1976*	*McWalter and Wimble 1976*	*Chabalier 1986*	*Okigbo and others 1980*
Location	Bambey, Senegal	M'Pesoba, Mali	Saria, Burkina Faso	Tarna, Niger	Samaru, Nigeria	Serere, Uganda	Bouaké, Côte d'Ivoire	Ibadan, Nigeria
Environment	Semi-arid	Semi-arid	Semi-arid	Semi-arid	Subhumid	Subhumid	Subhumid	Humid
Crops	Pearl millet	Cotton, sorghum, groundnut	Sorghum	Pearl millet	Sorghum, maize, groundnut, cotton	Groundnut, maize, finger millet, cotton, sweet potato	Maize	Maize cowpea, cassava, soybean

Organic materials	Pearl millet straw	Manure	Manure	Pearl millet straw	Cattle dung, sorghum and maize straw, groundnut hulls	Manure	Composted maize straw	Numerous mulches
Application method	Composted, incorporated	Unknown	Incorporated	Incorporated	Incorporated	Unknown	Composted, incorporated	Spread
Application rate (metric tons per hectare)	0, 11, 15	0, 10, 20	0, 5	0, 10	0, 2.5, 5.0, 7.5, 12.5	0, 6.3, 12.6	40	0, 10, 15, 25
Fertilizer (kilograms of nutrient per hectare)	N: 0, 30, 60, 90, 120, 150	Unknown	N: 8 P: 24	N: 0, 45, 90 P: 20 S: 25	N: 0–52 P: 0–30 K: 0–30	None	N: 0, 40, 80, 120, 160, 200 P: 100 K: 150	N: 0, 30, 40, 120 P: 0, 20, 30, 90 K: 0, 20, 40 60

Table 5–2. Results of Manuring Experiments at Five Sites

Location and crop response	*Pieri 1973*	*Pichot and others 1981*	*Pieri 1986*	*McWalter and Wimble 1976* [a]	*Stephens 1969*
Location	M'Pesoba, Mali	Saria, Burkina Faso	West Africa	Serere, Uganda	Uganda
Response to manure without chemical fertilizer [b]					
Sorghum	32.4	–	57.8	23.2	–
Maize	–	–	–	–	54.0
Finger millet	–	–	–	15.2	86.0
Groundnut	13.9	–	–	–	26.5
Response to manure with chemical fertilizer [b]					
Sorghum	11.7	93.7	79.5	–	–
Groundnut	9.1	–	–	–	–

– Indicates that a response was not available or could not be calculated from the reference. Responses were calculated at the reported treatment means for crop yields by (treatment yield - control yield)/input quantity.

a. Values are in cycle 3 of the experiments at 6.3 metric tons per hectare of manure without chemical fertilizer.

b. Kilograms of crop per metric ton of manure.

zones. Pichot and others (1981) reported responses in Burkina Faso of 35 kilograms of sorghum grain per ton of incorporated straw at Saria, and 45 kilograms per ton at Farako–Ba when 10 tons were used. When 20 tons were used, the gains were 18.3 and 33.3 kilograms per ton, respectively. Experiments with pearl millet on sandy soils in the semi–arid tropics showed a response on the order of 20 kilograms of grain produced per ton of residue incorporated (Pieri 1986, Pichot and others 1974).[3]

Summary of Evidence on Yield Effects. The basic point for agricultural extension is that there is a weak positive effect of manure and mulch on

3. Incorporating pearl millet residue sometimes depressed subsequent crop yields. However, Ganry, Roger, and Dommergues (1981) found no depressive effects of plowing crop residue (especially from pearl millet) into sandy soils in central Senegal if the residue was composted or plowed into damp soil just after harvest.

Table 5–3. Results of Mulching Experiments at Five Sites

Location and crop response	*Ganry and Bideau 1974*	*Pichot and others 1974*	*Pieri 1986*	*Heathcote 1970*	*Okigbo and others 1980*
Location	Bambey, Senegal	Tarna, Niger	West Africa	Samaru, Nigeria	Ibadan, Nigeria
Response to mulch without chemical fertilizer [a]					
Sorghum	–	–	-17.9, 67.4, 47.3	43.0	–
Maize	–	–	–	62.2	–
Pearl millet	12.0	17.5	–	–	–
Response to mulch with chemical fertilizer [a]					
Sorghum	–	–	63.1, 89.2, 80.5	–	40.0, 23.5
Pearl millet	23.0	-10.0	–	–	–
Cassava, fresh tubers	–	–	–	–	301.3

– Indicates that a response was not available or could not be calculated from the reference.

Note: Where more than one value is given in a cell, either methods differed within the experiment, or more than one year was reported.

a. Kilograms of crop per metric ton of mulch.

crop yields, as demonstrated in many careful studies in all agricultural environments. A second issue is the relative efficiency of chemical fertilizer, manure, and mulch. The scientific literature is not definitive about comparisons between different soil amendments because they were typically studied in the presence of chemical fertilizer. Where animal production is important, there is some indication that manure is superior to cereal crop residue, as was shown in the Saria and Samaru experiments reported by Jones (1971, 1974, 1976). Third, the specific effect of manure, if it exists, is small. This means that organic treatments can be compared directly to fertilizer on the basis of cost per unit of nutrient, and there would be no basis for recommending organic materials over fertilizer unless they were cheaper to produce, distribute, and apply.

Soil Quality

Important questions concern the effect of manure on soil quality and its interactions with fertilizer. If manure gives specific or long–term benefits in terms of soil quality, then crop–livestock integration would provide benefits in addition to those of fertilizer.

Jones (1971) studied the effects of cattle dung, fertilizer, and mulch at Samaru, Nigeria with data collected from 1949 to 1969. In a trial without fertilizer, soil carbon and nitrogen rose over an 8–year cropping period when 7.5 and 12.5 metric tons of manure per hectare were applied, but not with lesser quantities (Table 5–4). In an experiment with fertilizer, soil carbon and nitrogen rose over 9 years of cropping; soil C and N declined when only 2.5 metric tons per hectare of manure were applied, and stabilized with 5.0 metric tons per hectare.[4]

Pichot and others (1981) reported 20 years of continuous trials on sorghum at a semi–arid site near Saria in Burkina Faso. Continuous cultivation diminished soil quality. Manure and a light fertilizer treatment improved the soil, but crop residue alone did not. A light fertilizer application with manure was superior to a heavy fertilizer application without manure.

Chabalier (1986) studied the effects of fertilizer nitrogen and composted maize straw on crop yield and soil quality after 11 years at a subhumid site at Bouaké, Côte d'Ivoire. The effect of 40 tons of fresh compost per hectare was roughly 51 kilograms of grain per ton of composted dry matter. The interaction between N and compost was small in the first 5 years of the trial and positive in the following 6 years. With compost, 40 kilograms of N per hectare gave the same result as 200 kilograms N per hectare without compost. While compost maintained fertility for a few years in a new field, even high levels of compost did not completely prevent long–run soil degradation caused by continuous cropping.

A summary of evidence from different agroclimates suggests that applying large quantities of manure can reduce, but not eliminate, soil degradation caused by continuous cropping. Organic materials can substitute in part for heavy doses of fertilizer. There is probably a small positive interaction between organic materials and the response to chemical fertilizer. This suggests that there are substantial soil quality benefits to organic fertilizer which would justify crop–livestock integration, but that such organic sources could not entirely replace fertilizer. Because the experiments from which these conclusions are derived treat manure as a free good, they

4. The Samaru experiments to 1967 may have over estimated the true soil effects of cropping because all residue was removed from the plots. While farmers remove most of the crop residue, there is some left after grazing and trampling. This residue would restore organic matter to the control plots and reduce the estimated effects from treated plots. In northern Nigeria, van Raay and de Leeuw (1971) showed that 34 percent of sorghum residue was edible, all of which was grazed. Their results imply that about 5 metric tons per hectare of crop residue dry matter are left after grazing.

Table 5–4. Effects of Organic Materials on Soil Quality

	Percent change in	
Treatment	*Soil carbon*	*Soil nitrogen*
Trials without chemical fertilizer [a]		
Manure, 1961–1969 (metric tons per hectare)		
0.0	-12.0	-20.0
2.5	-6.0	0.0
7.5	22.0	25.0
12.5	34.0	27.0
Mulch trial, 1961-1970 (metric tons per hectare)		
5.0	43.0	33.0
Trials with chemical fertilizer [b]		
Trial 1, manure, 1959–1967 (metric tons per hectare)		
0.0	-32.0	-35.0
2.5	-7.0	-19.0
5.0	0.0	-11.0
Trial 2		
8-24-0 (kilograms per hectare of NPK)	-17.0	-5.0
Control (1969–1978)	-14.0	22.0
Plus crop residue	-19.0	-36.0
Plus 5 metric tons of manure per hectare	13.0	52.0
82-48-51 (kilograms per hectare of NPK)	-23.0	4.0
Plus 40 metric tons of manure per hectare	25.0	15.0

a. Soil carbon and nitrogen figures in the manure trial without chemical fertilizer are the differences between values in 1961 and 1969 as a percent of the 1961 value. The mulch trial values are the differences between the 5 metric tons of mulch per hectare and the control as a percent of the control in 1970, after nine years of cropping.

b. In Trial 1, the soil carbon and nitrogen figures are the differences between values in 1959 and 1967 as a percent of the 1959 value. In Trial 2, the figures are the differences between values in 1978 and 1969 as a percent of the 1969 value.

Source: Jones 1971.

cannot necessarily serve as a reliable guide to designing farming systems or making recommendations to farmers. The problem of the resource cost of manure is treated in a later section of this chapter.

Demand for Soil Fertility Inputs in Different Agroclimates

The theory of agricultural evolution argues that the type, quantity, and technique of soil fertility management are functions of agroclimate and population density, using the assumption that farmers make rational use of available resources. If this is true, it suggests that programs of information and extension can do little to increase use of soil fertility inputs without greatly increasing their supply. Field evidence strongly confirms this part of the theory (Table 5–5).

Humid Sites

In the humid zones, fallen vegetation from trees and bushes is the dominant form of fertilization. Because animal manure is not available, there must be a continuous recycling of vegetation from different levels via a type of self–mulching with cultivated species after destruction of the primary forest. Variations from the pattern are caused by variation in population density and stocking rates. Where there is little ruminant production and population density is very low, as in the Congo, then fallows are the main technique (Miracle 1967, pp. 41–133, for the Congo Basin). Where there is extremely high population density, as in parts of southeast Nigeria, fallow has disappeared (Lagemann 1977, field visits by authors).

Even where there is animal production at humid sites, manuring is rare if population density is sparse. At one site in southwest Nigeria, owners of large herds used no manure at all on their crop fields. At humid field sites with high population density, there were indications of more intensive manure use in southeastern Nigeria, despite the absence of cattle. On plots near households, sheep, goat, and chicken droppings were added to the soil along with household wastes and fallen vegetation. This is the pattern found by Lagemann (1977) for southeastern Nigeria, Ruthenberg (1983) throughout the humid tropics, and Miracle (1967) for the Congo Basin.

Subhumid Sites

Stocking rates rise throughout the subhumid zone as animal disease becomes less menacing. Manuring begins to complement fallow and mulching, and manuring arrangements occur between herders and farmers. Manuring interactions were observed in the field visits to Côte d'Ivoire and central Nigeria. Many studies have noted manuring around the same sites

(Bernardet 1984 and Landais 1983, for northern Côte d'Ivoire; von Kaufmann and Blench n.d., for Nigeria). Paddocking of animals on staple crops is the main technique. There were almost no instances of intensive manure production, and few of manure collected and transported by carts.

Powell (1986a) described the effect of population density on manuring interactions in two places within subhumid Nigeria. Manure contracts between farmers and herders were common in a more densely populated village and were tied to land access. Fifty percent of the farmers in the village hired Fulani herders to camp their animals on fields. Cash or in-kind payments were made according to herd size and manuring period. Manuring was less common in a less densely populated village and manuring contracts did not exist there.

Semi-Arid Sites

Animal manure is an essential part of soil fertility management in the semi-arid tropics, but there are marked differences among the semi-arid sites in manuring techniques associated with population density and the farming system. In one site of sparsely populated western Niger, farmers maintain fertility by bush and grass fallows, and no one uses chemical fertilizer. Manure is employed, but is limited to fields near households. The scarcity of animals limits manuring because most people own no cattle. There is no manure production or composting; collected manure is simply spread without incorporation. At another Nigerien site with higher population density, many cattle, and resident herders, fallows are scarcer and manuring is more common, although chemical fertilizer is not used.

There are mixed strategies at more densely populated semi-arid sites. In Zimbabwe, communal farmers use chemical fertilizer, manure, and some fallow, although this is not always true elsewhere in Zimbabwe.[5] Cattle manure is mixed with crop residue in corrals, spread, and later incorporated by animal traction at plowing time. There are few manure exchanges, sales, or barters. Kenyan farmers near Machakos employ manure, some fallow, and occasional fertilizer. Manuring is semi-intensive since it is produced in sheds, occasionally mixed with straw, spread, and then incorporated by plowing.

Highland Sites

Soil fertility management is most intensive in the highlands. Manure use was improved at only seven sites, all highland except for Machakos. In

5. Consumption of chemical fertilizer by Zimbabwean communal farmers has risen greatly since independence in 1980, particularly on food crops.

Table 5–5. Soil Fertility Practices Observed at the Field Sites, by Environment

Sites and practices	*Humid*	*Subhumid*	*Semi–arid*	*Highlands*
Number of sites	4	6	11	12
Shares of area in fallow				
None or very little	2	1	1	10
Moderate	–	–	8	2
Extensive	2	5	2	–
Legume cropping				
None or very little	2	5	1	3
Mainly as sole crop	–	1	2	7
Mainly as intercrop	2	–	8	2
Mulching				
None or very little	–	6	10	7
Passive [a]	4	–	–	3
Active [b]				
Coffee only	–	–	–	2
Other crops	–	–	1	2
Chemical fertilizer				
Frequency				
None	2	2	2	1
Rare	–	–	–	3
Occasional	2	–	9	6
Often	–	4	–	3
Always	–	–	–	–
Main use				
Food crops only	2	2	8	5
Cash crops only	–	1	1	4
Mix of food and cash crops	–	1	–	–
Used on sown forages	–	–	–	3
Manure				
Frequency				
None	2	2	–	–
Rare	2	–	–	3
Occasional	–	1	5	2
Often	–	3	6	1
Always	–	–	–	6
Main use				
Food crops only	–	2	11	5
Cash crops only	–	–	–	–
Mix of food and cash crops	–	2	–	4
Used on sown forages	–	–	–	2

Sites and practices	*Humid*	*Subhumid*	*Semi-arid*	*Highlands*
Main types				
Paddocking	–	6	7	–
Stall	2	1	4	6
Compost	–	–	–	3
Improved production techniques				
Mix with soil	–	–	–	–
Mix with litter	–	–	1	7
Application techniques				
Spread	2	4	11	8
Incorporate	–	–	3	3
Burn	–	–	–	1

– None observed at this site.
Note: There can be double counting of the main types of mulching and manuring.
a. Mulching is considered passive when plant material is simply left lying in fields.
b. Mulching is considered active when plant material is cut or collected and subsequently placed or incorporated in a field.
Source: Field visits by authors.

Kenya, the absence of fallow and the presence of permanent cash crops, mainly tea and coffee, create a strong demand for manure and fertilizer. This demand is met largely by manure produced from stabled cattle.[6] Since many cattle are on zero grazing, and all are stabled at some point during the day, there is good quality manure production based on Napier grass and crop residue. Manure is spread throughout the year and is sometimes incorporated by hand. In the Great Lakes countries, vegetable and animal wastes—banana leaves, other crop residue, maize and sorghum bran, weeds, and manure—are composted and spread in the fields.

Effects of Migration Within Two Countries

The field visits examined two instances when farmers moved from one agroclimate to another within a country, in Madagascar and Rwanda (Table 4–6). In each country, farmers moved from more to less densely populated places, which were also lower, hotter, and drier. In the lowland sites, the expectation that soil fertility techniques would become less intensive because more land is available was validated.

Migrants from the central plateaux of Madagascar formerly collected manure and compost which they incorporated by hand or by trampling

6. Some demand is met partly by manure exchanges between the highlands and the lower pastoral zones, and small local sales.

with oxen. Upon arrival at the lower site near Kianjasoa, they rapidly adopted animal traction, pastured cattle in harvested fields, and started incorporating manure with animal traction. Although composting disappeared in the move from the plateaux to the west of Madagascar, manure incorporation was still practiced, with the addition of animal traction.

Migrants from very densely populated Ruhengeri, Rwanda, were resettled to Bugasera in the 1970s. In Ruhengeri, there was direct application of manure with occasional paddocking, widespread composting, and no fertilizer. For example, the national agricultural census of Rwanda reported that 86 percent of farmers in Ruhengeri had compost pits (SEAS 1987, Volume I, Report I, p. 50). At Bugasera, manuring became less intensive because of the presence of grassed anti–erosion works which prevent direct manuring by animals or field grazing of crop residue.

Relieving Constraints to Better Soil Fertility Management by Crop–Livestock Integration

Constraints which hamper soil fertility management by crop–livestock interaction can be discussed in terms of biased extension recommendations, transport and labor costs, low fertilizer applications, markets and contracts as substitutes for mixed farming, and land competition between crops and livestock.

Biased Extension Recommendations

The study by Anthony, Johnston, and Jones (1979) examined farmer contacts with extension themes. In six rainfed farming sites in Africa they found that farmers were always informed about manuring. About three–quarters of the samples at five of six sites practiced manuring (Anthony, Johnston, and Jones 1979, p. 164). Ruthenberg (1983, p. 130) reviewed evidence about twenty-eight African farming systems. Twenty–three practiced manuring and four practiced stabling. The authors' field visits further confirmed these results (Tables 5–5 and 5–8), all of which suggests that farmers are well-informed about manuring.

Nearly all organic farming experiments mentioned in this chapter applied quantities of manure, mulch, or compost on the order of 2.5 to 20.0 tons per hectare. Such levels are rare on farms. The ICRISAT data from Burkina Faso reveal application levels of 175 to 681 kilograms per hectare in three zones of the country (Table 5–6). The only crops in the ICRISAT samples receiving high levels of manure are vegetables and maize grown on small plots near households, and cotton in one zone. Norman, Simmons, and Hays (1982, p. 188) report quantities of 0.2 and 3.4 metric tons per hectare for two groups of farmers without cattle, and of 1.4 and

4.0 metric tons for two groups with cattle. Ruthenberg's review (1983) does not report application levels, but makes clear that they are typically small. Given the field evidence observed by the authors of careful management of manure and other soil fertility inputs by farmers, it is unlikely that the large differences between experimental quantities and farmer practices are due to waste or neglect. Hence, extension recommendations of the large quantities used in experiments are probably inappropriate for most farmers.

Another source of experimental bias is application method. On station, a typical application method is to turn the material into the soil with tractors or animals, but this was rarely done at the field sites. Only at a single semi–arid site was manure mixed with litter, and it was incorporated at three sites. Manure was mixed with litter at seven of twelve intensively farmed highland sites (Table 5–5).

If these application methods are not adopted by farmers, the impact of manuring is lower. In areas with no animal traction, but where manuring is common (Niger and Burkina Faso), there is no hand incorporation, only paddocking. In areas with general animal traction (Zimbabwe, Machakos, and Kianjasoa), oxen were only occasionally used to incorporate crop residue or manure. Even in Machakos, where improved manure production is known and where there are tractor rentals, manuring consisted only of surface applications. The contrast between manuring techniques in the field visits and experiments suggests that many experiments exaggerate crop response to organic matter under farmer conditions, and could not always give useful extension advice to farmers seeking to practice crop–livestock integration.

Transport and Labor Costs

Because the specific effect of manure is weak or absent, it can be compared to fertilizer in terms of cost per unit of nutrient. By that measure, manure is more expensive than fertilizer because it is so much less concentrated. For example, a ton of diammonium phosphate (18-46-0), at a response of 6.5 kilograms of grain per kilogram of N, would give 1,170 kilograms of grain per ton of additional material. A ton of manure would give about 50 kilograms. Transport and labor costs per unit of grain output would therefore be much higher for manure and are serious impediments to its use. This finding is clearly seen in the farm budgets of Matlon and Fafchamps (1988), who show very high labor inputs per metric ton of manure applied. Even when the quantities of manure applied are small, the total labor requirements per farm tend to be large.

One obvious point of extension work would be to reduce transport and labor costs for organic fertilizer by changing farmers' management

Table 5-6. Organic Fertilizer Applied in Burkina Faso

Region and crop	*Crop area as percent of sole crops and mixes*	*Crop yield of sole crops (kilograms per hectare)*	*Cropping intensity (percent)* [a]	*Manure applied (kilograms per hectare)*	*Nitrogen from manure (kilograms per hectare)* [b]	*Nitrogen required (kilograms per hectare)* [c]	*Sufficiency of nitrogen from manure (percent)* [d]
Sahel							
Pearl millet	93	335	69	118	1.8	7.5	24
Sudan							
Pearl millet	27	412	65	161	2.4	8.7	28
Red sorghum	5	898	72	619	9.3	21.0	44
White sorghum	55	589	70	242	3.6	13.5	27
Northern Guinea Savanna							
Cotton	29	516	48	922	13.8	n.a.	n.a.
Pearl millet	22	340	63	141	2.1	6.9	31
Red sorghum	10	591	63	176	2.6	12.1	22
White sorghum	27	434	64	308	4.6	9.0	52

n.a. Not available.

a. (Years since last fallow)/(Years since last fallow + duration of last fallow).

b. Assuming manure contains 1.5 percent N.

c. Assuming crop exports 1.75 percent of N in grain and 0.5 percent of N in residue.

d. (N from manure)/(N required).

Source: Data from Matlon and Fafchamps (1988, pp. 12–14, 31, 35, 55, 127, 145, 163, 262, 280, 298, 361), calculations by the authors.

practices. Field evidence suggests that changes in management would not have a large impact on productivity. The efficient response of farmers to transport and labor costs for manuring has been shown by Ruthenberg (1983), Miracle (1967), and Norman, Newman, and Ouedrago (1981). In Burkina Faso, Matlon and Fafchamps (1988) showed soil fertility management by farmers to be well–adapted to population density, cattle ownership, plot location, crop type, and crop rotation.

Prudencio (1983) made a detailed study of the interaction of fertility strategy and transport costs in semi–arid Burkina Faso. He demonstrated an intricate spatial pattern of manuring, crop rotations, crop selection, and fallows as influenced by the transport and labor costs of fertility inputs. Fields near households received manure, while fields at an intermediate distance were intercropped or rotated with legumes, and occasionally received chemical fertilizer. The most distant fields were part of the fallow cycle and received little manure.

Field visits by the authors also showed that farmer use of manure is well adapted to transport and labor costs. In the sparsely populated areas of the West African semi–arid tropics, heavy manuring is only done on fields near compounds, and on those fields where cattle can be paddocked. Transport costs limit manuring by means other than paddocking to close fields in the sparsely populated areas, but intensive manuring is possible by paddocking on distant fields.

In the densely populated Kenyan highlands where fields are closer, intensive manuring is very common. Transport costs of manure are much lower in densely populated areas because fields are closer, but paddocking is impossible because of permanent cultivation and the risk of crop damage by animals. The general conclusion is that farmer practices appear to be efficient in their use of available resources. Unless extension were to develop new messages, it could not raise productivity by promoting better use of known practices.

Low Fertilizer Applications

The alternative to organic soil amendments is chemical fertilizer. If the latter is more profitable than manure, then it will be adopted by farmers and reduce crop–livestock integration. It is known, however, that chemical fertilizer use in Sub–Saharan Africa is typically less than 10 kilograms of nutrient per hectare of crop land. This is much lower than in Asia, for example, and suggests some specific barriers to greater use of fertilizer, which would make it costly to substitute chemical for organic nutrients. Much of the difference between Asian fertilizer use per unit of land and African is explained by the greater importance of irrigation in Asia. Because the great majority of Sub–Saharan agriculture is rainfed, the impact of irrigation on fertilizer demand is small.

Despite the lack of irrigation, the profitability of relatively small doses of fertilizer in rainfed farming is well established (for example, Charreau 1974, for Senegal). The literature generally shows that from 20 to 40 kilograms of nutrients per hectare would be profitable at market prices. Richards (1979) reported results from FAO trials throughout Africa. He found the incremental value of fertilizer to be greater than their additional costs for such major crops as maize, rice, pearl millet, sorghum, yam, groundnut, wheat, and teff. Couston (1971), using similar data, calculated incremental value cost ratios (VCRs) for seven west African countries: rice, 2.6 to 6.5; maize, 1.8 to 3.7; pearl millet, 1.8 to 4.3; and sorghum, 1.8.

In a major grain producing area of northern Nigeria, Goldsworthy (1967a, 1967b) found profitable experimental responses to nitrogen and phosphorus in sorghum and maize. Studies of maize response in Kenya (Okalo and Zschernitz 1971), Lesotho, and Botswana (Doyle 1971) gave an average of 2.1. For sorghum, the average was 0.89, meaning that fertilizer would not have been profitable. Positive responses have also been reported for wheat, groundnut, yam, cassava, finger millet, cotton, teff, and forage crops (FAO 1971).

Weaker fertilizer responses are typical of some important crops. In rainfed conditions, the crop most responsive to nitrogen is rice, followed by maize, sorghum, and pearl millet (Table 5–7). Sorghum and pearl millet have nearly five times the output of rice in Sub-Saharan Africa, but produce much weaker fertilizer responses. The less responsive crops also have more variable responses (Table 5–7), which would further tend to make using fertilizer on them less attractive.

Another explanation of low returns to fertilizer is the difference between experimental and farm results. Studies in Niger and Burkina Faso with farmer management and little external control showed responses of pearl millet and sorghum to be lower and more variable on farms than on stations, with negative effects on profits (McIntire 1986, Matlon 1984). Allan's (1971) work in Kenya found lower fertilizer responses on farms than on research stations, which he attributed to negative interactions among time of planting, density, cultivar, and fertilizer use.

A final factor is the effect of government policies. The historical impact of these policies was to subsidize inputs while holding output prices below international opportunity costs. While the overall effect of many African agricultural policies on output was negative (Jaeger 1991), policy cannot entirely explain the lack of fertilizer use. Studies of fertilizer price policies in Cameroon, Kenya, Malawi, Nigeria, Senegal, and Tanzania (Lele, Christiansen, and Kadiresan 1989) show that fertilizer would be profitable at a wide range of international input and output prices.

The effects of policy on input and output prices tended to offset one another. In the cost–benefit studies of the FAO fertilizer trials cited above, economic returns to fertilizer are calculated at local market prices for outputs and import parity prices for inputs, thus taking the consequences of government policies into consideration (Richards 1979, Couston 1971). The farm studies mentioned from Burkina Faso and Niger (McIntire and Fussell 1989, Matlon 1984) showed that removing the negative effect of output price and the positive effects of fertilizer subsidies from the economic analysis would have had a very weak effect on optimal levels of fertilizer application under farmer conditions.

Markets and Contracts as Substitutes for Mixed Farming

Given the easily identifiable crop response to manure, the absence of transactions would suggest that farmers placed no value on it. This would imply that greater manure use is at least partly constrained by lack of information. The authors' field visits therefore emphasized manuring interactions among production units, and the degree to which such transactions are substitutes for mixed farming.

Exchanges involving manure were common at all but the humid sites (Table 5–8). They were most widespread in the West African subhumid and semi-arid zones, as has been observed repeatedly in the literature (Bernardet 1984, for subhumid Côte d'Ivoire; Bernus 1974, for semi-arid Niger). Exchanges almost never involved markets or transactions over long distances. These restrictions on the types of transactions are explicable in terms of transport costs or in terms of the natural exchange between crop residue and manure.[7] Interactions take different forms in the highlands, where cash payments are more frequently seen.

Manuring interactions are typical of arid zones. Toulmin (1983) wrote of a case in central Mali where herders without water rights contract with well-owning farmers, and corral their stock on the farmers' lands in exchange. Similar water-manure exchanges are documented by Swift, Winter, and Fowler (1985) for Mali, McIntire (1982) for Burkina Faso, Horowitz (1975) for eastern Niger, and in the field visits to western Niger in 1987. Such evidence is clear proof that farmers are informed about the yield and soil quality benefits of manuring. Mixed farming, in the sense of owning animals, is unnecessary for reaping at least some of those benefits.

7. The single exception to this generalization about markets occurred in Kenya, where there are manure transactions between pastoral areas and the highlands. In the pastoral areas, there are many stock but almost no cropping, while in the highlands manure demand is strong because of high cropping intensities. A good road transport system between the pastoral areas and the highlands facilitates this natural interaction.

Table 5–7 Experimental Fertilizer Responses from Selected Studies

Trial characteristics	*Rice (unhusked)*	*Maize*	*Sorghum*	*Pearl millet*
Nitrogen applications				
Mean nutrient use				
(kilograms per hectare)	99	107	50	79
Marginal physical products				
(kilograms of grain per				
kilogram of nutrient)				
Number of observations	63	6	36	30
Mean	18.3	16.2	5.7	4.3
Standard deviation	10.9	8.2	4.9	4.1
Average physical products				
(kilograms of grain per				
kilogram of nutrient)				
Number of observations	63	6	19	20
Mean	21.4	20.4	9.9	5.9
Standard deviation	8.1	4.7	5.5	3.3
FAO fertilizer trials				
Mean nutrient use				
(kilograms per hectare)	45	40	20	20
Response range				
(kilograms of grain per				
kilogram of nutrient)	10–20	6–14	5–10	5–10
FAO fertilizer demonstrations				
Mean nutrient use				
(kilograms of grain per				
kilogram of nutrient)	30	20	20	20
Response range				
(kilograms of grain per				
kilogram of nutrient)	10–20	10–20	6–14	6–14
Phosphorus applications				
Mean nutrient use				
(kilograms per hectare)	n.a.	150	52	n.a.
Marginal physical products				
(kilograms of grain per				
kilogram of nutrient)				
Number of observations	n.a.	22	9	n.a.
Mean	n.a.	10.7	6.7	n.a.
Standard deviation	n.a.	12.6	5.3	n.a.

Trial characteristics	*Rice (unhusked)*	*Maize*	*Sorghum*	*Pearl millet*
Average physical products (kilograms of grain per kilogram of nutrient)				
Number of observations	n.a.	22	9	n.a.
Mean	n.a.	12.6	7	n.a.
Standard deviation	n.a.	7.8	5.7	n.a.
FAO fertilizer trials				
Mean nutrient use (kilograms per hectare)	20	20	20	20
Response range (kilograms of grain per kilogram of nutrient)	8–15	5–12	4–8	4–8
FAO fertilizer demonstrations				
Mean nutrient use (kilograms per hectare)	20	20	20	20
Response range (kilograms of grain per kilogram of nutrient)	4–12	2–8	6–15	6–15

n.a. Not available.

Source: Bono and Marchais 1966, Christenson 1981, Matlon 1984, McIntire 1986, Poulain and others 1976, Traoré 1974, Thibout and others 1980.

While contracts are important in providing manure to farmers with no cattle, or in transferring manure from herders to farmers, they are not perfect substitutes for mixed farming. If manuring contracts were perfect substitutes for mixed farming, there would be roughly equal manure use between cattle-owning and non-cattle-owning households in the same localities, but this is not the case. There are persistent large differences in manure use between households owning cattle and those which do not. Norman, Simmons, and Hays (1982, p. 188) found farmers with cattle using 20 to 600 percent more manure per hectare in northern Nigeria. Matlon and Fafchamps (1988, p. 31) observed farmers with animal traction using substantially greater quantities per hectare than farmers cultivating with hand tools. Walker and Ryan's work in India revealed higher manure use in villages with more bullocks (1990, pp. 42–48).

Transport costs explain some of the large differences in manure use between farmers owning cattle and those who do not. Because manure

Table 5–8. Manure Exchanges Observed at Field Sites, by Environment

Sites and exchanges	*Humid*	*Subhumid*	*Semi–arid*	*Highlands*
Number of sites	4	6	8 [a]	12
No manure exchanges	4	2	1	5
Exchanged mainly for				
Grain	–	–	4	–
Water	–	–	2	–
Crop residue	–	2	1	2
Grain plus crop residue	–	–	1	–
Transactions for cash	–	2	7	7

– Not observed at this site.
Note: There can be double counting of manure exchanges, if, for example, manure is sold for cash and traded for grain.
a. Information not available for three sites.
Source: Field visits by authors.

transport is costly, there is a natural 'wedge' between the cost to the supplier and the price to the buyer. That wedge prevents use per hectare from being equal between farmers with cattle and those without, and again stimulates farmers to adopt mixed farming to gain access to fertility inputs which they cannot otherwise obtain through markets.

Land Competition Between Crops and Livestock

Manure applications of 5 to 12 metric tons per hectare would have positive effects on crop productivity and soil quality, but are apparently greater than current use by farmers. Providing those quantities, however, would cause an inherent conflict in the farming system. Raising the stocking rate to produce more manure ultimately reduces the amount of crop land because of competition between fodder and human food production.

This point can be illustrated by adapting the model of Chapter 3 to show the effect of cropping intensity on manure demand and supply as it affects nitrogen balance. Table 5–9 shows the modeled crop nitrogen balance for a semi–arid pearl millet farming system. In this model, manure and fallow provide nitrogen to the crop, which exports nitrogen in its grain and residue. Population density determines the areas in crops and fallow.

Two different stocking rates are modeled. At the minimum feasible stocking rate, the lowest monthly quantity of fodder produced during the dry season sets the limit to the number of animals which can be sustained throughout the year. At the minimum feasible rate, much of the fodder produced outside the dry season is wasted. At the average stocking rate, the limit is the total annual quantity of fodder produced and made available to livestock continuously throughout the year. At the average rate, the fodder produced outside the dry season is not wasted. Because the average rate is much higher than the minimum feasible rate, the former makes possible the production of more manure at any given population density which, as will be seen, affects the results of the model.

The contribution of nitrogen from manure and fallow at various population densities is shown in Figures 5–1 and 5–2 for the specified stocking rates. In the absence of trade and with traditional technologies, fallow is only sufficient to supply the nitrogen needs of the crop up to a population density of about twenty persons per square kilometer. At the minimum feasible stocking rate made possible by seasonal forage production, fallow and manure supply enough nitrogen to maintain a population density of about thirty-five. At an average annual stocking rate consistent with seasonal forage production, fallow and manure supply enough nitrogen to maintain a population density of about ninety.

The theoretical insufficiency of manure, as shown in this model, is seen in practice (Table 5–6). On–farm research in semi–arid Burkina Faso shows that manure is insufficient to replace the nitrogen exported by the major food and cash crops (Matlon and Fafchamps 1988, p. 31). This is true even at yields well below the potential of those crops and in a country with abundant cattle production.

Another way of looking at land competition is to calculate the incremental forage production to maintain stocking rates sufficient to produce adequate manure. At the minimum feasible stocking rate, and a population density of 80 per square kilometer, additional forage production of 0.5 metric tons per hectare would be needed (Table 5–9). This would rise to 1.9 metric tons per hectare at a population density of 220. At the average stocking rate, and a population density of 80 per square kilometer, no additional forage production would be needed, but 1.5 metric tons would be required at the higher population density. This conforms to the observation of Walker and Ryan (1990, p. 53) about the land–scarce Indian semi–arid tropics: "Farmers . . . apply far less [manure] than what they view as desirable because of supply scarcities arising from limited fodder availability. . . . "

Crop–Livestock Integration Is Insufficient to Resolve the Soil Fertility Problem

The contribution of crop–livestock interactions to soil fertility maintenance depends on two factors: the interaction between agroclimate and

Table 5–9. Theoretical Relationship Between Population Density and Stocking Rate for 100 Hectares in Burkina Faso

Number of people [Column 1]	Fallow period (years) [Column 2]	Nitrogen exported by pearl millet crop (metric tons)[a] [Column 3]	Nitrogen from fallow (metric tons)[b] [Column 4]	Nitrogen needed from manure (metric tons)[c] [Column 5]	Manure needed (metric tons)[d] [Column 6]	Stocking rate: Needed (tropical livestock units)[e] [Column 7]	Stocking rate: Feasible (tropical livestock units)[f] [Column 8]	Feed gap (metric tons)[g] [Column 9]
Minimum feasible stocking rate								
0	100	0.0	1.63	0.0	0	0.0	4.7	10.8
10	24	0.07	0.39	0.0	0	0.0	5.1	11.5
20	12	0.13	0.19	0.0	0	0.0	5.4	12.3
40	5	0.26	0.09	0.17	12	10.2	6.0	-9.6
60	3	0.39	0.05	0.34	23	19.8	6.6	-30.0
80	2	0.52	0.03	0.49	32	28.4	7.3	-48.2
160	1	1.04	0.01	1.03	69	60.3	6.8	-121.8
220	0	1.43	0.0	1.43	95	83.5	1.4	-187.2

Average stocking rate									
0	100	0.0	1.63	0.0	0	0.0	39.9	91.1
10	24	0.07	0.39	0.0	0	0.0	38.9	88.6
20	12	0.13	0.19	0.0	0	0.0	37.8	86.1
40	5	0.26	0.09	0.17	12	10.2	35.6	57.9
60	3	0.39	0.05	0.34	23	19.8	33.4	31.1
80	2	0.52	0.03	0.49	32	28.4	31.2	6.5
160	1	1.04	0.01	1.03	69	60.3	22.5	-86.1
220	0	1.43	0.0	1.43	95	83.5	16.0	-154.0

Note: Table contains rounding errors.

a. A 100-hectare crop of pearl millet would yield 50 metric tons of dry grain, 150 metric tons of dry straw, and 1.6 metric tons of nitrogen.

b. Nitrogen from fallow is equal to the maximum nitrogen exported by the pearl millet crop, multiplied by the fallow period (in years), divided by 100.

c. Column 3 minus Column 4 if Column 3 is greater than Column 4, otherwise zero.

d. Column 5 divided by 0.015.

e. Column 6 divided by 1.14 (1 TLU produces 1.14 metric tons of manure).

f. Calculated from model results as depicted in Figure 3–4.

g. Feasible stocking rate minus needed stocking rate multiplied by the annual dry matter intake of 1 TLU (2.28 metric tons of digestible feed).

Source: Calculations by authors. Data are based on field visits by the authors, information from McIntire and Fussell (1989), and personal communication from Mark Powell, ILCA.

Figure 5–1. Pearl Millet Nitrogen Balances at Minimum Stocking Rate

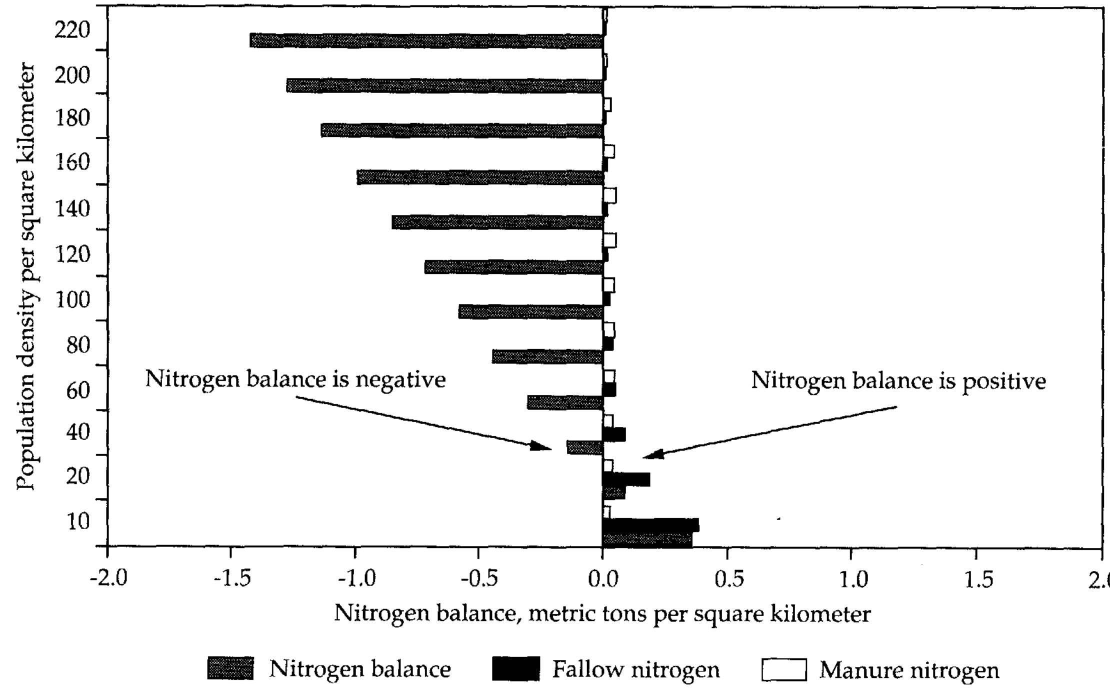
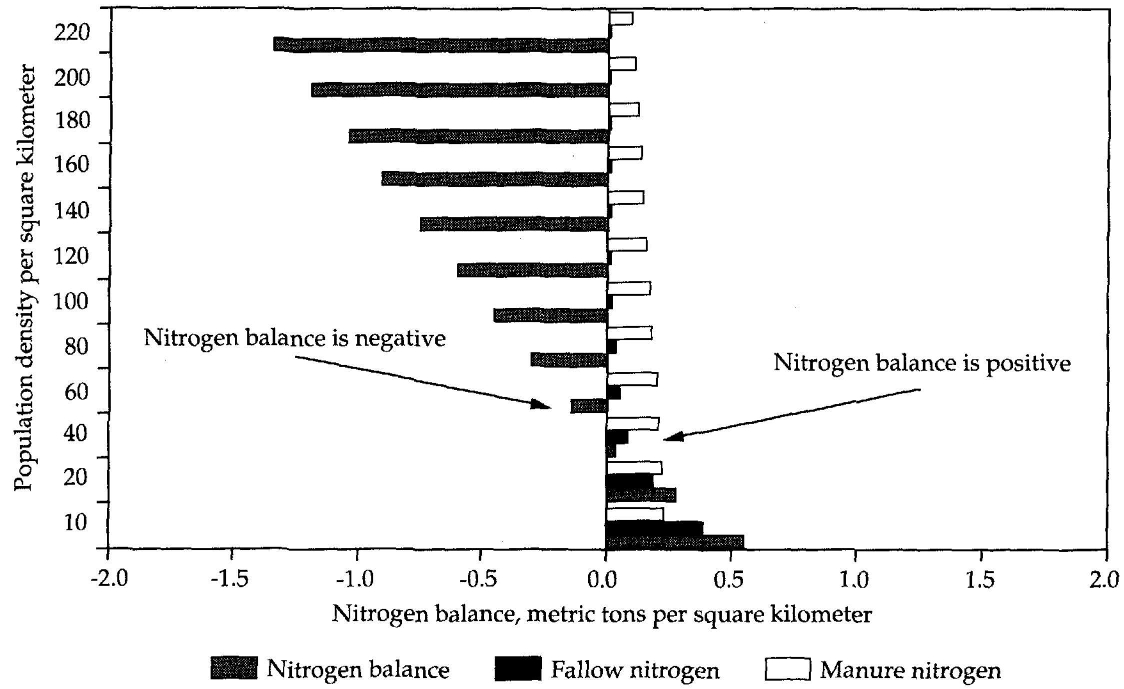


Figure 5–2. Pearl Millet Nitrogen Balances at Average Stocking Rate



population density, affecting the demand for fertility inputs, and the economic return to different techniques for supplying those inputs.

The evidence for the interaction between agroclimate and population density can be summarized as follows:

- Demand for all fertility inputs is weaker at lower population densities because fallow is available. Field visits and a literature review confirmed that manuring and mulching are rarer at lower population density in each agroclimate.
- Rising farming intensity leads to greater demand for fertility inputs in all agroclimates, notably in the densely populated highlands.
- Lack of information does not greatly constrain demand for soil fertility inputs because farmers know the benefits of different inputs. Field visits showed that manure is often used, contracts exist to move it from animals to crops, it is often allocated to responsive, high-value, cash crops, and it is occasionally traded in markets.
- These conclusions should not be interpreted mechanistically. Farmers in the same agroclimate or farming system will follow mixed strategies. Manuring, for example, does occur in extensive farming systems—but typically on higher–yielding crops such as vegetables, or on plots where transport costs are not high.

The second problem is the question of which fertility techniques are most efficient at different stages in the evolution of agriculture. At any given stage, the choice among techniques is one of lower input cost for a given output.

- If fertilizer is unavailable, the type of fertility differs among agroclimates. Where disease limits animal production, mulch dominates. Where cattle production is possible, manure dominates.
- Techniques are less labor intensive at lower population densities because labor is more costly. Mulching and composting, because of their greater labor intensity, are not found at low and medium population density sites. Where manuring is practiced, animal paddocking is dominant. Outside the densely populated East African highlands, there were no major examples of composting, manure improvement, or manure storage.
- Improved manure quantity and quality by storage or composting should give lower costs per unit of nutrient and hence of output. However, such improved techniques as storage and composting are severely

constrained by labor, especially for transport, and are rarely employed because the value of nutrients gained is less than the resources invested in them.

- Choosing between fertilizer and manure is a function of the specific effect of manure, the long–run effects of manure, transport and labor costs, fertilizer supply, and techniques to improve manure. Experimental evidence on the specific effects of organic matter is not definitive, probably because of complex interactions between the control fertility in the trial and added fertility. The specific effect is clearly small. Without a specific effect, the short–run effects of manure are due only to its nutrients and are thus directly comparable to the effects of fertilizer.
- Studies of the long–term effect of manuring suggest that even large quantities of manure are not complete substitutes for fallow (for example, McWalter and Wimble 1976). In northern Nigeria, annual application of 7 to 8 metric tons per hectare of manure, or a planted grass fallow three years in six, would maintain maximum soil organic matter. Restoring some crop residue to the soil would also be required (Jones 1971).
- Because of different transport and application costs, the choice between manure and fertilizer will almost always be resolved in favor of the latter, where it is available.
- Constraints to the supply of chemical fertilizer are a serious barrier to its use. While theoretical use per hectare is less in Africa than on other continents for reasons of profitability, theoretical use is still greater than actual use. The difference is primarily due to the availability of fertilizer. A study of fertilizer issues (Lele, Christiansen, and Kadiresan 1989, p. 47) in Cameroon, Kenya, Malawi, Nigeria, Senegal, and Tanzania concludes that "Supply constraints are by far the most significant in expanding fertilizer use on a sustained basis . . ."
- While average fertilizer application rates are low because of weak physical responses, these rates are still well below theoretically profitable levels. Even adjusting for differences between responses to fertilizer on farms and on experiment stations, theoretically profitable values on–farm are much higher than national averages in most African countries.
- There is little evidence for displacement of organic fertilizer by chemical fertilizer, as has occurred in Asia. Papers assembled at the International Rice Research Institute (IRRI) about biological nitrogen fixation show that falling fertilizer prices and rising wages eliminated green manuring of rice in Japan and in the United States, making it more economical to

use chemical fertilizer (IRRI 1988, pp. 45-61 and 257-274). Impediments to fertilizer use in Africa therefore actually encourage continued integration of crops and livestock by preventing the substitution of chemical fertilizer for organic fertilizer in some instances.

- The high cost of manure cannot be remedied simply by integrating animal and crop production. Manure supply is a function of the stocking rate, which is a function of comparative advantage in animal production. For any comparative advantage, at some point there is a land conflict between animals and crops. At that point, further increases in manure supply for crop production compromise land use for crop production. Because manure supply depends primarily on the stocking rate, changes in ownership or management of animals without an increase in their numbers—that is, crop–livestock integration—are not of major importance in determining manure supply and cost as long as farmers and herders can engage in transactions for manure.

6

Animal–Fodder Interactions

Inadequate nutrition seriously impedes livestock production in Sub-Saharan Africa. This impediment causes low milk yields, elevated young stock mortality, extended parturition intervals, and low animal weights. Given the genetic potential of the major breeds, improved nutrition could substantially raise livestock productivity.

There have been many efforts to improve livestock nutrition in the context of mixed farming. Proposed improvements have included sown forage, ley farming, and various management schemes for crop residue. Sown leguminous and grassy forage could provide a high quality supplement to native pasture, crop residue, and browse (Haque, Jutzi, and Neate 1986; Crowder and Chedda 1977). Ley farming, in which fallows are sown to forage and grazed as part of a crop rotation, would improve the soil while providing livestock fodder during the fallow. Crop residue as a by-product would be a cheap and abundant source of roughage.

Despite recognition of the animal nutrition problem and the efforts to solve it, unimproved natural pasture, browse, and crop residue are still the main feeds. Progress in extending forage crops to livestock producers has been slow. Ley farming is almost non-existent. Few farmers use concentrate feeds for ruminant production, and most crop residue is managed in the traditional manner.

This chapter explains why traditional sources of fodder dominate in Sub-Saharan Africa. The reasons that sown forages are not generally adopted despite their apparent benefits to animal and crop production are explained. In addition, field and economic evidence about fodder systems is reviewed, emphasizing competition for crop residue between the crop and animal subsectors.[1]

1. Ley farming is not discussed further because Ruthenberg (1983) devotes an entire chapter to the subject. His conclusion about the failure of ley farming, which is shared by Crowder and Chedda (1977) and others, is that the cost of leaving land fallow for the grazing part of the ley cycle is greater than the benefits to crop and animal productivity from the ley.

Sown Forage Production Is Rare

Farm management studies show only occasional cultivation of specialized forage crops in the principal agroclimates of Sub–Saharan Africa. The comprehensive studies of Ruthenberg (1983) and Jahnke (1982) mention them almost exclusively in the Kenya highlands. Cleave's (1974) major study of labor use in African agriculture hardly notes the subject. Lagemann (1977) found no forage crops in the humid zone in eastern Nigeria, nor did Miracle (1967) in the humid Congo Basin. Norman, Simmons, and Hays (1982), writing about the savanna of Nigeria, seldom refer to the issue. Matlon and Fafchamps' (1988) compendium of farm data from three regions of semi–arid Burkina Faso shows no specialized forage production, nor did field visits to semi–arid Zimbabwe, Niger, or Burkina Faso. Forage crops are not grown in most of highland Ethiopia, Madagascar, and in much of the Great Lakes countries, despite high animal stocking rates and an apparent demand for more fodder (Gryseels and Anderson 1983, for Ethiopia; Jones and Egli 1984, for the Great Lakes countries; authors' field visits for Madagascar).

This neglect of forage crops is not because they are not well–adapted to the production conditions of the subcontinent. The papers in Haque, Jutzi, and Neate (1986) indicate that sown forages would be more physically productive than traditional sources of forage in much of Africa. Crowder and Chedda (1977) demonstrated adaptation of many sown forages across the major environments of West Africa, and described how tested species gave good animal response and had acceptable agronomic characteristics in many situations. Ahmad's papers on humid, subhumid, and semi–arid West Africa show that technically viable new systems of producing fodder exist (Ahmad 1986a, 1986b, 1986c). While those papers and others like them suggest further experimentation, they make clear that usable techniques are now available in many places.

Resource Competition and Seasonality in Fodder Production

The conflict between the absence of sown forages and apparently favorable experimental evidence has three sources: resource competition for land and labor as affected by the evolution of farming systems; the seasonality in fodder supply, as caused mainly by rainfall variations; and animal mobility. Those environmental characteristics make crop residue, browse, and natural pasture cheaper than new competitors in most African situations.

COMPETITION FOR LAND AND LABOR. Farming intensity induces changes in animal fodder systems along the scheme developed in 1987 by Pingali, Bigot, and Binswanger (Table 6–1). In that scheme, resource competition

Table 6–1. Cropping Systems and Fodder Supply Systems

Cropping system	*Communal grazing*	*Communal grazing and supplementary feeding*	*Private grazing*	*Private grazing and supplementary feeding*	*Fodder production and crop residue*	*Not applicable*	*Total Cases*
Africa							
Forest fallow	2	1	–	–	–	2	5
Bush fallow	4	2	–	–	–	2	8
Short fallow	4	9	–	–	–	–	13
Short fallow with emerging annual cultivation	–	6	1	–	–	–	7
Annual cultivation	2	5	1	5	–	1	14
India							
Annual cultivation	–	–	–	1	4	5	10
Total cases	12	23	2	6	4	10	57

– No cases observed for this combination.
Source: Pingali, Bigot, and Binswanger 1987, p. 97.

operates in opposing directions, according to agroclimate and population density. At low population and cultivation density, animals graze pasture at lesser stocking rates. This practice has high land inputs and low labor inputs per unit of output. Sown forages, despite having higher yields per unit of land, are more costly in terms of labor input per unit of output. Therefore, unless the return to labor in forage is greater than that in grazing, forage will not be adopted, a prediction confirmed by the field visits and Jahnke's 1982 review.

At the other extreme of the land–use intensity continuum, for example, at the elevated population densities typical of the highlands, a new crop competes for land. Animals graze crop residue and farmers laboriously cut, transport, and store fodder from a variety of sources, which typically use less land and more labor per unit of output. Unless the return to land in sown forage production is greater than that in alternative crops, the former will not be adopted. Land competition with food crops is unfavorable to forage because farmers are generally unwilling to sacrifice food production to produce fodder for animals. The main situation in which sown forages have been adopted is with milk production using European breeds in the East African highlands (Stotz 1979, on milk production in Kenya is the best paper on the subject).

SEASONALITY IN FODDER SUPPLY. Most fodder in Sub–Saharan Africa grows with seasonal rainfall. Seasonality has characteristic effects on fodder supply (Figure 3–2). The rainy, post–harvest, and dry seasons are represented on the horizontal axis of Figure 3–2, while quantities of digestible crop residue, pasture, and total fodder are on the vertical axis. One rainy season and no irrigation makes the dry season long and the period of highest vegetative production short. Crop residue is unavailable early in the cropping season, peaks thereafter, and then declines rapidly. Similarly, pasture grows, attains its maximum in the cropping season, and then drops off. Crop production is therefore correlated with both pasture and crop residue supplies.[2]

The pattern of rainfall has two consequences for the returns to sown forages. First, the seasonality of forage production determines animal weights and prices of livestock products. When feed is scarcest, weights fall and unit livestock prices rise, and the return to a unit of fodder is then highest. Second, the seasonality of crop yields makes the opportunity costs of alternatives to sown forages lowest in the rainy and post–harvest seasons, and highest in the dry season. Because outputs from different fodder sources

2. Examples are ILCA studies of semi–arid Mali (de Leeuw, Wilson, and de Haan 1983), subhumid Nigeria (von Kaufmann and Blench n.d.), the Kenyan rangelands (Solomon Bekure and others 1991). Another example is subhumid Togo (Doppler 1980).

are correlated, a new source of fodder is cheaper only if it produces significantly more when crop residue and pasture are scarcest. It is not necessarily cheaper if the new source produces more when other feeds are most abundant, for example early in the rainy season, because it might require higher resource costs per unit of feed than its competitors.

ANIMAL MOBILITY. The search for cheaper feed determines mobility, and mobility in turn affects the possibilities for forage production. In general, there is an inverse relationship between farming intensity and herd mobility (Table 3–6). At low intensity in an arid pastoral environment, natural pasture and browse are the cheapest sources of fodder. Those sources can only support low stocking rates, and to maintain a reasonable herd size with few animals per unit of land, movement over large areas is required. That movement conflicts with growing forage crops. Hence pastoralists must choose among some mix of settling and raising crops, obtaining fodder through a market, or continuing to move and graze their animals in different places on seasonally available fodder. Many studies of arid environments show that pastoralists move regularly over long distances, do not sow forages, and sometimes do not grow crops at all (for example, Dahl and Hjort 1976, Dupire 1972).

With more productive agricultural environments and higher farming intensity in parts of the semi-arid tropics, less herd mobility is required. Herds remain closer to the point of crop production because of the greater abundance of crop residue. Animal traction and more intensive animal production may sometimes make it necessary to confine livestock or to otherwise restrict their mobility. Herd mobility still exists, but mainly in the growing season to use remote seasonal pasture and to avoid damaging standing crops (Delgado 1979, for Burkina Faso; Toulmin 1983, for Mali).

Farming intensity is even greater in the highlands. Animal traction is common, and stall feeding of stock develops. Mobility is less urgent as a grazing strategy, and some animals stay on the farm year round and consume crop residue as a major share of their diet. In those conditions, farmers have more incentive to sow forage crops in order to raise fodder yields, and can do so without interfering with stock mobility, which is relatively limited.

To summarize, land abundance explains why sown forages are not immediately adopted by nomadic herders. Land abundance discourages forage use in pastoral systems and in extensive arable systems because it encourages herd mobility and agricultural systems with low labor input per unit of output. Sown forages cannot compete with pasture and crop residue because these two can be grazed at low labor input, and their costs of establishment, maintenance, and protection are lower.

Obviously, there are farming systems of intermediate intensity in which introduced forages can compete. There are also some cases of intensive highland farming systems in which forage has succeeded for many years, such as those of Kenya and parts of Ethiopia.

Fodder Production Costs

Although adequately detailed studies of fodder productivity are uncommon, a few examples have been collated in Table 6–2. A detailed study of primary production in central Mali permitted calculations of costs for different forage production methods (Penning de Vries and Djiteye 1982, pp. 425–434). Expressed as a percentage of the cost per kilogram of bush hay, early–harvested grass was 150 percent, fertilized forage was 220 percent, and forage receiving both irrigation and fertilizer ranged from 240 to 510 percent.

Expressed as a percentage of the cost per unit of nitrogen from bush hay, early–harvested grass was 50 percent, fertilized forage was 57 percent, and forage receiving both irrigation and fertilizer ranged from 62 to 80 percent. Only if chemical fertilizer was available would sown forage be cheaper in cost per unit of nitrogen than ordinary bush hay. Sown forage would not be cheaper than an early grass harvest. A comprehensive investigation of the area around the Penning de Vries–Djiteye research site in central Mali found no sowing of forage, but did observe early harvesting of grass, practices which are consistent with the relative forage costs shown here (de Leeuw, Wilson and de Haan 1983).

Work in semi–arid Burkina Faso also enabled calculations of forage costs per unit of energy and nitrogen (Yilala 1989). Compared to the costs of providing energy from pearl millet crop residue, costs of sorghum residue were 73 percent, sole–cropped cowpea haulms were 37 percent, intercropped cowpea haulms were 137 percent, groundnut haulms were 8 percent, and *Dolichos lablab* hay was 104 percent. Compared to pearl millet crop residue, nitrogen costs from sorghum residue were 73 percent, sole–cropped cowpea haulms were 13 percent, intercropped cowpea haulms were 57 percent, groundnut haulms were 3 percent, and *Dolichos lablab* was 14 percent. While legumes furnished cheaper feed than cereal stover, the cheapest sown forages were the dual–purpose cowpea and groundnut, not the specialized *Dolichos*. This is reflected in the cropping patterns in northern and central semi–arid Burkina Faso: sorghum, pearl millet, cowpea, and groundnut occupy much of the cultivated area, but there are no sown forages (Matlon and Fafchamps 1988, pp. 12–15).

In a careful study of subhumid Togo, Doppler (1980) analyzed several major grass and leguminous forages at different levels of fertility and management, and his conclusions ought to be widely applicable in the subhumid zone. The costs of sown forages as a source of energy, with and without fertilizer, were higher than those of concentrate feeds, but the relative costs of bush hay and early grass were not estimated. Sown forages are rarely seen in the subhumid zone (von Kaufmann, Chater, and Blench 1986; Landais 1983; authors' field visits).

Stotz's research in Kenya calculated forage production costs in a number of highland dairying systems (Stotz 1983). As a percentage of the dry matter cost from maize stover, production costs ranged from 17 to 45 percent for pasture grazing, 30 to 60 percent for arable forage, and 50 to 70 percent for other food crop residue systems with supplements. As a percentage of the nitrogen cost from maize stover, production costs ranged from 26 to 70 percent for pasture grazing, 63 to 90 percent for arable forage, and 77 to 162 percent for other food crop residue with supplements. In contrast to the subhumid and semi–arid zones, improved pasture and arable forage do provide cheaper fodder energy than crop residue or natural roughage. This is consistent with the pattern of fodder production in the Kenya highlands, in which there are many sown forages (Stotz 1979).

Field Evidence About Fodder Interactions

Unimproved pasture, crop residue, and browse (Tables 6–3 and 6–4) are the main feeds at the field sites visited by the authors. In the humid zone, the abundant vegetation from open pasture, forest grazing, and bush fallow easily satisfies the limited feed demand. Crop residue feeding is less consequential than in other zones, and residue is mainly used as surface mulch ('Humid' column of Table 6–4).[3] There is only occasional use of by–products or concentrates, and grain fed to poultry is the sole form of intensive feeding. While it would be possible to use forage, concentrates, or agricultural by–products as high–quality supplements to roughage, the economics of doing so are generally unfavorable because diseases make livestock a poor investment compared to alternatives in transport and trade.

SUBHUMID SITES. Animal production rises as disease pressure falls in the subhumid zone. Feed exploitation becomes more intense and diverse. Browse and crop residue complement natural pasture, although the use of concentrates and by–products is still rare. Because the growing season is shorter than in the humid zone, seasonality and mobility become more prominent features of cattle production (Table 6–3). At all of the subhumid sites but one, there is significant animal mobility to use seasonal pastures and avoid land conflicts with standing crops in the rainy season.

Variations in crop residue management are related to cropping intensity and stock numbers. Where cropping intensity is high, crop residue is

3. One exception might occur in intensively cultivated areas with root crops, because the quality of some crop residue (for example, manioc leaves) is unsuitable for feed.

Table 6–2. Relative Costs (Percent) of Forage Energy and Protein in Selected Countries

Variable	*Togo*	*Burkina Faso*	*Mali*	*Kenya*
Environment	Subhumid	Semi-arid	Semi-arid	Highland
Feed	Legumes and grasses	Cowpea, cereals	Grasses, sown forage, bush hay	Grasses, cereals
Source	Doppler 1980	Yalila 1989	Penning de Vries and Djiteye 1982	Stotz 1979
Relative costs of energy				
Purchased concentrates and native roughage				
Concentrates	100	100	–	–
Bush hay	–	–	0	–
Early grass	–	–	150	–
Cereal crop residue				
Maize silage	167	–	–	30
Maize stover	–	–	100	–
Pearl millet stover	–	100	–	–
Sorghum stover	–	73	–	–
Legume crop residue				
Cowpea haulms	–	37–137	–	–
Groundnut haulms	–	8	–	–
Sown forages				
Unfertilized, rainfed	–	104	–	–

Fertilized	–	–	220	–
Fertilized and irrigated	–	–	240–510	–
Pastures				
Grasses				
Unfertilized	207	–	–	37
Fertilized	175	–	–	–
Legumes				
Unfertilized	–	–	–	45
Fertilized	260	–	–	17
Relative costs of protein				
Purchased concentrates and native roughage				
Concentrates	–	–	–	–
Early grass	–	–	50	–
Bush hay	–	–	100	–
Cereal crop residue				
Maize silage	–	–	–	216
Maize stover	–	–	–	100
Pearl millet stover	–	100	–	–
Sorghum stover	–	73	–	–
Legume crop residue				
Cowpea haulms	–	13-57	–	–
Groundnut haulms	–	3	–	–
Sown forages				
Unfertilized	–	14	–	–
Fertilized	–	–	57	–
Rainfed and irrigated	–	–	62-80	–

(Table continues on the following page.)

Table 6–2. (continued)

Variable	*Togo*	*Burkina Faso*	*Mali*	*Kenya*
Pastures				
Grasses				
Unfertilized	–	–	–	224
Fertilized	–	–	–	–
Legumes				
Unfertilized	–	–	–	292
Fertilized	–	–	–	120

– Not available.

Table 6–3. Cattle Fodder Systems at Field Sites, by Environment

Sites and allocation	*Humid*	*Subhumid*	*Semi–arid*	*Highlands*
Number of sites	4	6	11	12
Sites with cattle	0	6	11	12
Stall feeding				
Beef	–	1	–	1
Dairy	–	–	–	4
Draft	–	–	–	–
Low mobility				
Pasture only	–	–	–	–
Pasture and crop residue	–	6	11	7
Cut and carry	–	1	4	6
Beef	–	–	1	1
Dairy	–	–	–	–
Draft	–	–	4	5
High mobility				
Pasture only	–	–	–	–
Pasture and crop residue	–	–	7	–

– Not observed at this site.
Note: Multiple responses are possible. For example, in the semi–arid sites, cattle are split into village herds which graze near the village and others which are entrusted and graze far away.
Source: Authors' field visits.

privatized, but where intensity is low, there is open access (Table 6–5). While the intensity of crop residue use varied, as a rule there was open access to crop residue grazing. In southwest Nigeria, herders were indifferent about feeding crop residue because of the low cropping intensity in the subregion, which reduces the urgency of feeding crop residue. In central Nigeria, where local cropping intensities are higher, crop residue is crucial.

SEMI–ARID SITES. The feed supply is more precarious in the semi–arid tropics. There are more stock than in the wetter zones, but at the same time biomass production is lower and more sharply seasonal. Consequently, crop residue and browse become even larger shares of feed intake, and are vital in the post–harvest and dry seasons when pasture production is very low. By–products and grain are often provided to stock for short–term fattening.

In the semi–arid tropics, crop residue is a major share of feed intake. As the value of crop residue rises, investments in its production and tighter

Table 6–4. Uses of Crop Residue at the Field Sites, by Environment

Sites and residue use	*Humid*	*Subhumid*	*Semi-arid*	*Highlands*
Number of sites	4	6	11	12
Allocated to crops				
Incorporation	–	–	–	–
Surface mulching	4	2	–	–
Composting	–	–	–	3
Allocated to animals				
Grazing				
Draft oxen	–	1	6	6
Dairy animals	–	–	1	1
Other animals	2	5	11	12
Storage and feeding				
Draft oxen	–	1	4	6
Dairy animals	–	–	3	11
Other animals	–	1	5	6
Treatment and feeding	–	–	–	–
Total uses	6	10	30	45

– No uses observed.
Note: Where there is more than one important use, all are reported, thus the number of uses is greater than the number of sites.
Source: Field visits by authors.

restrictions on access begin to appear. Storage for later feeding becomes a regular practice. Near Machakos, Kenya, the value of crop residue comes mainly from draft animals. Although there are occasional crop residue transactions in markets, farmers buy, exchange, and store residue during the various seasons. Crop residue can be exchanged against plowing time, sold in the field, or traded for grazing. The value of residue limits grazing access; no one can graze crop residue or individual pastures without the owner's permission.

Another illustration comes from the field sites of semi-arid Niger. Cattle production is extensive: there is no animal traction, no grade dairy cattle, and intensive fattening is limited to sheep and goats. There are vigorous local markets for crop residue because it is valuable feed in an environment where biomass productivity is low.

HIGHLANDS. All forage is exploited in the densely cultivated and stocked highlands. Pasture is less abundant, and browse has disappeared with the destruction of the tree cover. Nearly all edible crop residue is exploited, and forage crops are sometimes grown.

Table 6–5. Restrictions on Crop Residue Use at the Field Sites, by Environment

Sites and restrictions	*Humid*	*Subhumid*	*Semi–arid*	*Highlands*
Number of sites	4	6	11	12
Restrictions on access				
None	4	2	–	–
Harvest stalks, open access to stubble	–	3	3	3
Harvest stalks, restricted access to stubble	–	1	8	9

– Not observed.
Source: Field visits by authors.

Where milk production is well developed, forage grasses are a major share of feed intake.[4] Where animal traction is widespread, then essentially all of the crop residue is harvested, transported, and stored for later feeding.

SUMMARY OF FIELD EVIDENCE. The authors' field work partly confirms the evolutionary hypotheses about feed resources. In the humid zones, the determinant of livestock production is animal disease; population density has little or no effect because the potential for animal production is slight. Seasonality and animal mobility are also less powerful in explaining feed use patterns.

In the drier agroclimates, animal disease is not so threatening. As population densities rise in the semi–arid tropics and highlands, feeding systems become more labor intensive, with higher yields per unit of land. This intensification is associated with tighter restrictions on pasture and crop residue access, especially to pastoralists with tenuous land rights for cropping.

Possibilities for specialized or market forage production exist in certain farming systems. Only some of the cost considerations preventing cheaper fodder production for use on–farm apply if the fodder is produced for a market. Because such markets are usually urban and have annual milk

4. The impetus for forage crops in Rwanda, Burundi, and to a lesser extent, Zaire, comes from publicly enforced erosion control measures, not from milk production, because farmers are sometimes legally obliged to grow forage grasses on bunds.

demand, they may offer a more permanent demand. Such an external market for fodder and animal products can also give a transport cost advantage to quality forage. Specialized forage production is, moreover, less affected by land scarcity since specialization is encouraged by urban demand which can occur near rural areas of high or low population density. In this situation, intensive forage production could be particularly attractive. Although many forms of fodder production for a market were found at the field sites, specialized fodder production for a market was nil.

The field work confirmed the hypothesized negative relation between animal mobility and the demand for sown forages. Where opportunities for mobility are greatest in the semi–arid and subhumid sites, then there is little sown forage despite a strong comparative advantage in livestock production. Where mobility is nearly absent in the highlands, then sown forages begin to emerge.

PROJECT EVIDENCE. Hartwig Schafer's internal review of World Bank projects substantiates these arguments about forage crops. Reviewing nine projects promoting forage crops, he found that they had failed in six. In three failures, grazing was already ample and there was no demand for new forage. In three other failures, in spite of land pressure the opportunity costs of land for fodder production in place of other crops were too great. Fodder crops succeeded as feed for dairy cows in Zambia, and as part of soil erosion control in Rwanda and in Cameroon. The successes in Rwanda and Cameroon were partly due to official subsidies and especially strong extension efforts. Schafer found no strong impact of urban markets in stimulating sown forage production. Competition from fruit and vegetable production in urban areas apparently made the opportunity cost of land too high for profitable forage production.

SUCCESSES. The only common situation in which improved forage production is cheaper than native pasture, bush hay, or crop residue is highland milk production in East Africa. The Kenyan case is the one cited by both Ruthenberg (1983) and Jahnke (1982) for forage crop development in Sub–Saharan Africa. The keys to this success are:

- A mild climate allows European–type dairy cattle to thrive.
- These cattle are capable of providing worthwhile milk yields, often more than 2,000 liters per lactation, which can only be sustained with high–quality fodder.
- The large Nairobi milk market is nearby.
- Coffee and tea production are other sources of cash income which can be used to purchase food, thus freeing land from food crops to be sown with fodder crops.

- Adequate rainfall and soils allow good pasture yields.

A somewhat different success involves short–term livestock fattening in West Africa with oilseed cakes, groundnut and cowpea hay, and sometimes molasses. The elements of this success are:

- Native sheep and goats have rapid short–term weight gain capacity so that exotic animals are unnecessary.
- Cowpea and groundnut can be interplanted with food crops or sole cropped to supply relatively cheap hay.
- Native browse and pasture have near–zero opportunity costs.
- High–quality oilseed cakes and molasses are available and can be stored for the dry seasons when roughage and hay are not available.

Alternative Fodder Systems

There remain several alternatives to traditional fodder production which might be worthwhile for farmers: alley farming, crop residue management, and reallocating crop residue between crops and animals. Each presents a solution to problems of seasonality, mobility, and resource competition which have barred sown forages from general adoption in Sub–Saharan Africa.

Alley Farming

One alternative to traditional feed and herbaceous forage is alley farming, in which rows of leguminous trees are planted between rows of annual or semiperennial crops. The tree foliage feeds the crops by recycling deep soil nutrients and fixing atmospheric nitrogen. These nutrients allow continuous cropping without fallow and to some extent replace chemical fertilizer. If alley farming provides soil nutrients at lower cost per unit than chemical fertilizer, it would be efficient where fertilizing forage crops or crop residue is not.

An additional advantage of alley farming could be in animal production. In the humid tropics, better–quality feed is often unobtainable so that even if animal disease is suppressed, available fodder cannot easily support more stock. Because the leguminous foliage contains more nitrogen than native grasses or crop residue, it can raise livestock productivity. In semi–arid regions, browse can be managed to avoid competition with pasture and crop residue in the rainy and post–harvest seasons and to provide feed when it is more valuable in the dry season. As long as the trees could be protected, their perennial nature would not interfere with livestock production systems requiring mobility.

PRODUCTIVITY. Research at IITA has shown alley cropping to be technically feasible in the humid tropics, where water does not constrain crop production. The economic question about alley farming is its cost of production per unit of output. Papers on Nigerian maize by Ngambeki and Wilson (n.d.); Verinumbe, Knipscheer, and Enabor (1984); and Sumberg and others (1987); and on rice in Sierra Leone by Raintree and Turay (1980) showed alley cropping to be profitable. The value of the crop response to organic nitrogen, plus the value of the labor savings from continuous cultivation, were greater than the loss of crop production caused by stand competition from the trees.

Results may differ where water is limiting because land competition between trees and crops is exacerbated by water scarcity. In semi–arid Kenya, Hoekstra (1983) concluded that Leucaena could raise profits in maize production despite water competition between trees and the maize crop. Walker (1987) found that alley cropping was unprofitable in the semi–arid tropics of India because of land conflict between leguminous trees and cereals. Interplanting trees was economically inferior to sole cropping of trees and cereals under most tree fodder/cereal price ratios.

Only one study compared mulching the leaves to feeding them to livestock.[5] In the humid tropics of Nigeria, Sumberg and others (1987) found mulch to be a slightly better use of the leguminous trees than fodder unless animal disease was controlled. With animal disease control, fodder was better because initial animal productivity was higher, thus giving a greater return to feed. Walker's results (1987) from India proved that sole stands of a nitrogenous tree could be profitable because of the high market value of fodder.

Crop Residue Management

Substantial research has been devoted to improving crop residue (Table 6–6). There have been studies of the indirect effects of fertilizer on crop residue production, chemical treatment of residue, shifting plant breeding emphasis from grain to straw, improving management of crop residue, and reallocating residue from animal to crop production. Such methods could lower the costs of animal production and hence alleviate crop–livestock competition.[6]

5. Many studies, notably that of Addy and Thomas (1977c) in Malawi, have confirmed the fodder value of nitrogenous browse without analyzing its opportunity cost as mulch.

6. Other possibilities are hay–making and silage. Ruthenberg (1983), Crowder and Chedda (1977), and Doppler (1980) concur that technical difficulties are likely to make them unprofitable in the tropics and they are not discussed further here.

Crop Residue as an Indirect Benefit of Fertilizer. Fertilized crop residue would be more abundant than nonfertilized. Fertilizer might also improve the nutritive value of crop residue (Powell 1985, for pearl millet and sorghum in Nigeria; Lulseged Gebrehiwot and Jamal Mohammed 1989, for wheat in Ethiopia). The residual effects of fertilizer on crop residue would not affect the labor, mobility, or seasonality advantages of crop residue, and hence could avoid some of the problems with sown forages.

The fertilizer effect on crop residue depends on the profitability of adding fertilizer to the main crop.[7] In Niger, McIntire and Fussell (1989) found that the incremental value of pearl millet stover did not alter economic comparisons between a fertilized and a nonfertilized treatment. Matlon (1984) in Burkina Faso; de Leeuw, Wilson, and de Haan (1983) in Mali; and Lulseged Gebrehiwot and Jamal Mohammed (1989) in Ethiopia obtained similar results. Because the additional benefits of crop residue do not make chemical fertilizer any more or less profitable, fertilizer would not increase crop residue production unless it was already profitable to fertilize the main crop. While expanded crop residue production would obviously result from more fertilizer use, that output would not be decisive in improving incentives to use fertilizer. Residue output resulting from applying fertilizer to crops, as a source of feed, is therefore limited by those factors constraining the growth of fertilizer use in general.

Treating Crop Residue. Treating crop residue by composting, ammoniation, or other methods has been exhaustively studied (for example, the papers in Said and Dzowela 1989, and in Preston and Nuwanyakpa 1986). There appears to be a general positive effect of treatment with urea or sodium hydroxide on feed intake by ruminants in Africa (Said and Dzowela 1989). Attempts at extending such techniques have failed. Either the techniques were too labor intensive, or they gave returns inferior to other uses of the treatments, such as employing urea for crop production. In addition, using fertilizer for treating crop residue faces the previously mentioned problem of inadequate supplies.

Changing Plant Breeding Emphasis from Grain to Straw. Recognition of the value of crop residue to farmers highlights two issues: the possible bias in selecting cultivars for grain yield where fodder is scarce, and the supposed poor feed characteristics of residue from

7. Many fertilizer trials do not report the value of crop residue yields, however.

Table 6–6. Previous Research on Crop Residue

Research theme	Total number of studies of research theme	Environment: Humid and subhumid	Environment: Semi–arid	Environment: Highlands	Did study measure effect of research theme on other use [a]
Crop residue allocated to crops					
Incorporation	–	–	–	–	–
Surface mulching [b]	2	1	1	–	1
Fertilization [c]	4	–	3	–	1
Composting [d]	1	1	1	–	–
Total to crops	7	2	5	–	2
Crop residue allocated to animals					
Grazing [e]	2	–	2	–	1
Transport, storage [f]	1	–	1	–	–
Treatment [g]	2	–	–	2	–
Change species fed [h]	1	1	–	–	–
Nutritive value [i]	5	1	3	–	–

Interactions with					
other feeds [j]	8	1	1	3	–
General survey [k]	2	–	2	–	–
Other [l]	8	2	4	–	1
Total to animals	29	5	13	5	2
Grand total	36	7	18	5	4

– No studies found.

Note: *Nothing was found on plant breeding for residue quality, or on fertilizing to improve residue quality.*

a. For example, of the two studies which examined surface mulching of crop residue, one considered the possible use of the residue for livestock feed. Of the two studies of grazing crop residue, one measured its effect on crop production.

b. Okigbo and others 1980, Dugue 1985.

c. Tanaka 1974, Jones 1976, Ganry and Bertheau 1980, Feller and Ganry 1982.

d. Gaye and Ganry 1978.

e. van Raay and de Leeuw 1971, Dugue 1985.

f. Miller, Rains, and Thorpe 1964.

g. Said 1981, Said, Wheeler, and Lindstad 1977.

h. Grieve 1976.

i. Kevelenge, Said, and Kiflewahid 1982a, 1982b, 1982c; Mbwile 1982; Umoh 1975.

j. Addy and Thomas 1977c, 1977d; Ahmad 1986a; Alemu Gebre-Wold 1977; Dia Ndumbe 1982b; O'Donovan 1978, 1979; Thomas 1977.

k. SODEVA 1981, Ly 1981.

l. Cabaret 1975; Edelsten and Lijongwa 1981; Dia Ndumbe 1982a; Faye 1981; Lhoste 1989; Piot 1975; Traoré, Soumare, and Coulibaly 1986; Tanaka 1976.

high–yielding grain cultivars. If either phenomenon is confirmed in African conditions, it would support a shift in the emphasis of plant breeding from grain to crop residue in order to make cereal cultivars more appropriate to farmer circumstances. Such a shift would promote crop–livestock integration by lowering the cost of crop residue for feed. The field visits found no instances of chemical treatment of crop residue.

Evidence for the value of fodder where it is very scarce comes from South Asia and Ethiopia. In three villages of semi–arid India, the share of sorghum and pearl millet fodder was about 32 percent of the value of the output of those crops from 1975 to 1984, and 38 percent from 1982 to 1984 (Kelly, Rao, and Walker 1990). The ratios of sorghum grain/straw prices for those periods were 6.9 and 5.5, respectively. In a study in Pakistan, Byerlee and Iqbal (1987, p. 14) showed that residue was from 29 percent to 57 percent of the total value of maize production, and that the price of grain was only about 2.7 times the price of stover.

Research in Ethiopia revealed market grain price to residue price ratios to be from 2.0 to 2.5; residue was from 35 percent to 48 percent of the value of a sorghum crop (McIntire and others 1988). In that Ethiopian case, altering a sorghum breeding program to obtain higher residue yields would have increased average income from sorghum production by 15 percent, assuming that the shift in emphasis did not change the costs of the breeding program. These studies suggest that, with increasing population and land–use intensity in Africa, research and extension programs should begin to put some additional emphasis on the value of crop residue. Any resulting increases in residue availability would assist crop–livestock integration by lowering fodder production costs to farmers.

Specific evidence from Africa is not available about the feed characteristics of residue from higher–yielding cereal varieties, but there is evidence from Asia. A negative fodder quality effect was reported with high–yielding sorghums in India (Walker and Ryan 1990, p. 52). Reed, Yilma Kebede, and Fussell (1988) showed that high–yielding Asian rice varieties do not have inferior straw digestibility, however, compared to traditional rice varieties. Moreover, the new rice cultivars do not lodge, and they sometimes allow double cropping, thereby increasing total dry matter yields so that their overall fodder quality effect was positive. This evidence is more ambiguous than that about the bias in selecting cultivars for grain yield against straw, and suggests a need to test improved grain cultivars for fodder quality and quantity under African conditions.

Farmer Practices with Crop Residue. Given the importance of crop residue as a feed resource and in reducing crop–livestock competition, a major goal of the authors' field work was to identify uses and management techniques for residue (Table 6–5). Changes in management could provide greater and more timely fodder availability to livestock producers at low cost.

Crop residue is typically used in the following forms, arranged in increasing order of labor requirements:

- Open access to whole residue on harvested fields.
- Harvest and removal of stalks with subsequent open access to stubble on harvested fields.
- Harvest and removal of stalks with subsequent restricted access to residue on harvested fields.
- Transport and storage for feed or sale.
- Transport, storage, and processing for feed or sale.
- Harvest of thinnings and weeds from cultivated fields for selective feeding before the harvest of the main crop and the residue.

The pattern of residue use fits well into the evolutionary model. Open access to crop residue occurs in monomodal rainfall systems where farmers have few stock, do not use animal traction, and herd collectively (Table 6–5). It is also seen in the most humid zones and at some arid sites with few livestock. The most intensive uses are in the highlands and densely populated regions of the other agroclimates. Farmers restrict access most closely in highland Ethiopia, Kenya, and at Ganawuri, Nigeria, which are densely cultivated and stocked.

Many earlier studies have reported restrictions on crop residue use. In dryland farming systems in Swaziland and South Darfur, Sudan, farmers fence their fields to prevent outsiders from entering harvested plots (Hughes 1972, Behnke 1985). Around Katsina, Nigeria, pastoralists must seek permission from farmers before grazing fields (van Raay and de Leeuw 1971). In the Abet Plains of Nigeria and in much of Ethiopia, the farmer has the right to designate a herder for the first grazing of stubble after harvest and removal of stalks (Powell 1986b, Gryseels and Anderson 1983). Restrictions were seen by Ingawa (1987) at several points in northern Nigeria. The economic behavior of farmers to restrict access to residue and to otherwise manage it suggests that they understand its value and use it appropriately.

Reallocating Crop Residue Between Crops and Animals

Despite research and extension recommendations to mulch crop residue, most residue is in fact consumed by livestock. There is a latent conflict between crops and animals for crop residue which has not been well analyzed. For example, one prominent scientist wrote of Nigeria: "At many experimental stations, for convenience, all above ground residues are routinely cleared from the field, even in long–term experiments" (Jones 1976, p. 117).

Would reallocating residue from animals to crops be efficient? Table 6–7 sketches a model of the competition between animals and crops for residue, which illustrates returns to grazing crop residue or to restoring it to the soil.[8]

Site Characteristics. Model sites in Niger, Nigeria, and Ethiopia represent the semi–arid tropics, the subhumid zone, and the highlands, respectively, with varying soils, population densities, altitudes, and degrees of mechanization. Cattle are modeled in Niger and Nigeria. Cattle, draft oxen, and sheep are modeled in Ethiopia. Typical herd structures and productivity were taken from published material.

Crop Characteristics. Pearl millet is modeled in Niger and sorghum in Nigeria and Ethiopia. Yields of grain and crop residue are those which could be obtained with available technology. Digestibility of crop residue has been estimated from published studies.

Unit Values. Weight and milk offtake are valued at appropriate market prices. The value of manure production was estimated via its impact on crop production because market prices were not available. A value was assigned to power in Ethiopia from a regression analysis of the grain production impact of draft oxen (Gryseels and others 1986). The value of crop residue was estimated from market prices, where available. Where prices were not available, the value of residue in animal production was used.

Crop Residue Disappearance. The disappearance of crop residue depends on selective grazing by livestock. The dry matter left on the soil after selective grazing is the difference between the dry matter yield of the crop residue and the quantity grazed.

Output Effects. Desiccated crop residue refused by grazing animals, or protected from grazing, produces an incremental grain yield. All indigestible crop residue passes through the animal and produces manure at a specified rate. Each ton of manure produces an incremental grain yield, whether it is left on the soil surface (lower yield) or incorporated (higher yield).

8. Details are in the Appendix.

PRODUCTION ALTERNATIVES. One alternative is to graze all crop residue in the field and paddock the animals there. The benefits are the contributions of crop residue to animal production, and of manure from paddocked animals to crop yields. The second alternative is to restrict grazing and to mulch residue on the soil. The benefits are the contribution of crop residue to animal production, manure to crop yields, plus the impact of residue on the subsequent crop yield. The annual value of animal production is the value of liveweight offtake, milk sales, manure production, and draft power. Gross revenue is the sum of revenue from crop residue and manure use at market prices.

COST OF PRODUCTION ALTERNATIVES. Herding labor is the only grazing cost. Labor is the cost of spreading (less labor) or of incorporating (more labor) manure and crop residue. Labor for herding, crop residue management, and manure application is valued at the local daily wage.

NET REVENUE OF PRODUCTION ALTERNATIVES. Gross revenue minus cost is the net revenue of the production alternatives.

RESULTS. In Niger, shifting to mulching from grazing crop residue would reduce income because the yield response of pearl millet to crop residue is weak. In Ethiopia, shifting to mulching would reduce income as well. Grazing crop residue is always superior because of the additional herd maintenance value of working oxen. Shifting crop residue from grazing to mulching would increase income in Nigeria where the yield of crop residue is high, and where the crop response to mulch might be stronger.

SENSITIVITY ANALYSIS. The sensitivity of these results was tested by varying the costs of labor and grain in each of three sites (Figure 6–1). Varying the cost of labor from 25 to 200 percent of its base value at each site would not change the results appreciably, and would never alter the decision to mulch or graze. Varying the price of grain from 50 percent to 200 percent of its base value in each site would change the results, in particular making mulching superior.

To further test the sensitivity of these results to assumptions about the availability of fertilizer as an alternative to crop residue, a linear programming (LP) model was devised for Niger. This is a good test case because the fertility of these sandy soils is especially poor, and the need to restore organic matter is greater. Because the LP model allows numerous alternatives in the competition between animals and restitution of residue—various pearl millet production methods, mulching, selling, or grazing crop residue—it permits a fuller inspection of the

Table 6–7. Model of Crop Residue Allocation

Model parameters	*Niger*	*Nigeria*	*Ethiopia*
Site characteristics [a]			
Main power source	Hand	Hand	Oxen
Population density (persons per km^2)	40	30	100
Altitude (meters)	300	600	1,850
Soil type	Sandy	Ferralitic	Vertisol
Crop characteristics [a]			
Crop	Pearl millet	Sorghum	Sorghum
Grain yield (kg per ha)	220	1,000	2,550
Fresh crop residue yield (kg per ha)	1,300	5,500	5,510
Crop residue dry matter yield (kg per ha)	1,040	4,125	3,306
Weighted mean of stem and leaf digestibility (percent) [b]	43	45	52
Unit values (US$ per kg) [a]			
Grain	0.29	0.25	0.26
Fresh crop residue	0.05	0.10	0.06
Dry digestible crop residue			
Market price	0.16	0.30	0.18
Maintenance value [c]	0.02	0.02	0.04
Manure	0.03	0.04	0.01
Labor cost (US$ per day)	1.82	1.25	0.50
Crop residue disappearance during selective grazing by livestock [d]			
Total fresh matter selected (kg per ha)	690	2,613	2,926
Total digestible dry matter selected (kg per ha)	279	990	969
Dry matter left on soil after selective grazing (kg per ha)			
All crop residue grazed	488	2,166	1,551
Half crop residue grazed, half mulched	764	3,145	2,428
All crop residue mulched	1,040	4,125	3,306
Output effects			
Crop residue effect on grain yields (kg grain per kg crop residue dry matter)	0.02	0.10	0.05

Model parameters	Niger	Nigeria	Ethiopia
Manure produced by grazing animals from crop residue intake (kg manure per kg crop residue dry matter)	1.12	1.12	1.12
Manure effect on grain yields (kg grain per kg manure)	0.14	0.15	0.15
Gross revenue of production alternatives (US$ per ha)			
Grazing all crop residue			
Grazing at maintenance value of crop residue [e]	5.00	20.00	37.00
Value of manure subsequently produced by grazed crop residue [f]	12.00	41.00	34.00
Selling all at market price of crop residue	164.00	1,222.00	606.00
Mulching all crop residue [g]	6.00	103.00	42.00
Labor use of production alternatives			
Labor use by alternative			
Grazing crop residue (days)	4	14	16
Mulching crop residue (days per metric ton) [h]	10	10	10
Labor cost of production alternative (US$ per ha) [i]			
Grazing crop residue	7.00	18.00	8.00
Mulching crop residue	18.00	13.00	5.00
Net revenue of production alternatives (US$ per ha) [j]			
All crop residue grazed	11.00	43.00	63.00
All crop residue mulched	(12.00)	91.00	37.00
Break–even grain price [k]	(0.74)	0.06	1.04
Ratio of break–even to average grain price	(2.54)	0.24	4.07

a. Unless otherwise noted, data in this section are from main sources.

b. Calculated from digestibility data and animal feed intake in McIntire and others (1988), for Ethiopia; and from papers in von Kaufmann and Blench (n.d.)

c. The maintenance value of digestible crop residue is defined as the annual value of production from an animal divided by the quantity of digestible crop residue necessary to maintain that animal.

d. Data on grazing selectivity of livestock are from von Kaufmann and Blench (n. d.), assumed to apply to all sites.

e. Equal to crop residue grazed multiplied by the maintenance value of that crop residue.

(Table continues on the following page.)

Table 6–7 (continued)

f. Calculated as the amount of grazed crop residue which passes through the animal and is converted to manure, and subsequently produces grain, multiplied by the grain price.

g. Crop residue dry matter multiplied by crop residue effect on grain yield multiplied by grain price.

h. Estimated from labor data on organic fertilization for cotton, pearl millet, white sorghum, and red sorghum shown in Matlon and Fafchamps (1988) for three zones in Burkina Faso.

i. Labor used multiplied by estimated market wages.

j. Gross revenue of production alternative minus labor cost of alternative.

k. The price of grain at which the net revenue from grazing the crop residue would be equal to that of mulching it. Negative values are in parentheses.

Source: Niger data from field visits and parameters in Coulomb, Serres, and Tacher (1980). Nigeria data from von Kaufmann and Blench (n. d.). Modeling of supplementation value of animals based on analysis in Sandford (1978). Ethiopia data from field visits and Gryseels and Anderson (1983).

competition for residue. The expected results are that having fertilizer would displace mulching by eliminating the need to provide soil nutrients with crop residue. Fertilizer would therefore allow higher animal stocking rates by making pearl millet stover available as livestock feed.

Results of the linear programming model are shown in Table 6–8.

- If fertilizer is available, then 61 to 68 percent of the available crop residue could be mulched profitably. The share of mulched crop residue would be slightly lower at higher stocking rates.
- If fertilizer was not available, then mulching could only be profitable with 41 to 59 percent of the crop residue. The fraction mulched would again be lower at higher stocking rates.
- Mulching is more profitable if fertilizer is available because fertilizer stimulates crop residue and the excess can be restored to the soil.
- Mulching is less profitable if fertilizer is unavailable. Without the stimulus of fertilizer, crop residue is in short supply and it is less efficient to restore it to the soil, which is the situation of pearl millet farmers in western Niger. The crop residue is grazed down to the stubble, which is later burned and turned into the soil at the start of the cropping season. Thus a mixed grazing and mulching strategy is followed in the absence of chemical fertilizer.

Summary of Residue Reallocation. Reallocating residue from animals to crops would not be efficient at two of the three sites analyzed

Figure 6–1. Effects of Grain Price and Labor Cost on Profitable Crop Residue Use

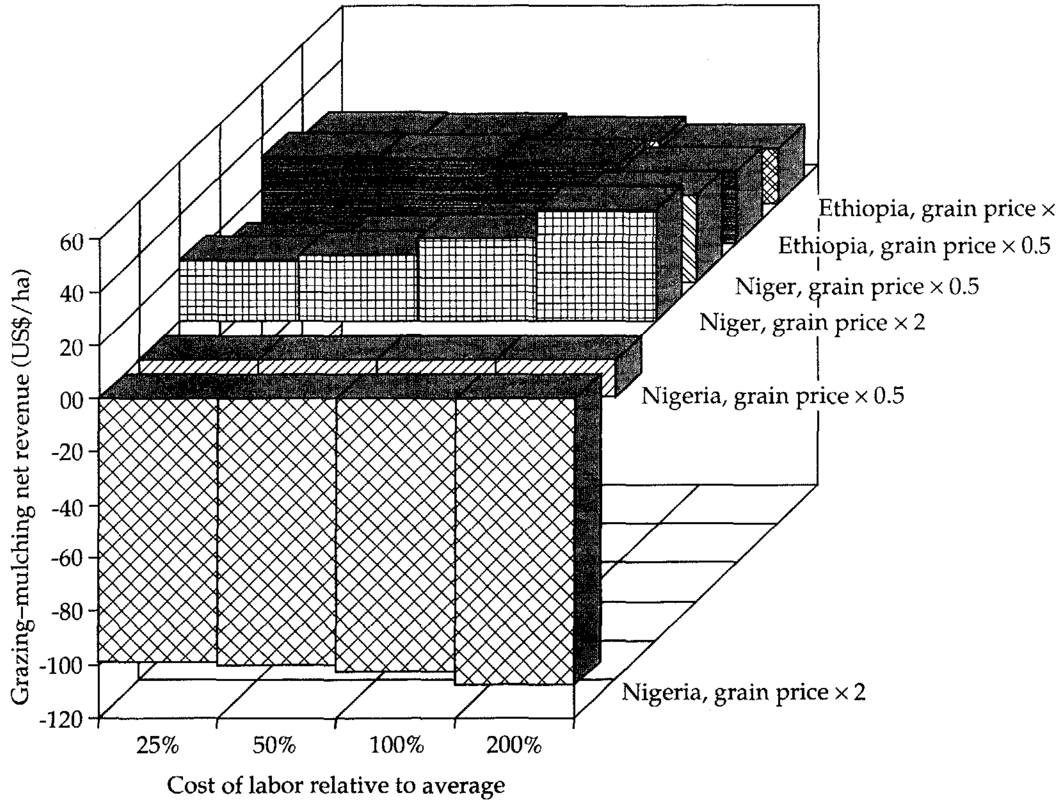


Table 6–8. Optimal Pearl Millet Residue Strategies in Semi–Arid Niger

	Share of crop residue used for	
	Grazing or sale (percent)	Mulch (percent)
Fertilizer available		
Stocking rates		
0.5 TLU per hectare ("low")	32	68
1.0 TLU per hectare ("high")	39	61
Fertilizer not available		
Stocking rates		
0.5 TLU per hectare ("low")	41	59
1.0 TLU per hectare ("high")	59	41

Source: Derived from optimal solutions of linear programming model developed by the authors.

because the opportunity cost of foregone livestock fodder is too high. At the third site, in the Nigeria subhumid zone, the opposite occurred because the maintenance value of crop residue used as livestock fodder is lower, and can be sacrificed to expand crop production via mulching. The dominance of feeding crop residue to livestock, as opposed to mulching it, was also confirmed in the field visits.

Summary

Lower fodder costs would increase crop–livestock complementarity by reducing a barrier to animal productivity at existing levels of crop production. While some introduced feed systems are viable technically, they have not been widely adopted in African agriculture despite extensive experimental work. This defeat occurred because fodder development was sometimes targeted to the wrong season and the wrong resources in given farming systems.

More specific conclusions about the successes and failures of improved fodder production are as follows:

- Agroindustrial by–products have been widely adopted and are apparently successful in raising productivity because they are consistent with the mobility and seasonality aspects of many African livestock production systems. They can be offered in seasons when competing sources of feed are most costly, do not interfere with livestock mobility, and do not compete directly for land and labor resources on the farm.

- Sown forages have not been widely adopted because they sometimes conflict with the mobility needs of livestock production, or because they demand scarce factors of production which are not readily available. The failure to find sown forages is common to both range–livestock and crop–livestock systems.
- Factors favoring adoption of sown forages in projects appear to be high population density and high–value milk production. Few examples were found of forage crops being introduced for meat production or to support draft animals.
- The most successful sown forages are intercrops and crop residue because they offer fodder at low resource costs and are already features of existing crop–livestock systems.
- Efforts to improve crop residue for livestock production hold only limited promise. Crop residue is now in widespread use as fodder and farmers appear to manage it appropriately. A reallocation of crop residue from soil restitution to grazing appears unpromising where livestock production is important because crop residue is already used for grazing. Some success might be obtained by placing more emphasis on the straw characteristics of new crop cultivars in plant breeding programs.

Studies have shown that experimental productivity advantages of sown forages are lost to the costs of fencing, land preparation, sward establishment, and management necessary for high forage yields (Doppler's 1980 work in subhumid Togo is the best example). This general cost constraint to fodder development suggests a reorientation of research and extension, which is suggested by the following four main livestock production systems.

RANGE–LIVESTOCK SYSTEMS. Reducing fodder costs in these systems confronts the basic conflicts of labor use and seasonality in a harsh environment to which few new plants can adapt. The difficulties of adopting sown forages and the slow rate at which crop residue becomes available make purchased concentrates the cheapest source of extra feed since they conserve well, use less labor, and inhibit mobility less.

In terms of labor use, sown forages are suitable only for partly sedentary herds because cropping in a pastoral system implies less mobility.

If women and children manage the sedentary herd while the men are away with the mobile herd, forage labor demand would be high relative to supply. Sown forages are thus an intensive means of production for part of the herd and confront labor shortages as a principal constraint. Absence of competition from crop residue means that in contrast to crop–livestock systems, the post–harvest/early dry season has the highest potential. The target forage is a long–cycle annual or perennial to be established early in the rains and to be grazed in the post–harvest period.

RAINY SEASON CROP–LIVESTOCK SYSTEMS. The prospects for forage introductions in this season depend on animal mobility. Where mobility is extensive, the situation is like that of range–livestock systems and the prospects for sown forages are practically non–existent. Where mobility is limited, sown forages face an acute labor conflict with arable crops and must therefore fit into specialized niches. An improvement strategy targeted at such niches must select for these factors:

- Earliness is important because forages sown with the first rains provide benefits before grasses, thinnings, weeds, or leaf strippings.
- If sown forages can tolerate being grown as an intercrop, then they compete less for land and labor than do sole cropped forages.
- Crops which thrive on marginal land or on fallow land are important.
- Another exception would be when high–potential milk production is introduced, thus raising the return to all types of forage and stimulating investments in them.

CROP–LIVESTOCK SYSTEMS IN THE POST–HARVEST SEASON. The prospects for lowering fodder costs in this season depend little on mobility and much more on the availability of alternative high quality fodder sources which use less labor. The main alternative source is crop residue. Its utilization is not as labor intensive as sown forages because it can be grazed and will dominate sown forages as long as the high quality fractions are available. A forage strategy includes selection for harvest when crop residue has disappeared or when its quality has fallen off, and sown forages grown in relay systems or planted with residual moisture after the main harvest.

Certain exceptional types of cropping systems would tend to favor sown forages more strongly. Examples are root or permanent staple crop systems where residue is scarce, and perennial crop systems where field grazing of fodder is difficult. In both instances the post–harvest scarcity of crop residue favors introduced forage.

Crop–Livestock Systems in the Dry Season. The chances of lowering fodder costs in this season are limited by water supply and the technical possibilities for conservation. Introduced forages might be most competitive in this season, nonetheless, because crop residue and pasture have disappeared. A dry season strategy includes:

- Selection for growth on residual moisture, making forage available in the dry season without irrigation.
- Selection for conservation quality in wet–season forage.
- Selection for long–cycle forages which can be sown in the rainy season and grazed later.
- Selection for sown forages which do not interfere with land preparation for the next cropping season. This conflict is severe in bimodal rainfall regimes where the short rains are necessary to prepare land for the long–season crop.

7

Fattening Animals on the Farm

ONE OF THE HYPOTHETICAL advantages of crop–livestock integration is on–farm animal production, also known as smallholder fattening, or 'embouche paysanne' in the francophone countries. Smallholder fattening could enable farmers who have arable land to use crop residue, pasture, and browse, all of which have little opportunity cost in other uses on the farm. Farmers would not need to own or manage animals year–round to fatten them for short periods. Animal traction would not be a necessary condition, nor would sown forages be required as they are for better milk production. Farmers could profit from seasonal fluctuations in livestock prices by purchasing thin stock when prices were low, fattening them, and then reselling when prices were higher. Some of the difficulties of large feedlots might be avoided by promoting operations on–farm, while giving small farmers an opportunity for higher income.

An example of a smallholder system in operation is that reported by Baur (1989) in semi–arid Mali. Farmers received public credit to buy thin cattle at the end of the wet season, when prices were depressed. They fattened the animals on crop residue, other local fodder, and cottonseed cake for 3 to 6 months, resold the cattle during the dry season when prices were highest, and repaid the credit.

On–farm animal production is not always profitable despite its apparent attractiveness. A review of World Bank livestock projects (World Bank 1985) found that about half of the smallholder fattening schemes in West Africa had failed. An unpublished 1988 World Bank report by Hartwig Schafer examined twenty-five smallholder projects in Sub–Saharan Africa and found that cattle fattening projects failed more often than not. Bartholomew (1988) estimated that 36 percent of smallholders had negative returns to fattening Zebu cattle in a semi–arid area of Mali, while Odoemele, Ingawa, and von Kaufmann (n.d.) found that 17 percent in a sample of Nigerian producers had negative returns. Holtzmann (1986) concluded that returns to fattening were inferior to returns from crop production in northern Cameroon. While Sanfo's (1983) study found sheep fattening to be widespread in northern Burkina Faso, its profitability was marginal.

The mixed record of smallholder fattening has spawned a number of questions which are addressed in this chapter:[1]

- What are the economic returns to smallholder fattening?
- What are current smallholder fattening practices? Do farmers integrate animals for on–farm fattening appropriately, in the sense that they manage crop residue and manure efficiently to maximize benefits from directly managing animals?
- What are the effects of labor and other inputs?
- What are the effects of the price and supply of animal feed?
- Do known animal feed responses permit profitable fattening given the prices of available feeds?
- Would changes in breed or species be required to improve profitability?
- What are the effects of government price policies on incentives to fatten, given the feed responses?
- Are there negative scale effects of smallholder production on returns to animal production?

Economics of Fattening

The economics of fattening animals can be discussed in terms of theoretical rates of return and estimates of actual rates of return.

Theoretical Rate of Return

The components of income from fattening are defined as livestock purchase and sale prices, feed costs, and nonfeed costs. While the variability of returns is an important factor, reliable information is lacking, so the discussion concentrates on average return.

INCOME FROM ANIMAL PRODUCTION. Consider the income derived from fattening an animal to sell. If

p_e = price of a fattened animal in currency per unit of weight

1. On–farm dairy production is not specifically reviewed because it will be more difficult to improve than fattening on–farm in many African environments. In addition, there have been a number of reviews of dairying, including the very recent study by Walshe and others (1991).

p_b = price of a feeder animal

w_e = fat weight

w_b = feeder weight

FC = total feed costs

NFC = nonfeed costs, such as housing, labor, veterinary care, and credit for animal purchase

B = other benefits, such as those from manure use facilitated by smallholder fattening, then

NR = the net revenue from fattening,[2] is shown as

$$NR = (p_e \times w_e - p_b \times w_b - FC - NFC + B).$$

In other words, the net revenue is revenue from sale less purchase cost, feed and nonfeed costs, plus other benefits.

To further examine feed costs, let

p_f = price of feed, calculated as a weighted average from market feed prices and the ration components

T = fattening period in days

d_w = weight change during fattening, equal by definition to $w_e - w_b$

DFI = daily feed intake of an animal

q_f = total quantity of feed consumed during the fattening period

FCR = feed consumption ratio, equal by definition to q_f/d_w

FC = $q_f \times p_f$ and

q_f = DFI × T.

Excluding nonfeed costs and other benefits, FR, the revenue from price changes alone without weight gains, is

$$FR = p_e - FCR \times p_f.$$

The ratio of the liveweight price of a fattened animal to the feed price must be greater than the consumption ratio if fattening is to at least cover the costs of feed.

2. All prices are per kilogram of liveweight, and all liveweights are in kilograms.

PURCHASE AND SALE PRICES. The gross revenue to fattening before deducting feed and nonfeed costs is equal to sale value less purchase cost. It has three components: price, weight, and a price by weight interaction (Agyemang and others 1988). The price component is the price change (p_e - p_b) multiplied by the feeder weight (w_b). The weight component is the weight change (w_e - w_b) multiplied by the feeder price (p_e). The interaction component is the change in price (p_e - p_b) multiplied by the change in weight (w_e - w_b). A positive (negative) price component and a zero weight component would mean that all profits (losses) came from price increases (decreases) during the fattening period, and vice versa, so it is possible for fattening to be profitable without weight gains or without any price changes.

FEED COSTS. Feed is the largest single variable cost. Letenneur (1973) found feed to be from 52 to 90 percent of total variable costs in various trials in Côte d'Ivoire. A study in Mali showed them to be 40 to 60 percent of the total cost of cattle fattening (CNRZ n.d.). Stotz's compilation of dairying costs in Kenya revealed purchases of concentrates and forage to be 28 to 49 percent of the total variable costs in zero–grazing systems (Stotz 1983, pp. 53, 54, and 59).

NONFEED COSTS. Housing, veterinary care, labor, water, and information about animal management are all nonfeed costs. Because housing, information, and veterinary care are fixed costs, they would not be proportional to feed costs. However, the variable costs of labor and water would be proportional to feed intake. Labor in particular is a function of the volume of feed to cut and transport. For example, crop residue, sown forages, and forage harvested from pastures are bulky and must be collected over a dispersed area, thus requiring more labor per unit of feed than concentrate feeds.

OTHER BENEFITS. Reduced costs of collecting manure, more efficient use of crop residue, and seasonal employment of labor are all other benefits of fattening animals. Of these, only the reduced cost of collecting manure is unambiguously positive. Crop residue and labor for animal production may impose costs (benefits) if those resources are diverted from other activities in which their use is more (less) remunerative.

Estimates of Rates of Return

Table 7–1 sums up the scanty evidence about rates of return from field data with cattle. While these estimates have been constructed in different ways, they tend to prove that smallholder fattening can be profitable. Bartholomew's (1988) account of a long-term research project in semi-arid Mali demonstrates that the idea is a remunerative one. In Niger, Mamadou (1983) found rates of return from 22 to 56 percent in cattle fattening. Wardle (1979), also working in Niger, found smallholder fattening to be generally successful. Other rates of return estimates for dairying, small ruminants, and beef are highly variable (Table 7–2). For example, in Mali, Kolff and Wilson (1985) calculated 11 percent as the mean return for intensive sheep fattening, but -12 percent when smaller quantities of high-quality feeds were employed.

In Table 7–2, the return to variable inputs is estimated from feed conversion ratios, liveweight prices, and feed prices. The return to all inputs includes that to land, labor, housing, and veterinary care.[3] The most consistently positive returns are found in the Kenyan highlands (calculated from Stotz 1983, as shown in Table 7–2). Returns to all inputs—variable inputs plus the costs of primary factors, animal purchase, and housing—are generally negative, except for milk production. The gap between returns to variable inputs and to all inputs is probably due to overvaluing costs of housing and labor.

Identifying the causes of variations in returns is more difficult. Only three studies partition the shares of price and weight gains in net returns (Table 7–1). Price gains appear more important in semi-arid Mali than in subhumid Nigeria or in subhumid Malawi, which is perhaps because fodder is more scarce at the semi-arid site, making weight gains more costly and giving greater importance to the price component (Table 7–1). Baur (1989) attributed variations in returns in fattening Malian cattle to differences in the quality of rations. Differing returns to cattle production between Cameroon and Côte d'Ivoire and central Nigeria appear to be due to lower feed conversion ratios in Nigeria, achieved by feeding animals for shorter periods (Lhoste 1977, for Côte d'Ivoire; Adesipe and Olayiwole 1982, for Nigeria).

Project reviews do not permit full economic or financial analysis of individual techniques, but do indicate factors affecting project success. According to an unpublished World Bank study by Hartwig Schafer, "The complete failure of stall feeding schemes . . . [was due to the fact that] the additional labor requirements for transporting and storing of forage [were not justified by the benefits from stall feeding animals]." A World Bank project audit attributed successes with smallholder fattening to country characteristics in which land pressure obliged producers

3. The returns to variable inputs should be comparable across sites because they are estimated from station data gathered under controlled conditions.

Table 7–1. Field Studies of Smallholder Cattle Fattening

Study elements	*Agyemang and others 1988*	*Odoemele, Ingawa, and von Kaufmann n.d.*	*Bartholomew 1988*	*Holtzmann 1986*
Country	Malawi	Nigeria	Mali	Cameroon
Environment	Subhumid, Lilongwe, Blantyre	Subhumid, Kaduna	Semi–arid, Banamba	Highland, Mandara mountains
Breed	Zebu	Zebu	Zebu	Zebu
Feed	Maize bran, groundnut meal, maize stover	Wheat bran, groundnut cake, molasses, roughage	Cottonseed cake, crop residue, bush hay	Sorghum grain
Costs	Animal, insurance, veterinary	Feed, animal credit, veterinary	Feed, animal, credit	Feed, labor, water
Benefits	Fattening	Fattening	Fattening	Fattening, manure on crops

Feeding period (days)	213	100	90	730
Liveweights				
Feeder (kilograms)	271	293	322	175
Fat (kilograms)	340	382	363	Unknown
Average daily weight gain (grams)	500	840	466	Unknown
Indicators of financial return (percent)				
Sample average	Unknown	33	11	Unknown
Share of sample with negative returns	Unknown	17	36	Unknown
Main sources of benefits (percent)				
Weight gains	60	62	40	Unknown
Price increases	18	29	52	Unknown
Interactions between weight and price	22	9	7	Unknown
Animal production	Unknown	Unknown	Unknown	50
Crop production	Unknown	Unknown	Unknown	50

Table 7–2. Estimates of Returns to Animal Production

	Rates of return	
Studies	To variable inputs (percent)	To all inputs (percent)
Semi-arid tropics		
Cattle fattening		
Cameroon [a]		
1970	-42	Unknown
1971	-35	Unknown
1973	-23	Unknown
1975	-37	Unknown
Côte d'Ivoire [b]		
Baoule	-55	Unknown
N'Dama	-24	Unknown
Zebu	-33	Unknown
Nigeria [c]	37, 47	Unknown
Extensive cattle		
Niono, Mali [d]	Unknown	25
Intensive sheep		
Niono, Mali [e]	37	Unknown
Extensive sheep		
Niono, Mali [e]	17	Unknown
Highlands		
Beef		
Kenya [f]	67, 50	-110, 28, 8, -6
Kenya [g]	3, 2, 48	Unknown
Dairy		
Kenya [f]	201, 156	-0.4, 11, 14, 29
Goats		
Kenya [f]	107, 125	-53, -6, 2
Sheep		
Kenya [f]	176, 191	-71, -4, -3

Note: Where more than one value is shown in a cell, each refers to a different technique within the basic system.

a. Lhoste, Pierson, and Ginisty (1975).
b. Lhoste (1977).
c. Adesipe and Olayiwole (1982).
d. Wilson, Hiernaux, and McIntire (1991).
e. Kolff and Wilson (1985).
f. Stotz (1983).
g. Mulder, Waweru, and Kamau (1973).

to intensify resource use, or in which livestock and crop production were closely linked before project initiation (World Bank 1985, Vol. I, pp. 57–70.)

Field Evidence about Fattening Practices

Short-term fattening of cattle, sheep, and goats is common in Sub-Saharan Africa (Table 7–3). Despite major differences in production environments, the key elements of ruminant livestock fattening by farmers in crop–livestock systems varied little. The technical level of livestock production was low (Table 7–4). Use of concentrate feeds was sporadic, and animal housing and water supplies were rudimentary.

ANIMAL SPECIES AND BREED. Most of the animals fattened are small ruminants. The one site with classic stall feeding of cattle was Kufana in central Nigeria, where access to the large Kaduna market is good. At sites with significant trypanosomiasis, some mix of trypanotolerant stock is raised. At sites with little trypanosomiasis, Zebu cattle and local races of small stock dominate. Only in the highland sites was dairying with crossbreed animals seen. Cattle fattening was not done at all in the Kenya highlands because feed competition favors intensive milk production.

FEED SOURCES. As shown in Chapter 6 (Tables 6–2, 6–3, and 6–7), native pasture, crop residue, and browse are the dominant feeds. Crop wastes—yam peels, grain washes, and brans—are employed assiduously as supplemental feed. Farmers fed grain to livestock at fewer than five field sites. At only two sites (Inewari, Ethiopia, and Kufana, Nigeria) were the products of labor-intensive crop husbandry—stripping leaves, harvesting weeds, thinning crops—used for fattening. At Inewari, such fodder is used for draft oxen and meat animals. Inewari is densely populated and thus grazing resources are at a premium, but it is also poor and offers few alternatives to livestock for cash income. Kufana is located on a main road near the major market city of Kaduna, and has good access to young stock; both factors make more intensive livestock production an attractive investment.

Smallholder fattening programs typically recommend rations with a high proportion of crop residue. Failure to observe farmers using crop residue for fattening would suggest either that there are latent gains from changing current uses or that the opportunity cost of residue in other activities is too great to use it for livestock. The field visits showed a strong association between animal fattening and crop residue use. Typically, crop residue was reserved for quality animal production, notably in the dry season when pasture was least productive.

Table 7–3. Summary of Animal Fattening at the Field Sites, by Environment

Sites and study categories	*Humid*	*Subhumid*	*Semi–arid*	*Highlands* *Mechanized*	*Highlands* *Unmechanized*
Number of sites	4	6	11	7	5
Species fattened	Sheep, goats	Sheep, goats, cattle	Sheep, goats, cattle, pigs	Cattle	None
Breeds fattened	Local trypanotolerant	Local trypanotolerant and susceptible	Local	Local, sometimes with exotics	Local, sometimes with exotics
Roughage	Natural pasture	Natural pasture, crop residue, browse	Natural pasture, crop residue, browse	Natural pasture, crop residue	Natural pasture, crop residue
Supplemental feed	Yam peels, bran	Bran, grain, oilseeds	Bran, grain, oilseeds	Grain, oilseeds	Grain

Purchase of supplemental feed (number of sites)	1	2	9	2	2
Fattening periods	<6 months	1–2 years in Kufana for cattle	Sheep, 6 months in Niger and Burkina Faso; cattle long–term (>1 year) in Kianjasoa	Unknown	Unknown
Other aspects of animal production at these sites					
Animal traction					
None	4	5	–	–	5
Rare	–	–	3	–	–
Occasional	–	1	2	–	–
Frequent	–	–	2	2	–
General	–	–	4	5	–
Milk production					
None	4	–	2	–	1
Local breeds	–	6	7	5	1
Crossbreds	–	–	2	2	3
Pure exotics	–	–	–	–	–

– None observed at the field sites in this environment.
Source: Field visits by authors.

Table 7–4. Observations of Use of Modern Inputs in Animal Production at the Field Sites, by Environment

Sites, services, and practices	*Humid*	*Subhumid*	*Semi–arid*	*Highlands* *Mechanized*	*Highlands* *Unmechanized*
Number of sites	4	6	11	7	5
Public veterinary care					
Not available	2	3	1	4	–
Veterinary assistant	2	3	8	–	3
Veterinarian	–	–	2	3	2
Average distance to nearest veterinary service (km)	<15	<35	<20	<5	<10
Purchases of supplemental feed	1	2	9	2	2
Intensive feeding					
Weeds	–	–	–	1	2
Crop thinnings	–	–	–	–	2
Leaf strippings	–	–	–	–	2
Poultry manure	–	–	–	–	2

Extension services					
Cattle production					
Breed	–	–	1	–	–
Feed	–	–	6	–	–
Health	–	–	1	–	–
Package of several	–	1	1	–	–
Dairying					
Breed	–	–	–	–	–
Feed	–	–	–	–	–
Health	–	–	2	4	–
Package of several	–	–	–	–	–
Small ruminant production					
Sheep	3	5	5	9	–
Goats	–	–	–	–	–
Sheep and goats	1	–	2	1	–
Poultry	–	1	4	–	–
Pigs	–	–	–	–	–

– Not observed at the field sites in this environment.
Source: Field visits by authors.

Unlike the lack of consistent association between animal traction and crop residue management found in Chapters 4 and 6, there was a clear relation between more intensive smallholder fattening and crop residue management. The field visits revealed grazing animals on crop residue to be common (Table 6–7), and little residue was fed as cut forage. This was because the labor cost of grazing is usually less than that of cutting, transporting, and stall feeding crop residue, while its benefits are similar.

OTHER BENEFITS. On–farm animal production should facilitate manuring of crops. Failure to observe appropriate use of manure might explain why smallholder fattening is not always profitable—it would suggest that farmers fail to gain part of the manuring benefits from managing the animals directly on their holdings. While Chapter 5 argued that intensive manuring is inefficient in much of Africa because it is too labor–intensive and provides weak crop yield responses, it revealed many farming systems in which manuring complemented smallholder animal production.

There were no field sites where confinement of livestock was done largely to capture manuring benefits. Confinement was always secondary to some form of animal production—milk (the Madagascar and Kenyan highlands in the field visits), stall feeding of beef cattle (Kufana, Nigeria; the Cameroon highlands as studied by Holtzmann 1986), or animal traction (Machakos, Kenya). While restricting cattle facilitates intensive manure production, it will not occur until some other technical change—in dairying, beef production, or animal traction—makes it profitable to shift animal management from grazing to confinement. This is because stall feeding is not a condition for obtaining benefits from manure. As was noted at length in Chapter 5, those benefits can be obtained by paddocking animals and should not be attributed entirely to stall feeding. Additional manuring benefits consequent to confined animal production are probably small and would add little to the economic return of smallholder fattening.

Labor

There are farming systems in which feed response, meat prices, feed prices, and supply favor more intensive animal husbandry. Labor, however, can be a constraint to further intensification. There are three issues about labor use:

- Does smallholder fattening require more labor compared to traditional forms of animal husbandry? The principal labor–using tasks in smallholder fattening are cutting and carrying fodder and watering stock. Significant additional labor demands will likely derive from cutting and carrying fodder (Stotz 1983, Holtzmann 1986, Baur 1989). Providing water, which is normally the most laborious task, would be only partially affected by the shift from grazing to smallholder fattening because animals will normally be taken to water even when they are confined for some of the day (Delgado 1977, for Burkina Faso; Swift 1981, for Mali).

- When is that labor required? If it is required in seasons when opportunity costs are low, then it is not a constraint. If labor is needed when it is required for cropping, then labor may be a constraint.
- What are the possible adaptations to increased labor requirements? Adaptations include the substitution of child labor for adult labor, livestock mobility, mechanization, and shifts in the timing of livestock production.

The best studies are those of Holtzmann (1986) in Cameroon, Stotz (1979, 1983) in Kenya, and Baur (1989) in Mali. Holtzmann's work shows smallholder cattle fattening to require a great deal of labor in relation to crop production and extensive livestock production. Much of this labor is in the growing season so that it might conflict with cropping. Most of the labor requirement specific to fattening was for cutting and carrying fodder, and hence would not have been incurred with more extensive methods of rearing cattle. While children do some of the herding, and their labor has a low opportunity cost, there is still an apparent conflict between crops and livestock. Under some delicate assumptions about the economics of the problem, Holtzmann found that returns to labor in cattle on-farm were theoretically competitive with those in crop production available to farmers in northern Cameroon, but that not all farmers could do it because of labor requirements.

Stotz's papers, which focus largely on dairying, delineate a sequence of technical changes in which ascending labor intensity is associated with more productive methods of forage and livestock output. In that sequence, the average return to labor rose despite greater labor inputs. Farmers made larger and more sophisticated investments in livestock, fodder, and animal husbandry, allowing growth in labor productivity.

Baur (1989) compared a smallholder fattening system to a mix of smallholder fattening and traditional extensive grazing. While he found labor costs to be higher in the former, feed intake, weight gains, and profits were also superior. This confirms Stotz's result that capital investments, by raising the return to labor, encourage producers to provide it. The Malian system analyzed by Baur differs notably from the one studied by Holtzmann in Cameroon because most of the incremental labor for livestock production was needed in the dry season, and not in the wet season. Therefore, despite its increased labor demands, smallholder fattening did not conflict with crop production.

Of the possible adaptations to the labor requirements of on–farm fattening—substitution of child labor, mechanization, livestock mobility, and shifts in the timing of activities—only mechanization seems to be absent. There were no cases of mechanized feed choppers, for example. Child labor, strategies of livestock mobility, and changes in the timing of crop and livestock activities to reduce conflict between the two were all employed by farmers. This was noted not only by Holtzmann (1986), Stotz (1979, 1983), and Baur (1989), but at the field sites visited as well (Table 6–3).

Barriers to More Intensive On–Farm Livestock Production

Despite many field observations about the practice of smallholder fattening, economic returns are mixed and more intensive means are not generally adopted. The failure to achieve better returns through intensive means may be caused by low responses to feed by the principal livestock breeds, unfavorable prices and inadequate feed supplies, and government price policies affecting the prices of livestock products and feed.

Feed Response

Years of animal production research have been dedicated to identifying rations with more efficient feed conversion (Table 7–5). In West Africa, Doppler (1980, pp. 129–130) found feed conversion ratios of Zebu cattle in the following intervals: 4.2 to 5.0 (four experiments), 5.2 to 6.0 (two), 6.5 to 6.9 (four), 7.3 to 7.9 (three), 8.6 to 9.0 (two), 9.9 (two), and >10.0 (three), depending on feeding period and ration. Lhoste (1973) reported consumption ratios between 7.4 and 11.0 in Cameroon, with an average of 9.8. Another trial in Cameroon (Lhoste and others 1975) gave a ratio of 9.8 and reported earlier ranges of 8.0 to 10.7. Lhoste's review (1977) in Côte d'Ivoire gave values of 10 to 12 for rations with sown forages (*Panicum* and *Stylosanthes*), natural pasture, rice straw, rice bran, cottonseed cake, and molasses. In Mali (CNRZ n.d.), the ratio was 10 to 12 for rations including cottonseed cake, molasses, and rice bran.

Schaefer–Kehnert (1978) proposed a range of 6 to 12 for the feed consumption ratio in East African conditions. Jepsen and Creek (1976) estimated values of 12 to 13 for Arsi and Boran cattle in Ethiopia on rations of molasses, maize grain, noug cake, and *Eragrostis* hay. Mulder, Waweru, and Kamau (1973) calculated values of 12 to 14 for rations based on Napier grass with Kenyan Zebus. Creek (1973) gave values of 6.7 to 10.5 in Kenya, with variations caused by breed and feed. The work of Addy and Thomas (1977b and 1977c) with Malawi Zebus produced ratios from 5 to 10 for rations based on maize stover, with various combinations of maize bran, cottonseed cake, and *Leucaena*, and from 11 to 20 for combinations based on *Panicum* or *Pennisetum* with maize bran.

BREED EFFECT IN CATTLE. Many studies have estimated the effects of animal breed on feed response. In Côte d'Ivoire, Letenneur (1973) compared Zebus to trypanotolerant Baoule and N'Dama for short (4-month) and long (1-year) fattening periods. Zebus were superior to Baoules and N'Dama for all periods and rations. Jouve and Letenneur (1972) found Jersey × N'Dama crosses gave consumption ratios of 9.3 when fattened for 55 days and 11.4 for 82 days. Lhoste (1977) reviewed experiments with N'Dama, Baoule, Zebus, and Jersey × N'Dama. Fattening periods were 2 to 3 months (intensive) or 6 months (extensive). Feed included sown forages (*Bracharia*, *Panicum*, and *Stylosanthes*), rice bran, cottonseed cake, maize, cassava, and molasses. Consumption ratios for all breeds were between 10 and 12. In Nigeria, Adesipe and Olayiwole (1982) estimated the ratio in Zebus to be 9.1 and 7.0 in crossbreds when animals were fed to maximize weight gain. When animals were fed to give an economic optimum, the Zebu ratio was 5.7 and the crossbred ratio was 5.1. Creek and Squire (1971) concluded that the conversion efficiencies of East African Zebus were generally greater than those of improved Boran or crosses with exotic animals.

SPECIES EFFECT ON FEED RESPONSE. The feed conversion efficiency of small ruminants may be superior to that of cattle (Table 7–6). Some of the difference might be because more concentrated rations of higher quality were fed to sheep and goats. This difference would create the appearance of greater feed conversion efficiency in small ruminants, when in fact the difference was an experimental one. While this conclusion cannot be definitive without site-specific studies, there appears to be some reason to favor small ruminants over cattle on the basis of superior feed conversion efficiency.

FEEDLOT AND EXPERIMENT STATION EFFECT. Conversion efficiency in feedlots and experiment stations is higher than on farms (Lhoste 1973, Creek and Squire 1971, Schafer–Kehnert 1978). Information from Mali, Malawi, and Nigeria suggests that the difference in daily weight gains

Table 7–5. Summary of Selected Cattle Production Studies

Study categories	*Addy and Thomas 1977a-d*	*Adesipe and Olayiwole 1982*	*Adesipe, Olayiwole, and Fulani 1983*	*Lhoste 1977*	*Lhoste, Pierson, and Ginistry 1975*	*Mulder, Waweru and Kamau 1973*
Country	Malawi	Nigeria	Nigeria	Côte d'Ivoire	Cameroon	Kenya
Environment	Subhumid	Subhumid	Subhumid	Subhumid	Semi–arid	Highland
Site	Smallholder	Feedlot	Feedlot	Feedlot	Feedlot	Smallholder
Breeds	Malawi Zebu steers	Zebu and crossbred	Zebu Bunaji, Zebu Sokoto	Baoule, N'Dama, Zebu	Adamawa Zebu	Zebu
Feeds	Guinea grass, pearl millet, maize bran	Undelinted cottonseed, sorghum grain, groundnut cake	38% brewer's grain, 9% delinted cottonseed, 8% groundnut cake plus sorghum	Hay, *Stylosanthes, Panicum*, molasses, concentrates	Grass, rice flour, cottonseed cake	Maize stover, Napier grass, rice straw, bean straw, brans
Fattening period (days)	100	97	140	60–160	85	Unknown

Typical liveweight						
Feeder (kg)	–	Zebus, 362	164–189	–	338	–
Fat (kg)	–	Zebus, 495	239–304	–	398	–
Average daily weight gain (grams)	Guinea, 547; pearl millet, 587	Zebu, 1,370	690 with brewer's grain, 780 with groundnut cake, 820 with cottonseed cake	Zebu, 500–700; Baoule, 250–400; N'Dama, 350–600;	707 with ad lib rice flour, and 1 kg cottonseed cake	437–552
Consumption ratios	Guinea, 16.2; Pearl millet, 14.7	7.0 with crossbreds, 9.1 with Zebu	10.4 with brewer's grain, 9.6 with groundnut cake, 9.8 with cottonseed cake	Baoule, 12.5; N'Dama, 11.0; Zebu, 9.5–13	9.8 with ad lib rice flour, and 1 kg cottonseed cake	12.0–14.0
Rate of return to 1 kg of feed	Unknown	At maximum gain 33% with crossbreds,-16% with Zebu	11% with brewer's grain, 3% with groundnut cake, 3% with cottonseed cake	-29.4%	-47.1%	2–48%

– Data not available

Table 7–6. Summary of Selected Studies of Small Ruminant Production

Study categories	*Zemmelink, Tolkamp, and Meinderts 1985*	*Bourzat and others 1987*	*Calvet and Denis 1974*	*Richard, Humbert, and Douma 1985*	*Richard, Humbert, and Douma 1985*
Country	Nigeria	Burkina Faso	Senegal	Niger	Niger
Environment	Humid	Semi–arid	Semi–arid	Semi–arid	Semi–arid
Breeds	Dwarf goats, castrated males, 6 months	Local sheep, males, 4–8 months	Local sheep, males	Local sheep, usually males, 6–15 months	Local sheep, males, 6–10 months
Feeds	Manioc meal, soybean meal, maize, maize gluten, alfalfa meal	Rice straw, cowpea hay, *Stylosanthes*, *Andropogon*	Maize bran, sorghum flour, cottonseed cake, groundnut hulls	Intensive: cowpea hay, sorghum grain, pearl millet bran, cottonseed cake	Extensive: pasture, rice bran, cowpea hay
Fattening period (days)	59	75–154	98	100	154
Consumption ratios	5.4–6.4	5.6–11.0	7.6–10.4	7–10	4–8
Rate of return to 1 kg of feed	Unknown	Unknown	17.8% at ratio = 8.6 -15.7% at ratio = 10.4 53.8% at ratio = 7.6	-54.3% at ratio = 8	-31.0% at ratio = 6

Note: Value of offal not included in Niger and Senegal calculations on similar rations between farms and extension stations is on the order of 15 to 65 percent.[4] Whatever the exact magnitude of the effect, it is clear that the better management typical of feedlots and experiment stations—in animal health, water supply, housing, and shorter feeding periods—would have a positive interaction on animal feed response.

Price and Supply of Feed

The experiments reviewed here suggest that the feed response of African livestock to mixed diets of native roughage and available supplements under both experimental and farm conditions is typically lower than those of livestock in temperate climates. However weak the physical response of stock to feed, fattening can still be profitable if feed prices are low enough or if livestock prices are high. The relationship between feed and livestock prices was studied by constructing feed price indices and comparing them to meat prices in countries for which data were available, and then comparing those results to the feed conversion ratios.

ILCA has assembled data (Table 7–7) on cattle and feed grain prices at the farm gate or in nearby primary markets.[5] This sparse and sometimes dated information indicates that the average ratio of liveweight price to grain price is about 5.6, which is below feed conversion ratios typically observed in African cattle. Price data on crop residue, browse, and natural pasture are even scarcer than those on concentrate feeds, but information from a study in semi–arid Mali indicates that the costs per forage unit of oilseed cakes were from 200 to 300 percent those of roughage, and that grain was about 65 percent more expensive (Baur 1989, Annex B). At that ratio of cattle liveweight prices to feed grain prices, grain could not be economically recommended as a dominant element in a ration; it could only be combined at a fairly low concentration in a ration composed mainly of cheap roughage.

A significant exception to the normal price ratios between concentrates or sown forages and roughage is Stotz's (1983) calculations of forage production costs in Kenya. Highland Kenya allows good yields of Kikuyu grass, Napier grass, and other sown forages, which per unit of dry matter cost about 37 percent of the cost of maize stover. Those sown forages are used widely in Kenya's dairy industry.

4. For Mali, Baur, Sissoko, and Deborh 1989 (farm) and CNRZ (n.d.); for Malawi, Agyemang and others 1988 (farm) and Addy and Thomas 1977a, 1977b, 1977c, 1977d; for Nigeria, Odoemele, Ingawa, and von Kaufmann n. d. (farm) and Adesipe and Olayiwole 1982.

5. The ILCA database contains too few observations on oilseed prices to allow a similar comparison for that feed.

Table 7–7. Feed and Livestock Price Series for Selected Countries

Country, local currency, and year	Observed prices (undeflated) in domestic currency: Cattle (per kg liveweight)	Feed grain (per kg)	Price ratio (liveweight/ feed grain)
Botswana (pula)			
1980	0.37	0.12	3.08
1981	0.47	0.13	3.62
Burkina Faso (CFA francs)			
1980	212.42	45.00	4.72
Ethiopia (birr)			
1981/82	1.17	0.39	3.00
1982/83	1.23	0.38	3.24
Kenya (shillings)			
1980	4.74	0.70	6.77
1981	6.21	1.05	5.93
Malawi (kwacha)			
1984/85	0.51	0.16	3.19
Mali (CFA francs)			
1982/83	300.00	96.25	3.12
Nigeria (naira)			
1982	1.82	0.22	8.27
1983	1.89	0.22	8.59
Sudan (pounds)			
1983	1.09	0.25	4.36
1984	0.99	0.35	2.83
1985	0.58	1.28	0.45
Zaire (zaires)			
1980	7.92	1.16	6.83
1981	8.94	1.17	7.64
1982	11.95	1.20	9.96
1983	21.00	1.51	13.91
Zambia (kwacha)			
1980	0.81	0.10	8.10
1981	0.95	0.13	7.60
1982	1.02	0.14	7.29
Zimbabwe (Zimbabwe dollars)			
1980	0.56	0.10	5.89
1981	0.68	0.11	6.18
1982	0.91	0.12	7.91
1983	0.73	0.13	5.62

Country, local currency, and year	Observed prices (undeflated) in domestic currency: Cattle (per kg liveweight)	Observed prices (undeflated) in domestic currency: Feed grain (per kg)	Price ratio (liveweight/ feed grain)
1984	0.79	0.16	4.94
1983	0.60	0.13	4.62
1984	0.69	0.16	4.31
Average			5.78
Maximum			13.91
Minimum			0.45

Source: ILCA (1990)

AGRICULTURAL BY-PRODUCTS FOR FEED. There has been considerable research and extension activity to augment livestock feed supplies with improved management of agricultural by-products or processed feeds (for example, the volumes edited by Preston and Nuwanyakpa 1986, Said and Dzowela 1989, Dzowela and others 1990). These works provide the basis for profitable recommendations to African livestock producers in several situations. For example, many of the 57 papers in Dzowela and others (1990) report significant improvements in livestock productivity when traditional fodder sources are complemented by forage crops, agricultural by-products, or grain having higher forage content per unit of dry matter.

The major problem with implementing such recommendations is that the total supply of by-products cannot feed a major share of the continent's livestock, even with better management. Jahnke's data (1982, pp. 10 and 216) allow the calculation that the major agricultural by-products in Sub-Saharan Africa—the residue and waste of cereals, tubers, sugar cane, oilseeds, and other crops—would have had the potential to feed about 10 percent of African ruminant stock in the late 1970s. Although there was continuous and rapid growth in the quantity of by-products fed throughout Sub-Saharan Africa from the 1960s to the early 1980s (Bedingar 1989) the percentage contributed by those materials to total feed supplies had not changed as of the mid-1980s.

While available data do not permit statistical analysis of livestock production efficiency using such feeds on African farms, the growth in the volume of by-products and the authors' field visits provide abundant evidence that producers understand well the feed value of by–products and manage them appropriately. Consequently there are likely to be few gains from different management without new resources.

Price Policies

Price policies for African livestock have been criticized for their negative effects on farmer incentives to operate feedlots in Kenya (Creek and Squire 1971), and by Holtzmann (1987) for smallholder beef in Cameroon. These policies have allegedly discouraged fattening of livestock in general, and more specifically, impaired adoption of more intensive techniques for fattening livestock on the farm.

It is very difficult to evaluate the precise impact of these policies because there is little information on prices actually received by farmers or on marketing costs, but there is some reason to think that the situation has recently improved. A paper by Williams (1990, p. 70) on policies in five major livestock producing countries concluded that "since the early 1980s there has been a reduction in the level of price discrimination against livestock producers in [Mali, Sudan, Nigeria, Côte d'Ivoire, and Zimbabwe]. This reduction in taxation . . . represents an improvement over the situation in the 1970s."

FEED PRICES. Government feed policies also affect incentives for smallholder fattening. Such policies are less formal than those for food grains: the authors identified no feed grain marketing boards, no strategic feed reserves, no restrictions on domestic movements of feed, and no tariff or nontariff barriers to international feed trade. But there could be indirect effects of exchange rate and other economic policies, creating significant differences between national and international prices of grain and other feed items.

A representative ration of grain, oilseeds, and roughage ought to be constructed for typical production sites, and valued at export parity prices to examine the impact of polices on feed costs to the farmer. This could not be done because African feed price data are very hard to obtain and compare to international standards (ILCA 1990). Based on data in the ILCA studies (ILCA 1990, Bedingar 1989), the following can be concluded:

- African crop residue, pasture, and browse are typically nontraded commodities not affected by government policies. As such, their domestic market prices probably closely reflect their scarcity values. Distortions in the prices of such livestock production inputs would be small and would not have affected choices by farmers of production techniques.

- African grain prices were sometimes set below international levels with a variety of official measures whose net effect was to subsidize African livestock producers by allowing them cheaper feed grain (for example, Jaeger 1991, Cleaver 1985), thus encouraging more intensive smallholder fattening. The importance of this subsidy probably decreased in the 1980s.
- Groundnut is a major African oilseed cake, with an internationally quoted price. In the period 1961 to 1984, the average FOB export unit value for African groundnut cake was 79 percent of the quoted international price. The minimum percentage was 51 percent and the maximum was 103 percent (IMF 1991, Bedingar 1989). This comparison includes international transport costs plus reported domestic purchase, processing, and transport costs in the exporting African country. This evaluation suggests that African livestock producers feeding groundnut cake were subsidized consistently for more than 30 years, albeit at a low rate.[6]

Species, Breed, and Scale

The animal species and breed to be fattened and the enterprise scale are all factors which may influence the return to on-farm animal production.

SPECIES. Table 7–8 summarizes possible differences in efficiency between cattle and small ruminants. In general, there is a slight advantage to small ruminants in feed response and perhaps another in liveweight price (Tables 7–5 and 7–6). Moreover, small ruminants have been understudied relative to cattle (McIntire 1985), and according to an unpublished World Bank study by Hartwig Schafer, fattening projects have largely emphasized cattle. The advantages to small ruminants would not alone necessarily justify expanded research and development efforts because of the greater disease risk, and higher mortality typically encountered in small stock production. Hence, on the grounds of efficiency alone, there are no obvious general recommendations about whether to support cattle or small ruminant production in on-farm projects.

CATTLE BREEDS. Limited experimental evidence from Côte d'Ivoire and Kenya suggests that introduced breeds of cattle give superior feed responses in meat production. This evidence might not be a reliable

6. Overvalued exchange rates would have depressed the prices of such tradable feed inputs as grain, thereby possibly stimulating livestock production.

Table 7–8. Variables and Differences for Cattle or Small Ruminant Production

Variable	*Difference*
Ratio of fat/feeder prices per kg	Possibly higher for cattle because of greater seasonal price variation
Concentrate feed costs	No difference, but lower total requirement favors small ruminants if supplies are rationed
Roughage costs	May favor small ruminants at marginal grazing sites
Conversion efficiency	No major differences with local breeds and feed if appropriate ages chosen for fattening
Labor use per animal	Higher for small ruminants because of diseconomies of scale for grazing and cut-and-carry feeding
Income distribution effects	Better for small ruminants because the initial investment is much smaller

Source: Authors' analysis.

guide to project decisions about choice of cattle breed under smallholder conditions, for several reasons. These experiments do not make a true economic comparison of fattening introduced cattle in terms of the opportunity cost of alternative uses of farmer resources. Those alternatives include fattening local livestock, importing livestock products, or doing something else with the land. This is especially true where introduced livestock need to be fattened with sown forages, the cost of which might turn the analysis in favor of fattening local breeds (for example, Lhoste 1977, for Côte d'Ivoire).

In addition, such comparisons do not always consider higher disease risks in exotic breeds where veterinary standards are low. In addition, if sown forages and veterinary care can be developed to a level sufficient to support introduced breeds, then they might be better developed for milk production, not for beef. Given these qualifications to conclusions about breed choice based mainly on experimental feed response, any decision based at least partly on feed response characteristics must consider other local factors. As with the choice between small ruminants and cattle, there are no obvious recommendations about cattle breed in smallholder fattening projects based on efficiency grounds alone.

SCALE. The returns to large–scale production would only be superior if there are economies of scale in housing, extension, and veterinary care, or if large units achieve greater feed conversion efficiency. The experience with large–scale feedlots is so varied that these questions can only be answered with site–specific studies (Table 7–9).

A typical conclusion from an empirical analysis of feedlots is that of Schaefer-Kehnert (1978). "The economic conditions under which intensive [feedlot] beef production [is profitable are] extremely narrow in a developing country like Kenya." The main reason is that the level of management cannot be sustained for long enough to cover the incremental start–up costs in a large enterprise.

Table 7–9. Variables and Differences for Feedlots or Smallholder Cattle Production

Variable	*Difference*
Feeder prices per kg	Similar unless feedlots have monopoly
Fat prices per kg	Higher in feedlots if closer to markets
Concentrate feed costs	Lower in feedlots because better preservation, lower losses, closer to sources of imported supplies
Roughage costs	Lower for smallholders because closer to sources of supply
Conversion efficiency	Higher in feedlots because of better veterinary care and housing
Labor use per animal	Much lower in feedlots
Income distribution effects	Much worse in feedlots

Source: Authors' analysis.

Veterinary and Extension Services

Inadequate veterinary care is known to impede livestock production in Sub–Saharan Africa (Simpson and Evangelou 1984, de Haan and Solomon Bekure 1991). The authors' field visits confirm that general proposition. Veterinary care was unavailable at one–third of the sites, and was rudimentary at those sites where it was available in some degree (Table 7–4). Extension was even sparser, with twenty–one sites having no extension contact for cattle raising, and twenty–two having none for small ruminants, poultry, or pigs.

Conclusions

Before engaging in intensive smallholder fattening, crop farmers have other alternatives to achieve competitive returns to their livestock investments. One is to entrust livestock to absentee herders. This is often done where owners lack adequate knowledge of animal production, where animal mobility is important, or where economies of scale exist in livestock production (see Chapter 3).

A second alternative is to manage livestock directly without making major additional investments in fodder production, housing, or veterinary inputs. This second alternative typically begins with small stock, and as farmers accumulate capital, acquire knowledge of animal production, and achieve economies of scale in livestock management, cattle begin to appear (Chapter 3 and field visits).

This second alternative for animal production can be profitable even if the direct return to incremental feed and labor is negative. This is because seasonal differences between livestock purchase and sale prices are often high enough to cover ordinary feed costs plus those of labor, housing, water, veterinary care, and other inputs necessary to integrate livestock on the farm. There is abundant evidence about seasonal price changes (Delgado 1977, Arditi 1977, Shapiro 1979, Baur 1989). Most farmers can trade animals to benefit from such easily anticipated price changes, independently of their access to feed and veterinary services, and managing ruminant stock to exploit seasonal price variations indeed occurs all over Africa (Jahnke 1982, field visits).

Before discussing a third alternative—smallholder fattening—it is legitimate to ask why such seasonal price variations persist and to speculate about what would happen in their absence. The main reason for persistent seasonal price differences is that transport costs and trade restrictions, both national and international, isolate livestock markets so that they cannot easily clear, hence maintaining excessive seasonal price differences. Reductions in transport costs and trade barriers would tend to eliminate such price differences. This decreased seasonal variability would have countervailing effects which could only be considered with project–specific studies. On the positive side, falling transport and trade costs would raise livestock product prices and give better incentives to all forms of livestock production, but would not necessarily favor fattening on–farm. On the negative side, the disappearance of seasonal price differences, in the absence of technical changes to promote better weight gains in stock managed by smallholders, might eliminate much of the incentive for smallholder livestock production.

The third alternative is to manage stock directly at higher intensity using some variant of smallholder fattening. The smallholder fattening alternative begins to be most profitable where population pressure on land restricts extensive livestock production, where feed conversion is better, or where the ratio of meat to feed prices is relatively high, possibly because of better market access. In all such instances farmers have an incentive to invest in more intensive fodder production, and smallholder fattening begins.

Some of the determinants of the return to livestock production explain why this third alternative is less common than the first two. The more intensive nature of smallholder fattening, in terms of feed and labor requirements, is often economically inefficient because returns to additional feed and the other additional resources that go with it, are negative. Low profitability in fattening on–farm is primarily because feed is unavailable or expensive relative to weight gains. The problems of feed availability and cost are compounded by the interaction between the bulky feeds used in the absence of processed concentrates and the additional labor necessary to mange those feeds.

Other factors contribute to the mixed record of fattening on–farm:

- Of the 'other benefits' associated with animal production on–farm, only the reduced cost of manure is unambiguously positive. Crop residue and labor for animal production may impose negative benefits (costs) if those resources are diverted from other activities. Failure to achieve such benefits (or reduced costs) would explain little if any, of the low profitability of smallholder fattening.
- The effects of government price and exchange rate policies are mixed. They harmed incentives for animal production in general through overvalued exchange rates which depressed prices of livestock commodities, although recent reforms have improved the situation. The major instance of government policy having improved incentives for animal production is through the depressing effect of the exchange rate on the prices of tradable grain and oilseeds.

- It cannot be generally concluded that the absence of exotic breeds or of crossbred animals prevents animal production on–farm. The effects of animal breed in experimental studies of weight gain are not very large. Moreover, experiments probably overstate the breed effect as the basis for making recommendations to farmers because such effects are presumably higher under experimental conditions than under farm conditions.

8

Conclusions and Recommendations

Competition and Complementarity in Crop–Livestock Interactions

MANY EFFORTS TO ASSIST African agriculture have been based on two apparently contradictory premises: there are substantial costs to resource competition between crops and livestock, but there are also substantial benefits to better interactions between the two.

The main focus of this study, therefore, was twofold: *What is the extent of crop–livestock resource competition? How does this competition affect the benefits from interactions?*

Differences in crop–livestock competition among agroclimates are defined almost exclusively by the costs of livestock production. Land competition is most acute in the highlands, which have a comparative advantage in livestock production, and least acute in the humid lowland tropics, which do not have a comparative advantage because the incidence of livestock disease is higher. Within the subhumid and semi-arid environments, which also have a strong comparative advantage in livestock production, land competition is further determined by population density. These conclusions would be different if fertilizer and other modern inputs were generally available, because the relative costs and benefits of crop and livestock production would change if such inputs were used. Because these inputs are not available in many African farming situations, agroclimate and associated livestock diseases remain the dominant influences on comparative advantage.

Land Competition

Land competition was analyzed in terms of the cost of livestock production. With traditional agricultural technologies prevailing throughout Sub-Saharan Africa, that cost is a function of the stocking rate in the agroclimates having a comparative advantage in animal production.

Land competition does not limit the stocking rate until relatively high population densities, and hence does not prevent farmers from reaping the benefits of integrating crops and livestock. The simple reason is that the expansion of cultivation stimulates livestock production. This apparent paradox is explained by the fact that cropping changes the seasonal pattern of fodder supply where there is a single cropping season. Crop residue provides animal fodder in the post–harvest and dry seasons when pasture is least abundant, thus sustaining livestock production at a level above that which could be obtained with pasture alone.

A numeric model was devised to analyze land competition in the semi–arid and subhumid zones, where such competition is expected to become more acute. The minimum feasible stocking rate during the year was used as the index of land competition. The model first asked what stocking rates were feasible at a given population density and land productivity. In the semi–arid tropics where population density is generally low and land productivity is poor, the minimum stocking rate occurred in the dry season when fodder was most scarce. Hence, livestock production was not limited by rainy season cropping, and land competition between crops and livestock would not occur in general. As population density approached 100 persons per square kilometer, the land needed for crop production would grow proportionately. The lowest stocking rate would then be in the cropping season because crop land replaced pasture and reduced total forage production. At that higher population density, land competition from cropping would limit livestock output.

The interaction between population density and basic land productivity was examined with the same model for its effect on land competition. The average grain yield attainable with traditional technology—local crop cultivars, few or no chemical inputs, and little or no mechanization—was used as a measure of land productivity. At a yield of 0.25 metric tons per hectare, population density did not affect the minimum stocking rate until it approached 60 persons per square kilometer. The minimum stocking rate still occurred in the dry season. At a grain yield of 0.5 metric tons per hectare, population density did not affect the feasible stocking rate until it reached nearly 100. Higher land productivity postpones crop–livestock land conflicts because less crop land is needed to support a given population density. A similar conclusion about the effects of land productivity is well known from the works of Boserup (1965) and Ruthenberg (1983).

This model exaggerates the real magnitude of crop–livestock competition for land because it does not consider farmer adaptations to competition. Among those adaptations are technical changes to produce higher crop yields per unit of land, thus permitting less land to be used for crops and more for livestock, or vice versa. Another adaptation would be the development of regional or international trade in crop or livestock commodities. Such trade would encourage farmers to specialize in the production of commodities, thereby achieving higher incomes at every level of competition between crops and livestock, and postponing the arrival of land competition between the two.

Principal Responses to Land Competition

The field evidence compiled in Chapters 4 through 7 confirms and extends what is known from the work of Ruthenberg, Boserup, and others: the main response everywhere is to intensify production. Intensification involves more crop labor per unit of land, more labor–intensive livestock production, greater quantities of fertilizer and manure, higher–yielding food and forage crops, animals of superior feed–efficiency, and the assiduous use of crop residue as feed. The following sections review the effects on competition for land of intensifying technical changes in animal traction, manuring, and fodder production. Evidence about the efficiency of those responses is later summarized in the recommendations on priorities by agroclimate and the recommendations for research and extension by theme.

ANIMAL TRACTION. While the effects of animal traction cannot be analyzed entirely satisfactorily because adequate studies of farmers before and after adopting animal traction are lacking, a good deal of research demonstrates that its main benefits are more cultivated area and less labor use per hectare and per unit of output. Field evidence is inconclusive about yield and cropping pattern benefits imputable to animal traction.

The basic model of land competition was used to study the effects of animal traction. The cost of achieving area and labor benefits from animal traction, in terms of lowered stocking rates, is not high where population density is less than 60 persons per square kilometer. That cost rises as population density grows. At a population density of 160 persons per square kilometer—which is elevated by African standards—replacing hand tool cultivation with animal traction would reduce the feasible stocking rate by about 25 percent. The losses from this lower stocking rate are gross, however, not net. They must be compared to the value of output from the expanded area in crops, and the value of the cost savings from lower labor input into crops. If, in addition, there are yield or cropping pattern benefits to oxen power, then they would also make up the value of lost animal production. Hence, even where the use of animal traction reduces the feasible stocking rate, its net economic effects would depend on the relative prices of commodities and labor, and could be positive, zero, or negative.

Farmers have many responses to the land competition associated with animal traction. These encompass mechanizing with engines, using cows for traction, plowing with fewer animals in the team, and intensifying fodder production from common properties or by exploiting fodder resources which were previously unused. African examples are known from Zimbabwe (Mombeshora, Agyemang, and Wilson 1985) and Senegal (Lhoste 1989). A further response is to forego the area benefits, and use animal traction largely as a means of saving labor on a constant cropped area while fattening animals for eventual sale. This is typical of very densely populated areas, such as the Ethiopian highlands, where it is impossible to cultivate more land.

MANURING. In principle, manuring allows higher crop output from a smaller area, thereby preserving pasture from the encroachment of additional cropping and alleviating land competition between crops and livestock. In practice, manuring can only allay land competition at low population densities. At higher population densities its positive effect is limited by the cost of feed necessary to produce manure. The land competition model shows that fallow and manure can only supply enough nitrogen to maintain crop yields at the low average of 0.25 metric tons per hectare in the semi–arid tropics, up to an intermediate population density of about 90 per square kilometer. The reasons are that raising animals for manure requires fodder production, and the conversion efficiency of fodder into soil fertility inputs by animals is very low. While manuring obviously has a positive effect on intensively farmed areas, that effect is limited to small fractions of the land in crop production, such as household gardens.

FODDER PRODUCTION. The beneficial effect of fodder production in reducing land competition is now due to the use of crop residue and not to sown forage crops. Sown forages are a technically efficient alternative to extensive grazing. They would afford higher forage yields per unit of grazing land, thereby saving crop lands from pasture encroachment and easing land competition. Yet sown forage crops have been notoriously difficult to extend to African farmers, and have done little to relieve land competition. The basic reason for this failure is that forage is too costly per unit of useful animal feed with respect to the alternatives available. In arid areas, forage yields are too low given the cheap supply of pasture, browse, and crop residue. In wetter, more productive zones, most notably the highlands, forage yields are too low with respect to the opportunity cost of food crops unless higher–yielding dairy animals can be introduced.

Labor Availability

Labor availability is a general barrier to gaining the benefits of crop–livestock interactions because the economics of enhancing traditional resource use through augmented labor input are inherently unfavorable. Most crop–livestock interactions are technically inefficient because they are not managed to attain their maximum physical yield. While many experiments demonstrate that it is possible to obtain higher physical output through more labor–intensive management, many farmers do not do so because it would be economically inefficient. The reason is that high–bulk, low–value, materials—manure, crop residue, and agricultural by–products—do not repay labor–intensive management simply because they have such dilute concentrations of useful ingredients. This was observed in the field visits and has been found in many previous studies.

Mechanization is a possible response to the labor requirements of traditional resource management. For example, oxen power or tractors can be used to incorporate crop residue or manure into the soil. This has been done in some instances with manure, but is not a widespread practice because manure is scarce, and obviously mechanization can have no effect on manure supply. Mechanized incorporation of crop residue is rarely done, if at all, because of the opportunity cost of using residue for animal feed. The general adoption of incorporating crop residue into the soil may have to await more widespread use of forage crops or the introduction of tractors, which would reduce the labor requirements of incorporating crop residue into the soil.

Labor availability is a specific barrier to adoption of new techniques in arid environments where livestock production typically has a comparative advantage. Short–run labor competition is more acute where land is abundant. Labor–intensive agriculture is not customary because the return to extra labor per unit of land or per animal is less than the return to adding another unit of land or per animal. Farmers add land to their farms, but do not cultivate the land more intensively to obtain higher yields. Herders add animals to their herds, but do not manage their herds more intensively to improve the yield per animal. Moreover, the productivity response to crop residue, manure, and fertilizer is weaker in arid environments so there is less incentive to use additional labor than in wetter or temperate environments.

In richer environments, labor–intensive techniques are taken up more rapidly for two reasons. First, as land of all types is occupied, it is difficult to cultivate a larger area and find the feed to sustain more stock. Farmers and herders must work harder with what they already have. Second, highland environments, with better soils and longer growing seasons, allow crossbred animal production and beverage crop production. The yield in those enterprises is high. Both factors—land scarcity and high productivity in some enterprises—encourage intensification by providing a better return to additional labor than in less productive zones.

Transitions to Mixed Farming and Specialization

A common assumption of many projects has been that mixed farming would replace separate crop and animal production as agriculture became more modern. At a later stage, specialized animal or crop production would replace mixed farming as markets developed further or as modern inputs became increasingly available. This study asked two questions: *Where does crop–livestock integration occur as mixed farming? Where does specialization occur?*

Mixed farming was historically limited in much of Sub–Saharan Africa. The fact that agroclimate defines the comparative advantage of livestock production in much of the subcontinent has been discussed. Livestock production has a comparative advantage where pasture and fallow land are abundant. Animal and crop production were separated historically for cost reasons in such conditions. While this separation has now practically disappeared, it explained much of the historical absence of crop–livestock integration and justified many farming practices which seemed unproductive to outside observers. Extensive animal production did not require labor–intensive feed or housing, hand–tool cultivation was cheaper than mechanization, fallow was cheaper than manure for restoring soil fertility, and extensive grazing reduced manure use by raising the costs of collecting and transporting manure from dispersed grazing sites to crop fields.

Forms of crop–livestock interaction, of which mixed farming is only one, depend on the demand for animal inputs into arable farming, and the costs of using animal inputs. Where demand for those inputs is weak and costs to obtain them are low, contracts among herders, stock owners, and farmers govern exchanges of land, crop residue, and manure. Where the demand becomes greater, costs rise correspondingly and contracts or markets for interaction become less efficient. Farmers then have incentives to integrate crop and livestock production on the farm and abandon contracts or market solutions, while herders have incentives to settle and begin mixed farming themselves.

Most mixed farming now occurs in the East African and the Malgache highlands, where population density and stocking rates are elevated. The population density of these zones requires continuous cultivation, which necessitates more soil fertility inputs at the same time as it circumscribes grazing areas. Hence, closer integration of animal production on the farm is both profitable and necessary and promotes more sophisticated techniques for feeding, housing, and watering animals. Animal traction or other innovative farming practices are necessary to relieve the burden of labor input imposed by continuous cultivation.

The transition to mixed farming with animal traction, more intensive manuring, and use of crop residue as fodder is advanced in much of the semi–arid tropics and parts of the subhumid zone. These zones are where the basic conditions for agricultural mechanization are satisfied in terms of population density and market access, notably near the major river basins or where there is a cash crop. Farmers employ some or all of the components of mixed farming throughout these zones.

Even where mixed farming is not well developed, its use is not necessary to benefit from individual investment and soil fertility interactions. Many owners employ hired herder–managers because animals do not require direct management by the owners. Absentee ownership does not rob owners of their investment, but does relieve them of the direct cost of managing animals. Separate animal management and ownership preserve the advantage of extensive grazing over intensive animal production, hand–tool cultivation over mechanization, soil fertility restoration via fallowing, and animal paddocking over restoration via manure and crop residue. Mixed farming is not a condition for animal manuring as long as manure can be obtained through contracts between crop farmers and herders.

Specialized production of cash commodities for markets is rare due to input costs, product market failures, and transport costs, and should only be the basis for projects under a restricted set of conditions. Cash commodities typically require purchased inputs, especially fertilizer and other agricultural chemicals, veterinary drugs, and concentrate feeds. Because of differences between market and owned input costs, few farmers can rely completely on a cash crop and abandon a livestock enterprise, or vice versa. While market costs of inputs will decline in the long run, some high–bulk, low–value materials, especially manure and crop residue, will always be cheaper on the farm than in a market. As long as there is a difference between farm and market costs of such materials, farmers have an incentive to use them and maintain animals. Only long–term declines in transport and purchased input costs, especially fertilizer and concentrate feeds, will shift farm incentives toward specialization.[1]

1. A second barrier is the uncertainty of market food supplies, which increases the risk of specializing in cash production. High transport costs for produce to be sold off–farm are a related problem that reduces the benefits of specialization. A third barrier is the rapid growth of urban labor markets. Growth raises the opportunity cost of farm labor and lowers the profitability of labor–intensive techniques. If males leave the farm and women are left to grow the family food, the incentive for market–oriented specialization is reduced further because of the demands on women for domestic work.

Recommendations to Promote Crop–Livestock Interactions

A recommended sequence to promote crop–livestock interactions and obtain greater benefits from them involves policy, project, and research and extension phases. General policy issues are described, followed by guidelines for project preparation and the design of research and extension programs.

What should be the policies to alleviate crop–livestock competition and to gain more of the benefits from interactions? Policies can be grouped in four categories according to what they affect: relative prices of outputs and inputs, land management, credit, and public services such as veterinary care, research, and extension. Public services are not discussed in this section, but are covered with the recommendations for individual environments and themes. Table 8–1 synthesizes the discussion.

Relative Prices

Substantial research has shown that government price and trade policies have harmed agricultural production in Africa (Jaeger 1991, Cleaver 1985, Jaeger and Humphreys 1988). Policies often maintained an overvalued exchange rate, restricted international trade so that producer prices were low compared to world market opportunity costs, and set barriers to internal trade. These measures had the general effect of taxing producers and subsidizing consumers of agricultural commodities, with the overall result of lower income from agriculture.

Agricultural policy reforms are now well–advanced in Africa. Many nations have moved to a more competitive exchange rate through which producers receive higher prices for internationally traded goods and consumers pay higher prices. Tariff or nontariff barriers have been reduced, thus giving greater incentives to participate in international trade. Other countries have eliminated restrictive internal policies, such as commodity boards, with the goal of promoting regional comparative advantage within the country.

Two issues emerge in the analysis of the results of such reforms. One is the impact of reforms on the costs of crop and livestock production, with consequent effects on their level of interaction. Reforms will promote or discourage the integration of crop and livestock production according to their net effect on the relative prices of traded and nontraded agricultural inputs and outputs. If the net effect of reform is to make tradable inputs (fertilizer, veterinary drugs, concentrate feeds, agricultural chemicals, and fossil fuels) cheaper relative to nontradable ones (manure, crop residue, pastures, and animal power) then crop–livestock integration will recede, and vice versa.

Examples of measures which have had negative effects on crop–livestock interactions are fertilizer and veterinary service policies which have often made such inputs more expensive to farmers. Reforms resulting in cheaper and more widely available chemical fertilizer would eliminate a benefit of keeping animals on crop farms because manure would become more costly relative to chemical fertilizer, thus harming crop–livestock integration.

The effects of policy reform on the cost and availability of veterinary services might be quite important in determining the best scale for livestock production. Because of economies of scale associated with prevention and treatment of livestock disease, and because of the weak effective demand for veterinary services among small and widely dispersed producers, most veterinary inputs are now concentrated on larger production units. This places small producers at a cost disadvantage. Reform in veterinary services to provide cheaper and more reliable service to small producers would assist them in overcoming their cost disadvantage against larger animal production enterprises. Cheaper and more timely delivery of veterinary services to small farmers would probably promote crop–livestock integration by reducing the cost of livestock production at given levels of crop output.

The second issue is the impact of reform on the intensification of methods of crop and livestock production. Reforms will promote or discourage intensification according to their net effect both on the relative prices of traded and nontraded inputs and on those of products. Unreliable supplies of fertilizer and other market inputs are now the main impediment to more intensive production methods. Exchange rate reform resulting in higher prices for tradables will promote intensification by raising relative returns to crops or livestock according to which sector has a greater comparative advantage. Associated with a shift to more intensive methods is likely to be a shift to greater specialization.

While the substantial benefits to agricultural policy reform in Sub–Saharan Africa are likely to disrupt the trend toward crop–livestock integration both by promoting use of tradable inputs and by promoting specialization, their net benefits would still be positive. The costs of foregone crop–livestock interactions should not be seen as an argument against reform. Given the likely and desirable continuation of policy reforms, analysis of crop–livestock interactions would have to consider the following probable outcomes of reform.

- Reform in overall agricultural policy is likely to reduce incentives for crop–livestock integration by making internationaly tradable and market inputs cheaper, thus making projects promoting crop–livestock interaction themes less successful.

Table 8–1. Policy Recommendations to Promote Mixed Farming and Specialized Production

Environment	*Policy types*		
	Relative prices	*Land management*	*Credit*
Humid, subhumid (high trypanosomiasis)	Trade protection and subsidies likely to be very inefficient because zone lacks comparative advantage in livestock production even with reform	No specific incentives for ranches or other forms of livestock production. Segregating crops and livestock not relevant	None until fodder production and veterinary services greatly improved
Subhumid (low trypanosomiasis)	Better access to fertilizer without subsidies	Do not segregate crops and livestock. No specific incentives for livestock. No specific incentives for land clearing for livestock production because not likely to be profitable	Credit for fattening on-farm if research results support credible extension packages

Semi–arid	Better access to fertilizer without subsidies. Small variable levy on milk imports if protection required	Reinforce traditional forms of pasture management	Public credit for fattening on–farm if incentive problems can be solved and if technical conditions favorable
Mechanized highlands	Continue general policy reform. Small variable levy on milk and meat imports if protection required	None	Public credit for dairy production and fattening on–farm if incentive problems can be solved
Unmechanized highlands	Continue general policy reform. Small variable levy on milk and meat imports if protection required	None	Public credit for dairy production and fattening on–farm if incentive problems can be solved

Source: Analysis by authors.

- Better producer incentives resulting from policy reform will reduce crop–livestock interactions by making specialization a more profitable, less risky alternative to mixed farming, with the same consequence for projects.
- Reform will promote agricultural intensification, but the consequences of that on crop–livestock integration cannot be generally predicted and would need to be studied on a project-by-project basis.
- In zones having a comparative advantage in livestock production, a small variable levy on livestock product imports may be justified to support livestock producer prices which have fallen subsequent to reforms creating greater openness in African economies.

Land Management

One outstanding land management policy has been the attempt to lessen crop–livestock competition by segregating crop and animal production. The justification for this policy was thought to be reduced land competition in agricultural areas, and in some cases, lessened conflicts between herders and farmers. The error of this segregationist policy was to ignore the many adaptations which farmers and herders have developed to lessen resource competition. One example is grazing reserves in Nigeria, where it has been cogently argued by von Kaufmann and Blench (n.d.) that such policies are misguided because they ignore the possibilities of complementarity, particularly those which involve grazing crop residue. The field visits in this study revealed many other examples of successful adaptations to the competing resource needs of crop and livestock production.

A second policy was land management to control stock numbers. While this was principally a policy to arrest land degradation caused by overgrazing, it can be seen as a means of relieving land competition. As does the segregationist policy, proposals to control herd sizes ignore the successful adaptations of livestock producers to resource competition and scarcity. Jarvis (1985) contends that overgrazing, caused by inadequate incentives for producers to maintain the productivity of common property pasture, incurred relatively small costs in several major livestock producing countries of Africa. In addition, the economic costs of overgrazing might be smaller than the costs of enforcing a stock control program, so that the net benefits of the policy could even be negative.

A better alternative to variations of these two policies is to promote technical changes in crop and livestock production. An appropriate sequence would be to:

- Identify sites at which land competition between crops and livestock decreases total net income from the two sectors, or at which the costs of externalities, such as those caused by overgrazing, decrease net income.
- Review producer adaptations to the land conflict between crops and livestock. One of these adaptations, which has been discussed in many previous studies, is the allocation of customary grazing rights by traditional authorities.
- If those adaptations are unsuccessful or cannot be bettered through extension, then review policy impediments to technical changes, such as inappropriate prices or supply conditions for inputs.
- If extension or policy reforms are unsuccessful, then undertake research on novel technical means to alleviate crop–livestock competition for land.
- If technical means are unavailable or cannot be generated and transferred through research and extension, then consider restrictive land management policies, taking care to ensure that the costs of administration have been properly calculated.

Credit

Credit is often recommended to bolster livestock productivity by enabling small producers to purchase more stock and invest in better production methods. Many public livestock credit project components have failed (World Bank 1985). A principal reason for failures with public livestock credit is that it suffers from lack of information about characteristics of smallholders and inadequate collateral. Because credit programs cannot obtain information cheaply about borrowers, they undertake too many risky loans and ultimately fail.

Even if appropriate information about smallholder borrowers was available, a more basic criticism of public credit for smallholder livestock is that it does not solve the fundamental impediments to wider stock ownership and greater productivity. The main constraint to wider ownership is not the financial capacity to invest in animals, but lack of breeding stock, fodder, and veterinary services. Because the supply of breeding stock is fixed in the short–run, credit to purchase animals raises the price of breeding stock without doing anything for fodder availability or animal health. While the supply of breeding stock is more elastic in the long–run, expansion depends on investments in fodder, veterinary care, and other inputs, and not on the financial capacity to purchase animals. Unless credit solves those long–run supply problems, it cannot increase the total number of animals or their productivity.

The role of public credit in a sequence of livestock development could be seen as follows in light of the serious information and input supply problems it faces:

- Define the roles of public and private credit with respect to information costs about potential borrowers. Because information about large borrowers (for example, feedlot investors) is cheaper, private credit ought to be available to them, and there would be no justification for public credit.
- To further define an appropriate domain for public credit, programs must distinguish among different inputs. Inputs such as fertilizer and veterinary drugs do not pose a moral hazard problem. Financing inputs such as animals, which are an inelastic supply, does pose a moral hazard problem. Credit for the former can succeed as a private enterprise, while credit for the latter will probably have to be public or be subsidized through private banks.
- In deciding on the nature of a public credit program, review constraints to wider ownership of stock and to greater productivity from individual animals to decide if lack of finance really is a key problem compared to the availability of breeding stock, fodder, and veterinary care.
- Review private alternatives to public credit, such as animal borrowing (White 1984), which may solve information problems about borrowers while permitting farmers who want to rebuild their herds access to long–term credit by borrowing breeding stock and repaying in labor.
- If finance is really a key barrier to livestock productivity and if private alternatives are unavailable or inefficient, then investigate the viability of public livestock credit with minimal subsidies.
- Within a public livestock credit system, consider creating collateral substitutes for small borrowers. One alternative is producer groups

which can provide a collateral substitute while reducing transaction costs in lending to many small borrowers.

Priorities by Agroclimate

Projects designed to gain the benefits of crop–livestock interactions will require allocation of investments by principal commodity, scale, key inputs, and packages of appropriate techniques. Table 8–2 summarizes project recommendations for the main agroclimates, which, in light of the previous chapters, are briefly discussed below in terms of what they might imply for crop–livestock interactions. More detailed research and extension recommendations are presented in a later section.

Humid Zone

Recommendations for the humid zone derive from the expectation that disease will continue to curtail livestock production. If that expectation changes—notably from progress with trypanotolerant stock, new methods of controlling trypanosomiasis, or the effects of sustained population growth on the habitat of the tsetse fly—then the situation will become more and more like that of the sub-humid zone, and the recommendations would change accordingly.

COMMODITY PRICES. In the tsetse-infested humid zones, projects should emphasize trypanotolerant small ruminants or cattle. Meat is the commodity priority because of the high cost of milk production. The latter is likely to persist due to biological factors (heat stress in lactating cows and the low milk yields of trypanotolerant stock), and economic ones, especially cheap livestock product imports (Walshe and others 1991).

SCALE. The choice between smallholders and larger enterprises depends on the cost of management, veterinary services, breeding stock, and feed. Some aspects of scale—availability of feeder stock, quality of veterinary services, and prices and supply of feed—differ sharply among agroclimates. In decisions affecting animal traction, forage production, and soil fertility management, economies of scale are much less important, and smallholder activities are more easily justified by equity considerations because the efficiency effects are probably smaller.

Table 8–2. Synthesis of Livestock Project Priorities by Agroclimate

	Project elements			
Environment	*Commodity*	*Scale*	*Key inputs*	*Crop–livestock interactions*
Humid, subhumid (high trypanosomiasis)	Meat	Smallholder, subject to adequate veterinary care	Animal health, feed quality	Soil fertility effects of leguminous feeds
Subhumid (low trypanosomiasis)	Meat, traction or milk depending on markets	Smallholder, if veterinary care is good. Larger possible near breeding areas	Feed quality, animal health, forages for quality (extensive)	Animal traction, soil fertility effects of leguminous feeds
Semi-arid	Meat, traction	Smallholder, some argument for larger-scale finishing	Feed quantity, feed quality, fertilizers, economies of by-product use, forages for quality in second season with residual moisture	Crop residue management, manure

Mechanized highlands	Milk, traction	Smallholder, some argument for larger-scale finishing	Feed quantity, feed quality, crop residue management, forages on marginal land for quality, including double cropping	Fertilizer, manure
Unmechanized highlands	Milk, meat	Smallholder, some argument for larger-scale finishing	Feed quantity, feed quality, crop residue management, forages on marginal land for quality, including double cropping	Fertilizer, manure

Source: Analysis by authors.

Veterinary services are the most crucial determinant of scale in the humid environment. Given the poor capacity of public and private veterinary services in the humid countries, it is for practical reasons difficult to improve veterinary coverage broadly and quickly among many small and dispersed livestock producers.[2] It would follow that veterinary services should concentrate on a few projects in the short–term, while measures to improve the quantity and quality of veterinary services should be pursued vigorously in the longer term. Another aspect of project scale in the humid zone is the supply of feeder stock. Where feeder stock are widely available, feedlots have an advantage in buying large numbers of thin animals at cheaper prices. Because the humid zones are distant from breeding areas, there is no local source of feeder stock and large units would therefore have no cost advantage over small ones in purchasing thin animals.

KEY INPUTS. The main inputs are veterinary services and high–quality feed, such as might be provided in a mixed alley farming and livestock enterprise. Because crop residue and natural pasture are abundant, extensive animal production would not face an immediate feed shortage, and it is possible to raise the stocking rate if animal health can be improved.

CROP–LIVESTOCK INTERACTIONS. Crop–livestock interactions now have an insignificant role in the humid zone and limited benefits can be expected from them in the near future as long as animal disease pressure remains high. Because animal traction contributes nothing to crop output, projects should not force an association between animal production and draft power. Where labor is scarce for cropping activities, mechanization should be directed toward non–field operations, such as processing and transport.

Animal manuring can do little for soil fertility because it is so expensive to raise the stocking rate. Moreover, technical alternatives exist to manuring. At high population densities, soil fertility can be amended with continuous mulching techniques (such as multistory cropping) and chemical fertilizer. At low population densities, shifting cultivation has maintained soil fertility. While shifting cultivation is now less viable because of sustained population growth, it is likely to be superior to animal manuring because of barriers to higher stocking rates.

Although feed quality is a key constraint in the humid environment, improving it depends mainly on veterinary services. Sown forage

2. An example is the introduction of Baoule cattle to the Central African Republic (Jahnke 1983). While this study suggests that farmer inexperience with cattle is not an insurmountable obstacle, the long–term history of the project shows the high costs of external veterinary inputs.

production would not provide a high return because of high stock mortality, which is itself partly caused by the lack of veterinary services and the low feed response of trypanotolerant stock. One promising avenue is with concentrate feeds, for example processed cassava, but that is not necessarily a part of better crop–livestock integration.

Subhumid Zone

Where the disease challenge is stiff, the livestock situation in the subhumid zone is like that of the humid; where it is weaker, the situation is more like that of the semi–arid tropics.

COMMODITY PRIORITIES. Meat is the first priority, followed by traction and then milk. Milk is least important again because of the unsolved research problems necessary to augment dairy productivity in the tropics.

SCALE. The conclusion about enterprise scale differs from the humid zone because the subhumid zone has feeder stock. Feedlots can be efficient because it is possible to buy feeder stock at lower average cost than in small farmer enterprises.

KEY INPUTS. The stocking rate is better and there is potential for quality animal production. The returns to feed improvements might therefore be higher. Secondary emphasis should be on other animal diseases such as streptothricosis.

CROP–LIVESTOCK INTERACTIONS. Mixed farming in the subhumid zone is possible where permanent animal production is economic. The choice is then between more intensive means of mixed farming, possibly involving animal traction, sown forages, and ley farming, and extensive mixed farming in which the stocking rate rises, animal traction is rare, and fodder production is limited to crop residue and native pasture. Intensive techniques will probably be unsuccessful because projects cannot hope to introduce intensive manure and crop residue methods in sparsely populated areas at an incipient stage of animal production. Where permanent animal production is not possible, the association between animal production and collateral techniques should be avoided, as in the humid zone.

Semi–Arid Zone

Crop–livestock interactions are a prominent feature of most semi–arid farming systems, and the transition to mixed farming is often advanced. Because many semi–arid farming systems exhibit growing competition for land between crops and livestock, the short–run emphasis must be on improving resource–use efficiency, with long–run emphasis on raising primary productivity.

COMMODITY. The commodity priorities are meat and animal traction. Given the relatively small urban populations and low incomes, milk production should not be a priority unless world prices rise dramatically. Even then, technical constraints to milk production will always be great.

SCALE. With good access to feeder stock, agricultural by–products, grain, and veterinary care, there is a wide spectrum of different scales in animal production. Large producers have a cost advantage because of economies of scale in veterinary care, feed management, and marketing costs. Small producers have an advantage in feed costs because transport costs for roughage are cheaper for them. These countervailing cost differences will tend to create a mixed equilibrium in which smallholders raise stock at young ages when weight gain is quickest, and then sell to feedlots for finishing.

KEY INPUTS. The principal constraint in this zone is primary production. Efforts to loosen this constraint should emphasize soil fertility, feed quality, and improving the efficiency of techniques for crop and fodder management.

CROP–LIVESTOCK INTERACTIONS. Animal traction will soon be a characteristic feature of semi–arid agriculture. This trend will exacerbate feed competition between draft oxen and other stock as population density continues to grow rapidly. In the short–run, therefore, projects and associated research components should concentrate on more efficient uses of available feeds for fattening or traction. In the long–run, projects and researchers should attempt to increase primary production to reduce the competition between crops and animals for crop residue, by–products, and other fodder.

Low basic soil fertility and competition from animals for crop residue make animal manure fundamental. Nonetheless, manuring is inherently limited by the availability of fodder to support livestock production. Major quality improvements in manure cannot be foreseen because they are too labor intensive to be profitable. Therefore, whatever projects achieve on manure or crop residue efficiency, major policy and project emphasis must be on chemical fertilizer.

The intrinsic problems in raising primary productivity in the semi–arid tropics are compounded by the difficulties of incorporating forage crops into smallholder systems. An appropriate project sequence on feed quality is to insist on extension of currently available by–products, valued at correct economic prices, while maintaining a long–term research effort to develop primary production.

Highland Zone

Crop–livestock interactions are already prominent in the highlands, and there is little to be gained by promoting them further in the absence of strong exogenous technical changes.

COMMODITY. Milk probably gives the best return in highland projects and should be the commodity priority. In some areas where animal traction is widespread, the potential of milk production is unlikely to be realized without reduced feed competition from draft animals.

SCALE. The dense population makes large projects unwise on efficiency and equity grounds. With respect to efficiency, projects to produce both milk and meat can be managed effectively by smallholders. With respect to equity, the scale considerations mentioned for the semi–arid tropics apply.

CROP–LIVESTOCK INTERACTIONS. The distinction between the mechanized and unmechanized highlands affects which key interactions are chosen for promotion. Mechanized highland projects should emphasize the conflict between animal traction and milk production, soil fertility, and efficiency in collateral techniques. Fertilizer profitability is better in the highlands and thus can make a strong contribution to soil fertility. This is all the more true in that crop residue is essential for livestock fodder and cannot be diverted to soil restoration.

Efficiency in crop and fodder management is an avenue of improvement because feed competition constrains both crop and animal production. Projects should concentrate on reducing the feed burden of draft animals to release crop residue for milk production and soil restoration, including such techniques as mechanization and perhaps multipurpose animals.

In the unmechanized highlands, the emphasis should be on intensive animal production, soil fertility, and collateral techniques. Because the potential for animal traction is small, there is no feed conflict between draft and other animal products. The population density of the unmechanized highlands makes severe demands on soil fertility. Confined animal production permits manure recycling, but fertilizer is necessary and profitable for the reasons mentioned earlier. This makes it imperative to continue a long–term research effort in primary production, with the objective of developing forage crops with the triple purposes of feed, labor economy, and soil fertility management.

Research and Extension Recommendations

Recommendations for research and extension are summarized by theme: animal traction, soil fertility, fodder resources, and on–farm animal production (Table 8–3). In making these recommendations, it is assumed that reforms in agricultural policy will continue to make African economies more open internationally.

Animal Traction

The discussion on animal traction is considered in three sections: why projects should not always be organized around animal traction, introducing animal traction, and improving animal traction.

PROJECTS SHOULD NOT ALWAYS BE ORGANIZED AROUND ANIMAL TRACTION. The argument against using animal traction as a organizing project theme in agricultural development projects can best be seen by comparing environments. In the humid tropics, the problem is comparatively simple: hand cultivation will practically always be cheaper than animal power (Pingali, Bigot, and Binswanger 1987). The latter will not develop at all, or will be confined to special points such as rice cultivation in river valleys. Associating otherwise profitable elements of crop–livestock interactions to animal traction might therefore prevent their extension. Including those elements in projects must be on a case-by-case basis, and not as a package.

Where animal traction is economically competitive with hand cultivation but has not yet developed, there are different problems. In the subhumid tropics, animal disease is a constraint. In parts of the highlands, small hilly farms impede the use of draft animals. In either situation, introducing animal traction will not work unless solutions are first found for those specific problems. Tying other crop–livestock interactions to animal traction would make development of those interactions unnecessarily costly because of the extra time required to find solutions to the special barriers to animal traction. It could only be justified if it was shown that other interactions— on–farm fattening, forage production, soil fertility management with manure—depend on the use of animal draft power. Field evidence suggests that this is not the case. The appropriate project sequence would be to extend other interactions which can be shown to be profitable without linking animal power to those interactions.

Animal traction can succeed as a central theme where it is clearly cheaper than hand cultivation, but where it is not yet fully developed. Examples abound in the subhumid and semi–arid tropics where the costs of animal disease, hilly topography, and knowledge of animal production do not stop animal traction from expanding. The issue in project preparation is whether there are economies of scale in extending several techniques at once, and since there probably are, animal traction is feasible as a central theme.

Where it is appropriate to make animal traction a central theme in project extension, the ownership or use of animal traction should not be a condition for project participation. This is because poor farmers would lose since they are initially slower to adopt animal traction than rich ones. Despite their lag in adopting oxen power, poor farmers can benefit from information about divisible agricultural improvements, such as fertilizer, which require smaller initial investments than do animals.

INTRODUCING ANIMAL TRACTION. The roles of research and credit as conditions for the introduction of animal traction must be carefully scrutinized before undertaking new initiatives. In that scrutiny, it is essential to distinguish between introducing animal power to a farming system in which it is unknown, and improvement where it is partially or fully adopted. Introducing animal traction depends so much on exogenous factors—agroclimate, soil characteristics, population density, and off–farm wages—that research has no prospect of success if exogenous factors are unfavorable. Improving mechanization, where it is developed or has begun to grow, depends less on exogenous factors and can be more successful. This distinction places most project and research stress on improving animal traction where farmers already employ it.

Efforts to introduce animal traction must establish that the base conditions for mechanization exist. Many programs have failed because they involved zones where the environment was unfavorable. Barriers to mechanizing the humid zone are so strong it is unlikely that a research program can break them. While techniques for releasing the constraints are known—clearing land with machines, replacing root crops with rice, improving animal health—such techniques have failed in many instances, as Belgian colonial agronomists observed long ago in humid central Africa (Muller and de Bilderling 1953). A promising area is the subhumid zone, which will probably mechanize rapidly as conditions

Table 8–3. Synthesis of Research and Extension Recommendations by Theme

Environment	*Animal traction*	*Soil fertility*	*Feed resources*	*Fattening*
Humid, subhumid (high trypanosomiasis)	None	Chemical	Quality with soil fertility contribution	Small stock, health interactions important
Subhumid (low trypanosomiasis)	Constraints to introduction, association with smallholder fattening	Chemical	Extensive forage legumes	By–products, forages
Semi–arid	Reducing feed burden, shorten work period to coincide with natural growth	Chemical, manuring; [a] crop residue, chemical, manuring [b]	Crop residue and by–products, long–term effort in forages	By–products, shift from cattle to small stock
Mechanized highlands	Substitutes for animal traction or other means to reduce feed burden	Fertilizer or manure depending on economic relations	Milk where feed burden of draft animals is not too great	Reducing feed burden, shorten work period to coincide with natural growth
Unmechanized highlands	None	Fertilizer or manure depending on economic relations	Cultivated forage on marginal land	Milk production probably more efficient

a. If feed burden of draft animals cannot be reduced.
b. If feed burden of draft animals can be reduced.
Source: Recommendations by authors.

of population density and economic growth become more favorable. Because the basic conditions have begun to emerge, it is possible to promote mechanization in the subhumid zone via technology transfer from adjacent ones, as Blench (1988) observed in subhumid Nigeria (Chapter 4).

A primary lesson of previous studies of animal traction is that research has had little impact on the introduction of animal traction because agricultural mechanization depends so much on the evolution of the farming system. Ethiopia and Madagascar, with well–developed oxen traction, have had almost no research on the subject (Goe 1987, for Ethiopia; Munzinger 1982 and field visits, for Madagascar). Senegal and Nigeria, with some animal traction and some research on associated problems, have seen little connection between research themes and successful extension. Starkey (1988) even argued that some tool research has retarded mechanization with animals.

The one research finding known to promote rapid introduction of animal traction is a cash crop. Successes have been seen with groundnuts in central Senegal and Gambia, rice in the Niger delta of Mali, and cotton in southern Mali, Chad, and Tanzania. Important base conditions had already been satisfied in each instance before the introduction of animal traction, and given those conditions, the cash crop facilitated faster adoption of animal traction. While animal traction research consisted of little more than adaptation of techniques and implements developed elsewhere (Starkey 1988), it built upon a successful base of crop production technology transfer.

Animal nutrition is not an important constraint to introducing animal traction. If nutrition hampered the introduction of traction, farmers would be expected to invest in better nutrition. For example, initially there should be intensive crop residue management—harvesting, transporting, storing, feeding—as means of improving the working capacity of stock. Instead, such intensive management only occurs after a long process of adoption of animal power. Few farmers adopt improved feeding of draft animals where they were not already important. Many farmers selectively feed other stock at the expense of draft animals.

Just as with credit programs to purchase stock or livestock production inputs, credit for animal traction must be capable of generating enough cash flow to pay for itself. Pingali, Bigot, and Binswanger (1987, p. 11) argued that private agents are reluctant to supply credit for animal production, including traction, because borrowers can give them no reliable collateral. They concluded that public credit for animal traction is justified "as part of an extension effort to promote the use of animal traction." This is a specific case of the previous remarks about credit. Their argument is valid only if animal traction is a lower–cost technology and can maintain its cost advantage once the credit has been repaid. If animal traction is not a lower cost technology than hand tool cultivation, then there is a high risk that the credit will not be repaid and farmers will abandon animal power once the credit is withdrawn. Therefore, the provision of public credit must be tied to a careful cost–benefit analysis of the animal traction program.

IMPROVING ANIMAL TRACTION. Research and extension can contribute more in the subhumid, semi–arid, and mechanized highland zones, where animal traction is already well–known. Mechanization must still justify itself with the gains from area, yield, cropping pattern, and labor effects, but it has a greater probability of success than in the humid zone and unmechanized highlands. In areas satisfying the basic conditions for field mechanization, research and extension should concentrate on the problems of working efficiency and other means to reduce the costs of maintaining draft animals per unit of output.

The area of working efficiency summarizes aspects of animal nutrition, implements, and animal health. While the most important aspect of working efficiency is probably nutrition of draft animals, successful research faces a number of serious obstacles.

Supplementary feeding of draft animals is likely to fail because of competition from other uses of the feed. The marginal unit of feed is likely to be more profitable to meat or milk production than to feeding draft animals. This is certainly true of animal traction compared to milk production, and probably true compared to fattening.

It is plausible, but probably uneconomic, to recommend sown forages for draft animals. Animal traction is most prevalent in highland East Africa and the semi–arid tropics. Those environments present contrasting illustrations of why sown forages are ordinarily too costly to feed draft oxen.

- In the highlands, small farms oblige a new crop to compete for land. Land competition restricts forage introductions because farmers prefer to grow forage for milk production, for which the economic return is higher. A second reason is that land allocated to forage would displace land for food crops, causing farmers to increase reliance on markets for food. Farmers may be reluctant to increase their reliance for food on a risky and thin market, so they continue to maintain draft animals on low–quality roughage and avoid the production of sown forages despite the recognized cost of foregone animal production.

- In the semi–arid tropics, farmers produce extensively and potential new crops are obliged to compete for labor. Labor competition restricts forage introductions because farmers will not use labor to grow forage for low-productivity animals given the alternative adaptations available to them. Competition with food crops is also a reason not to grow sown forages in this zone.

Economic competition between power, meat, and milk animals means that experiments with draft animal nutrition must be redesigned to study feed competition between work and other animal outputs. No farmer will adopt improved animal traction—from feeding, better implements, or healthier animals—unless it is more profitable than competing animal production activities, but evidence in Africa to make practical recommendations is ambiguous. Studies of the effect of nutrition on working animal performance are unclear (Chapter 4). Draft animal feeding practices are diverse and their consequences not well quantified, notably at many sites where traction is common without supplementation of working stock. That feeding practices are so poorly understood suggests a need for more rigorous experimentation of their effects on work output. While taking this variability into account will make experiments more expensive, complex experimental designs are the only way to ensure meaningful results.

Alternative methods to reduce the burden of feeding draft animals must be studied. If the goal of feeding draft animals is to raise power output on the farm but the return is less than that in feeding dairy or meat animals, it may be possible to achieve the goal by other means, including tractor rentals, cow traction, reducing the number of oxen in the span, mechanization with engines, or new tools. Despite these apparently promising alternatives, there should not be too much optimism about reducing the feed burden by making minor incremental changes in farming practices. The principal means of reducing the feed burden of draft animals is now rental markets. Because these rental markets exist everywhere there is animal traction, their continued introduction or refinement is not likely to be very important. The authors found only one other important example in Africa where a major change—to cow traction—developed indigenously. Other changes, most notably the advent of tractors, came from outside.

Reducing the feed burden of draft oxen might have to await tractorization. The feed burden of draft oxen could be lightened by increasing the feed conversion efficiency of individual animals, which is unlikely, or by reducing their number. The authors found two instances of the latter, in which farmers replaced draft oxen with machines, thus leaving more feed for other stock. In highland Madagascar, shrinking farm size and the development of a private tractor service enabled farmers to sell their draft animals and invest in milk production. In Kenya, the growth of private tractor services permitted some farmers to sell their working oxen and buy dairy cows.

Analysis of mechanization should include the opportunity cost of feed. Studies of animal traction or engine mechanization commonly assign no cost to the feed used by the former or saved by the latter. For oxen power, if the working animals have been converted from the beef herd, then the cost of additional feed will be small or zero and the analysis would not change. For tractors, if it is possible to replace draft animals with machinery, then the benefits of feed savings may be substantial. The value of feed savings would be greatest in the mechanized highlands where improved milk production is possible with the feed saved from working animals. They might also be important in the semi–arid tropics for meat production. Both examples suggest that there might be long–run benefits to mechanization with engines imputable to savings of feed costs.

Better study of disease × work interactions is required. There is really only one study of this problem (Bourn and Scott 1978, in Ethiopia), and further specific studies are needed. They should be conducted jointly with studies of cropping techniques and the nutrition × work interaction.

Mechanized cropping techniques might offer some potential to improve land productivity. The yield and labor–use effects of many cropping techniques, with and without mechanization, are not well understood. A salient example is ridging crops in Nigeria, which is done by hand in the subhumid zone and with oxen in the semi–arid tropics. Another possibility is mechanized cultivation techniques at key sites. Yet another example is lowlands with potential for higher yields, higher value crops (for example, vegetables), and greater cropping intensity. It is worth investigating if mechanization could exploit that potential more quickly, especially because these lands are generally the first to be mechanized.

There are important complications to such a program. First, these areas are small (von Kaufmann and Blench n.d., for subhumid central Nigeria) in proportion to the total area cultivable. Second, their use for crops may have a high opportunity cost in seasonal grazing. Third, higher value crops, especially seasonal fruits and vegetables, might face narrow markets and other constraints, such as diseases and insects, which could limit their profitability.

Soil Fertility

Manuring is a universal component in agricultural development projects in Sub–Saharan Africa. It is a technique which can be extended to farmers who do not employ animal traction, or where markets exist, to farmers who do not own cattle. Despite this universality, many recommendations are based on erroneous impressions about its actual use, are economically inappropriate, and give inflated expectations about what manuring can achieve.

Animal manuring is widespread. The authors' field visits and years of farm management studies have shown that manure is used throughout Sub-Saharan Africa. The pervasive use of manure and the wealth of contracts governing it suggest that farmers understand its value. If this is correct, it is difficult to argue for the existence of major inefficiencies of allocation. In the absence of such inefficiencies, research or extension programs promoting manuring as a novel source of gains have little foundation.

Labor costs are often too high to justify more intensive manuring. Field visits and literature reviews revealed little intensive manuring except in the densely populated highlands of East Africa. Elsewhere, the principal manuring technique is to paddock cattle and throw the manure into adjacent fields. Improving manure by mixing it with litter or by incorporating it into the soil is infrequent. On larger farms of 5 to 15 hectares sometimes found in the semi-arid tropics, intensive manuring is confined to plots adjacent to households or to vegetable gardens on which the return is very high. Elsewhere on these larger farms, fallows, rotations, intercrops, and small quantities of fertilizer maintain fertility more efficiently. The labor intensity of manure production makes it inefficient compared to those alternatives on large areas. While labor costs are expected to fall with rising population density, thus encouraging more intensive manuring, promoting the trend toward more intensive manuring is not a research problem, but an extension problem. Because it appears that farmers are already well informed about manuring, the additional gains to extension are likely to be small.

While a long experimental history has demonstrated the positive yield effects of manuring, it is improbable that manure alone can maintain long-term soil fertility except in very productive agroclimates. Without fallows, manuring can maintain soil fertility only on farms that are too small to be viable unless their base yield is initially high. Such farms are probably only found in the East African highlands. In other environments, sufficient manure to shorten the fallow cycle can only be produced at stocking rates so high that they would conflict with crop production.

If research and extension are to improve the economic efficiency of manure use, there must be changes in experimental design and the resulting extension recommendations. Experiments with manure must be designed with realistic nutrient levels, must be amenable to economic analysis, and should have labor input as a covariate. That farmers do not adopt apparently profitable manuring techniques suggests bias in the experiments on which those techniques are based. Many experiments used very high nutrient levels from manure that were nearly always unsuitable to the target farming system. Few examples of economic analysis were found, and none in which labor input was adequately measured.

The principal alternatives to animal manure are crop residue and chemical fertilizer. Both face serious constraints of supply and the former confronts strong resource competition on farms.

There is little green manuring or mulching. The labor costs of mulching are excessive, and the crop response to mulch is weak. The main instance of mulching is the multistory cropping system of the humid tropics described by Lagemann (1977) in eastern Nigeria. This system exists because animal manure is not available, and because it uses little labor. Intensive mulching is commonly found only where it is obligatory, such as with coffee in Rwanda and Burundi.

The competition between crops and livestock for crop residue has been underestimated. Jones (1971) concluded that it would be better to restore crop residue to the soil than to remove it. Field visits and the literature review showed, however, that recycling was rare. Where it is the practice, as in western Madagascar, usually only the stubble is incorporated and most of the straw is fed to livestock. The field evidence does not mean that the experiments on crop residue management were wrong, only that farmer recommendations derived from them are sometimes economically inappropriate. Recycling crop residue through the soil requires more labor than leaving it for grazing or even collecting it for feed. The immediate benefits of feeding residue to livestock are larger than the long–term benefits of incorporating it into the soil.

While animal traction facilitates recycling crop residue through the soil, animals require that same residue as fodder. The opportunity cost of residue as a soil amendment is typically too high in view of the maintenance requirements of draft animals. This explains why the apparently fruitful idea of using oxen to plow under residue has been so difficult to put into practice.

Experiments with mulch must be designed with realistic nutrient levels and must allow comparison with other uses, particularly feed. The criticism made of soil fertility research with manure applies even more strongly to mulching experiments. Because mulch usually has many uses, experiments must consider all major uses in a given environment.

The expectation that a fall in the price of chemical fertilizer relative to the price of labor would reduce interactions was not confirmed. Chemical fertilizer was in fact associated with increased interactions in manure use and animal traction. In Asia, this hypothesis can be considered as accepted, so that the contrast between Asia and Africa is now one of the stage of development and is not a fundamental difference in the mechanism of agricultural growth.

Because fertilizer use is not more widespread suggests a supply constraint that requires analyzing fertilizer distribution policies. There is good experimental evidence that fertilizer can be employed profitably on many African crops. Farmers have rapidly adopted fertilizer in projects or at other sites where they have special access. In contrast to intensive manuring, which has evolved slowly, there are many instances of rapid growth in fertilizer use.

Fodder Resources

Improved fodder resources must be a major avenue to boost livestock production in Sub–Saharan Africa. Although this strategy has been well known for some time, and despite many efforts to promote change, native pasture, crop residue, and browse are the maintenance feeds for most African livestock. There have been limited movements toward feeding grain or manufactured feeds. Farmers do use some processed by–products such as oilseed cakes, but only for a small share of the continent's livestock, and have usually refused to sow forages. There are a number of major lessons to be learned from the failure to promote better forage production.

Agroindustrial by–products have often succeeded with little research or extension. These products have advantages—especially lower transport costs per unit of feed and little competition for land and labor—that sown forages lack. Their consumption has grown rapidly with no more stimulus than local adaptive research to design rations and explain them to farmers.

The most successful sown forages are intercrops and crop residue because they avoid resource conflicts related to seasonality of forage production. Intercropping is successful because conflict between the primary and secondary crops can be avoided. It is successful with *Acacia albida* trees for that reason, and because the trees come into leaf in the dry season when forage is scarce.

New forage crops and pasture management techniques have largely failed except when used for milk production with crossbred animals. Except in heavily subsidized state farms or ranches, such techniques as enclosing natural pasture, oversowing pasture, and grazing in rotation have almost totally failed. In spite of major research efforts, especially in East Africa, there has been no adoption of introduced forage crops in the semi–arid areas, and very little in the subhumid and humid areas.

The introduction of sown forages failed because they were often incompatible with African farming systems. The authors found specialized forages only in highland milk production (Kenya), or in strict erosion control programs (Rwanda, Burundi). Too much effort has been put into refining agronomic recommendations for sown forages which have little prospect of adoption under any circumstances.

These observations should lead to a reorientation of forage research. Because the basic constraint to forage is typically not the capacity to grow it but cost competition from alternative feeds, a research strategy is necessarily more complex. This implies:

- Forage databases must include enough information about farming systems to permit the construction of feed supply and demand profiles at experimental and extension sites. Forage cultivars should be screened for their cost competitiveness with other sources of fodder in the farming system, just as they are screened for yield.
- The zonal emphasis of forage crop research ought to be on sites with high potential for milk production. Land and labor competition discourage sown forage production unless intensive milk production is profitable. Such milk production with grade animals is most profitable in the highlands if feed is available, and the return to research on sown forages is highest there.
- Research should emphasize dry season fodder in arid zones with less potential. In such zones these plants are not likely to succeed as general feeds because their yields are low and labor competition with other crops is severe. This argues for dry season forage research when labor competition is lower and competing feeds are more expensive.
- Forage crop research must always be compared in terms of resource competition to crop residue, agricultural by–products, and other feeds. Because feeds are grown as inputs to other enterprises, programs to educate farmers on their use are more complicated than programs on food crops. Sharp attention must be paid to resource competition at all stages of the research and extension process.
- Irrigated trials should not be a main focus of forage research. While irrigated trials provide valuable information on growth characteristics of forage plants, they do not address the fundamental issue of comparing the cost of sown forages with the fodder alternatives. Irrigation as a production technique provides high quality feed in the dry season when there is no rainfed fodder, but it is rare in sub–Saharan Africa and therefore should not be the main focus of forage research.

Crop residue management offers little scope for major improvements. Modifications in fertilizer, chemical treatment, plant breeding strategies, or management do not appear to be economical approaches to substantially raising the fodder supply from crop residue. This is not to say that growing quantities of crop residue will not support more livestock, but rather that such quantities will be an adventitious product of greater crop output resulting from fertilizer applications, new cultivars, or an expansion of cropped area.

Fattening Animals on the Farm

Farmers throughout Africa use crop residue and agricultural by–products to fatten livestock at times when the opportunity cost of labor is low. Projects commonly try to build on this well known practice by providing complementary resources, notably credit, to further exploit seasonally underutilized labor and crop residue. It is recognized that this type of animal production is a successful form of crop–livestock integration. However, the low additional returns to projects promoting it, and the difficulties in achieving adequate weight gains of stock under farmer conditions, suggest that there are serious deficiencies which must be corrected before further promotion.

The fact that smallholder fattening is so common all over Africa weakens the argument that resources are underutilized as the justification for projects or for further research. This suggests that projects to promote on–farm livestock production are not limited by a basic knowledge of animal production.

The principal constraints to further development of fattening are feed and veterinary care. The disparity in weight gains for given breeds between experimental and field sites is largely due to differences in veterinary care and fodder availability. Almost none of the field sites had professional veterinary care or improved feed. The constraints to technical changes in fodder production, noted above, will require long–term research, while those relating to veterinary care could be improved in the short–run by appropriate changes in policies affecting the delivery of veterinary services.

There should be more emphasis on small stock. There has been an historic bias in research, extension, and veterinary services against small stock, yet the rate of return to small stock might be higher, credit is less constraining, and wider participation of poor farmers is possible.

Feeding trials must be reevaluated to make more appropriate rations. Some evidence suggests that longer feeding periods do not maximize profits, given the mix of concentrate and roughage available to most African farmers. Important interactions among weight gains and season, veterinary care, and housing must also be considered in making project recommendations from experimental findings. The genetic potential of the breeds being fattened is apparently not fully exploited because experiments show higher rates of gain than field studies with the same breeds and diets. This suggests that breed improvement is not yet required for higher gains.

Promotion of on–farm fattening as a vehicle for crop–livestock integration may conflict with better soil fertility management. Chapters 5 and 6 concluded that grazing crop residue was sometimes more efficient than mulching or incorporating crop residue. Fattening schemes based on cereal bran, oilseeds, or leguminous feed which raise animal requirements for roughage derived from crop residue could then exacerbate the conflict between allocating crop residue to crops or to livestock. That conflict is a research problem which requires site–specific studies with due attention to the effects of government policies on the relative prices of crops, livestock products, and feeds.

Lessons learned from animal production in feedlot conditions ought to be generally applicable to smallholder fattening. Short–term fattening by smallholders and feedlots offers similar solutions to the same problem, not radically different choices. The problems are how to manage spatial and temporal variation in feed and water supplies, and how to exploit compensatory weight gains. The smallholder fattening found throughout Africa presents the same solution as do feedlots—a dry season source of feed and water which compensates for pasture deficiency, and which exploits seasonal weight gains in a short period.

Conclusions about enterprise scale will be site–specific and adequate generalizations cannot be made. Table 7–9 has earlier summarized possible sources of efficiency differences associated with enterprise scale. There is no strong reason why beginning animal prices should differ much between feedlots and smallholders since the source of feeder animals would be much the same. Fat prices might be higher in feedlots because of better market access and lower transport losses. Concentrate feeds would be cheaper in feedlots because of reduced costs of distribution and use. Roughage, especially pasture and crop residue, would be cheaper for smallholders for similar reasons. Conversion efficiency might be better in feedlots if they have better veterinary care or more uniform feeding. Labor use and income distribution would be much worse in a feedlot system.

Final Remarks

A main finding of this study has been that crop–livestock integration is well advanced in much of sub–Saharan Africa. Where crop–livestock integration is not strong, the reason is almost always that the agricultural environment—the complex of agroclimate, population density, relative prices, and other factors affecting agricultural practices—does not favor it. Barriers to crop–livestock integration which were initially hypothesized to be important, such as lack of information and appropriate traditional technology, were not found to be major obstacles.

Farmers and herders have developed complex adaptations of the components of crop–livestock integration. These include fodder management, animal power, soil fertility management, and on–farm livestock production. While there are obvious and sometimes large gaps between the physical productivity of these techniques under experimental conditions and on farms, the economic efficiency of the techniques, given the resources and knowledge available to African farmers, is high.

Barriers to more productive forms of crop–livestock interactions are of three types. One is the historical policy discrimination against African agriculture. Policy reforms—which are well advanced in many countries—would in fact encourage the separation of crop and livestock production in many instances. This would be accomplished by making the use of modern, internationally traded agricultural inputs more profitable than the use of nontraded traditional inputs, such as the crop residue, pasture, manure, and oxen power now available through crop–livestock interactions. Policy reforms might also encourage intensification of many crop and livestock production systems by giving better economic returns to modern inputs, thus further reducing the contribution of traditional agricultural technologies and spurring the transition to more specialization.

A second barrier is lack of information about profitable technologies. Field visits to thirty-three sites and an extensive review of literature showed that farmers were well aware of many of the component techniques of crop–livestock integration, while at the same time national extension and veterinary services were very weak. Although farmer knowledge does not prove that more information would not be productive, it does challenge existing extension programs to demonstrate that the information provided is genuinely novel and indeed more productive than current farmer practices. While the weakness of the national extension and veterinary services is a serious constraint to adequate agricultural growth, it is a much more serious constraint to the extension of new techniques derived from modern scientific research, and not to the extension of the traditional component techniques of crop–livestock interactions which are already understood and widely practiced by farmers.

A third barrier is the absence of relevant, profitable farming techniques. The lack of these techniques is much more costly to the productivity of African agriculture than lack of information about current techniques. This problem cannot be solved through the transfer of technology or scientific information from other environments, an approach which has been tried many times. The generation of new knowledge through basic research under African conditions is required.

The prospects for overall agricultural growth through better crop–livestock integration are small even if their full productive potential were to be attained through policy reform, extension, and adaptations of techniques generated through research elsewhere. This is because the inherent productivity of the components of crop–livestock integration is low. There are gains to be made from policy reform, better extension services, and adaptive research by refining and promoting the component parts of integrated crop–livestock systems. But those gains are small in comparison to those which could be captured from creating the more radical technical changes which have fomented agricultural growth in other tropical regions of the world.

Appendix

Land and Crop Residue Competition Models

TWO SIMPLE MODELS were devised to analyze the land competition between crops and livestock, and the competition among differing forms of crop residue management.

Land Competition Model

The model summarized in Tables A–1 and A–2 was used to analyze land competition between crops and animals on 100 hectares in monomodal rainfall zones with an annual rainfall of between 500 and 1,000 millimeters. Example calculations and results are in Table 5–9.

MODEL CHARACTERISTICS. The model is deterministic, and structural variables are fixed at average levels. It is not an optimizing economic model. Profits are not used to determine economically efficient levels of crop or livestock production.

The model has five blocks which calculate:

- Grain yield per hectare necessary to support a given population density.
- Land available for crop or livestock production.
- The possible feed supply given the land allocations to crops or to sources of livestock fodder.
- Feasible stocking rate given the supply of usable livestock fodder.
- Nitrogen balance implied by the supply variables (quantities of fallow land and manure) and the demand variable (nitrogen required to produce the necessary grain yield).

NECESSARY GRAIN YIELD. The model takes a given population density and base grain yield, and assuming a given grain consumption per person,

Table A–1. Parameters for Land Competition Model

Parameter	*Value*
Land use	
Population density (people per square kilometer)	100
Waste or nonagricultural land (as percent of total)	10
Implicit R-value (percent) [a]	40
Grain supply and demand	
Grain consumption (metric tons per head per year)	0.2
Total grain consumption (metric tons per year)	20
Necessary grain output (metric tons per hectare per year)	0.2
Livestock production	
Base feed intake (digestible dry matter as percent of liveweight)	2.5
Weight of 1 TLU [b] (metric tons)	0.25
Intake of digestible dry matter of 1 TLU per year (metric tons)	2.28
Feed supply	
Pasture yield (metric tons per hectare)	4.5
Pasture digestibility (percent)	45
Browse yield (metric tons per hectare)	1.2
Browse digestibility (percent)	40

a. The R-value (Ruthenberg 1983, p. 15) is the "number of years of cultivation multiplied by 100 and divided by the length of the cycle of land utilization."
b. Tropical livestock unit.
Source: Model constructed by the authors.

projects the amount of grain production necessary to satisfy that population.

LAND USE FOR CROPS OR LIVESTOCK. From the given grain yield per hectare and the total demand for grain, the model calculates the land necessary for grain production. It assumes that some land is waste or nonagricultural, and subtracts waste land and crop land in every month of the year from total land to calculate the land available for feed production.

FEED SUPPLY. The model multiplies the land available for animal production by pasture and browse yields to calculate the quantity of feed available from those sources. It then adds the quantity of crop residue

Table A–2. Crop Production and Manure Parameters

Parameter	*Value*
Pearl millet grain quality (percent)	
Dry matter content	90.0
N content	1.75
P content	0.50
K content	0.40
Pearl millet residue quality (percent)	
Dry matter content	50.0
N content	0.50
P content	0.25
K content	1.70
Manure quality (percent)	
Produced from feed intake	50.0
Dry matter content	30.0
N content	1.5
P content	0.5
K content	2.0

Source: Grain quality parameters are personal communication from Mark Powell of ILCA. Manure quality parameters are from Powell and Mohamed-Saleem (1987, pp. 270-272).

produced on the land in grain production to arrive at the total amount of available feed. The model weights the total amount of available feed by the digestibility of various feeds and by the fractions which animals typically refuse to calculate the total quantity of usable digestible feed.

FEASIBLE STOCKING RATE. The total usable digestible feed is divided by the monthly intake of one tropical livestock unit (TLU) to calculate the number of TLU which can be supported on 100 hectares. This is done for every month. The lowest monthly stocking rate calculated in that manner is defined as the minimum feasible stocking rate. That minimum feasible stocking rate is multiplied by the quantity of manure produced per TLU and by the nitrogen content of manure to calculate manure and nitrogen production.

NITROGEN BALANCE. The total supply of nitrogen available for crop production is equal to the nitrogen from manure plus that from fallow land. The nitrogen required to produce the necessary grain production is then compared to that supplied by manure and fallow. If the required nitrogen is less than that supplied by manure and fallow, then land competition between crops and livestock does not yet limit income from the two activities. If it is greater, then land competition is a limiting factor.

MODEL ITERATIONS. The model is recalculated several times at different population densities, rainfall amounts, and base grain yields.

Crop Residue Competition Model

A second model was used to analyze competition among different forms of crop residue management. Example calculations, results, and data sources are in Table 6–7.

CROP CHARACTERISTICS. One hectare of grain is the reference crop at each site. Grain and straw yields, crop components and their digestibility are estimated from ILCA studies by Gryseels and Anderson (1983) and von Kaufmann and Blench (n.d., for central Nigeria).

ANIMAL PRODUCTION. Cattle are the only species modeled in Niger and Nigeria. Cattle, draft oxen, and sheep are modeled in Ethiopia. Animals consume a mixed diet of pasture, browse, and crop residue. Typical herd structures and productivity were taken from published material, which includes age and sex structure, offtake rates, liveweights, milk production, and calving rates. Liveweight offtake, milk offtake (the difference between milk production and the calf's consumption), and manure production were calculated from the herd structure, productivity, and feed intake data. Liveweight and milk are valued at local market prices. The value of manure production was estimated via its impact on crop production. A value was assigned to animal draft power only in Ethiopia from a regression analysis of the grain production impact of draft oxen (Gryseels and others, 1987).

CROP RESIDUE DISAPPEARANCE. Fixed shares of each crop residue fraction are grazed or left in the field. All crop residue eaten is grazed in the field; none is removed for later feeding. From the crop residue data and the intake rate, annual crop residue intake is calculated. All crop residue not grazed is assumed to be incorporated into the soil.

ECONOMIC VALUE OF CROP RESIDUE. Market prices of crop residue were used where available and converted to equivalent digestible prices by dividing by the appropriate digestibility. Where market prices were not available, the value of residue in herd maintenance was used. This maintenance value is equal to the annual value of animal production divided by the annual consumption of crop residue. The annual value of animal production is the sum of the values of liveweight offtake, milk offtake, manure production, and draft power. If, for example, the annual value of animal production is US$500, and annual crop residue intake is 2 tons of digestible dry matter of which 50 percent is crop residue, then the maintenance value of 1 kilogram of digestible crop residue is US$0.25.

MANURE AND MULCH PRODUCTION. All indigestible crop residue fractions pass through the animal and produce manure at a specified rate. (The effect of crop residue grazing on manure quality is ignored). Each ton of manure produces an incremental grain yield at a specified rate, according to whether it is left on the soil surface (lower yield) or incorporated (higher yield). The grain yield is valued at the market price. Desiccated crop residue refused by grazing animals also produces an incremental grain yield when it is incorporated, and that yield is also valued at the market price of grain.

The estimates of the effects of manure and straw are derived from experiments reported by Jones (1971, 1976) for sorghum and maize at Samaru in northern Nigeria, Ganry and Bideau (1974) for pearl millet in Senegal, Pichot and others (1981) for sorghum in Burkina Faso, and Pichot and others (1974) for pearl millet in Niger. Estimates in Senegal and Niger for straw composted and plowed into pearl millet show a response of about 20 kilograms of grain per ton of compost. The Samaru estimate is 100 kilograms of maize grain per ton of incorporated residue.

PRODUCTION ALTERNATIVES. One production alternative is to graze all crop residue in the field and paddock animals there. The benefits from this alternative are the value of crop residue in animal production, and of manure from paddocked animals on crop yields. The costs are herding labor alone. Manure is simply left in the field so there is no labor cost of incorporation.

The second production alternative is that farmers can restrict crop residue grazing and restore some of the residue to the soil. The benefits are the contribution of crop residue to animal production, manure to crop yields, and the impact of crop residue on the subsequent crop yield. The costs are labor for herding and incorporating crop residue.

GROSS REVENUE. Total gross revenue is the sum of revenues from crop residue and manure use. Gross revenue from crop residue use in animal production is the quantity grazed multiplied by the market price or by the maintenance value. The manure produced by grazing animals from crop residue intake also produces revenue, which is calculated by estimating the grain yield effect of manure, and then valuing the yield at the market grain price. Gross revenue from residue use in crop production is calculated by estimating the incremental impact of crop residue application on grain yields, and then multiplying the incremental yield by the grain price.

COST OF PRODUCTION ALTERNATIVES. Herding labor is the only grazing cost. Labor is the only cost of spreading (less labor) or of incorporating (more labor) manure and crop residue. Labor for herding, crop residue management, and manure management is valued at the local daily wage.

NET REVENUE OF PRODUCTION ALTERNATIVES. Gross revenue minus cost is the net revenue of a production alternative.

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