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Working Paper

57

ENVIRONMENTAL CHANGE AND DRYLAND MANAGEMENT IN MACHAKOS DISTRICT, KENYA 1930-90

PROFILE OF TECHNOLOGICAL CHANGE

Michael Mortimore and Kate Wellard

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Michael Mortimore and Kate Wellard

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OVERSEAS DEVELOPMENT INSTITUTE
Regent's College
Inner Circle, Regent's Park
LONDON NW1 4NS

UNIVERSITY OF NAIROBI
P O Box 30197
Nairobi
Kenya

MINISTRY OF RECLAMATION AND DEVELOPMENT
OF ARID, SEMI-ARID AREAS AND WASTELANDS
Nairobi, Kenya

Preface and Acknowledgements

ODI Working Papers present in preliminary form work resulting from research undertaken under the auspices of the Institute.

This Working Paper is part of a study which aims to relate long term environmental change, population growth and technological change, and to identify the policies and institutions which are conducive to sustainable development. The first stage, published in these Working Papers, is to measure and assess as precisely as the evidence allows the changes that have occurred in the study area, the semi-arid Machakos District, Kenya, over a period of six decades. Degradation of its natural resources was evoking justifiable concern in the 1930s and 1940s. By several measures it is now in a more sustainable state, despite a five-fold increase in population. A long-term perspective is essential, since temporary factors, such as a run of poor rainfall years, can confuse analysis of change if only a few years are considered. The study is developing a methodology for incorporating historical, physical, social and economic data in an integrated assessment. The final report will include a synthesis and interpretation of the physical and social development path in Machakos, a consideration as to how far the lessons are relevant to other semi-arid environments, and recommendations on policies for sustainable economic growth.

The project is directed at ODI by Mary Tiffen, in association with Michael Mortimore, research associate, in co-operation with a team of scientists at the University of Nairobi, and with the assistance of the Ministry of Reclamation and Development of Arid, Semi-Arid Areas and Wastelands in Kenya. We are grateful to Professor Philip Mbithi, Vice-Chancellor of the University of Nairobi, for his support and advice. We also thank the Overseas Development Administration, the Rockefeller Foundation and the Environment Department of the World Bank for their financial support. Views expressed are those of the authors and do not necessarily reflect the views of ODI or supporting institutions. Comments are welcome, and should be sent directly to the authors or project leaders.

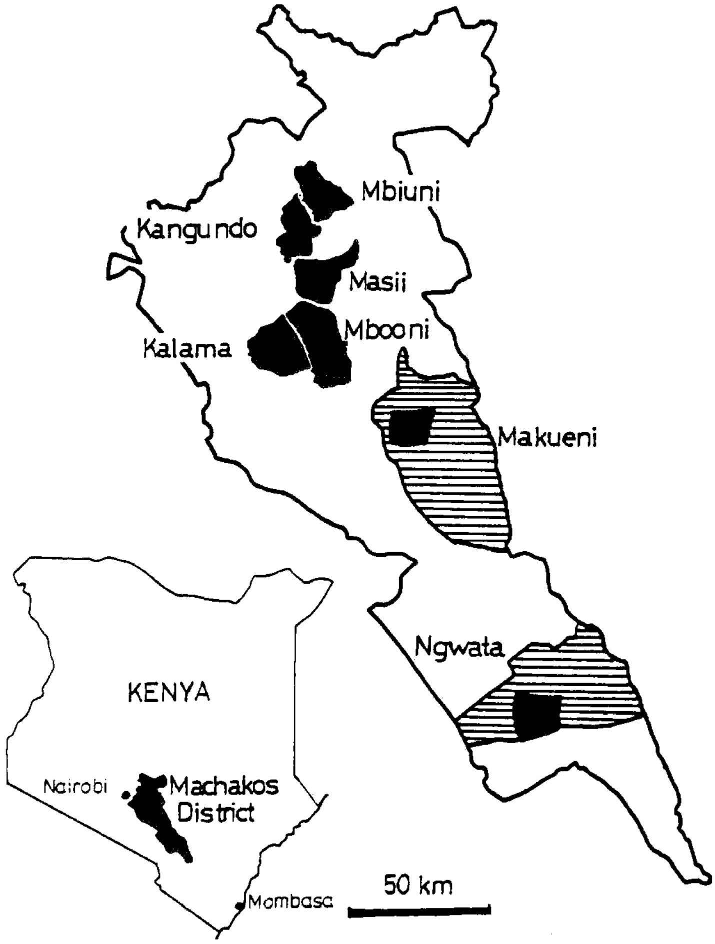
Other titles in this series are:

Machakos District: Environmental Profile
Machakos District: Population Profile
Machakos District: Production Profile
Machakos District: Conservation Profile
Machakos District: Land Use Profile
Machakos District: Institutional Profile
Machakos District: Farming and Incomes Systems

Michael Mortimore and Kate Wellard are the authors of this paper. Michael Mortimore is a Research Associate, and Kate Wellard a Research Fellow, of the Overseas Development Institute.

The authors wish to acknowledge a working contribution made to this paper by Dr F.N. Gichuki, University of Nairobi.

Preface Figure: Machakos District, Kenya, showing study locations
(In Makueni and Ngwata Locations, field studies were mostly within the areas shown black.)



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1. INTRODUCTION

In less than a century, Akamba farming systems moved from extensive cattle and goat rearing, accompanied by shifting cultivation with the digging stick, and having little integration of crops and livestock, to permanent terraced fields with ox-ploughing, intensive tree crops and horticulture, and relatively integrated crop and livestock enterprises. The land resource itself has been transformed from an apparently misused and rapidly degrading latent 'desert' into a partially capitalised, still productive, and appreciating asset.

According to Boserup (1965, 1981), endogenous technological change may be driven by population growth. That is to say, even in a system having no significant integration with the market, as the dependent population grows and agricultural land becomes scarce, intensification technologies that are already known tend to be applied on a wider scale, so that average output per hectare increases. Such a view of technological change implies that innovation adoption is an integral part of demographic and economic change and can only be understood in historical context. The present study covers six decades of dry land management in Machakos District, during which time the population grew by a factor of five. Land moved from abundance to scarcity and the supply of labour increased, not withstanding enhanced education and migration.

According to some modernization theorists, technological change is exogenous, that is to say, innovations originate from sources external to the system. Farmers are cast in the somewhat passive role of 'adopters' and differentiated by response - early or 'progressive', average, late or 'laggard'. Often, economic or technical incentives are seen as driving forces and socio-cultural factors as barriers or impediments. Therefore promotion or extension is necessary to speed up the rate of adoption. Such is implicit in views traditionally held in agricultural research and extension organisations.

Formal theories may not always pay much attention to the observable intricacies of decision making by small scale-farmers and livestock owners. Recent research, however, has re-emphasized the experimental and adaptive properties of smallholder resource management. There is increasing recognition of the value of their accumulated experience in managing specific agro-ecological environments. The reasons for their sceptical reception of some technologies, energetically promoted by external agents of change, are also better understood. Clearly, the influence of demographic and market variables, and the impact of promotion, on technological change are mediated by autonomous decision making at the levels of the community, household and individual.

The sources, promotion and diffusion of innovations are of interest to agencies of intervention, whether government or non-government. To accommodate the observable diversity of sources and modes of diffusion, Biggs (1989) has proposed a multiple source model, which provides an alternative to a centralised and hierarchical view of agricultural transformation as the outcome of government research institutions and extension services. It stresses that 'innovations come from anywhere in geographic space, from any research or extension institution, and from any instant in historical time' (ibid.:26). Such a model accommodates the possibility of endogenous change and a more active, even equal role for the farmer.

The dynamism of its production systems, and the number and diversity of technologies that have been tried (if not always widely adopted), indicate that Machakos provides an innovatory environment suitable for testing theories of technological change. The scope of this Paper includes those technologies that have been adopted in order to increase or sustain biological productivity or income generation. It is implicit in the analysis which follows that the technologies identified either were exogenous (introduced to the District during the period 1930-90), or endogenous (their adoption has significantly extended in the District during that time, though they were present at the beginning). This distinction we do not, however, consider to be important. Agriculture (and livestock husbandry) in Machakos during the last century has been dynamic. Whether a given technology originated inside or outside the District boundary is less important than its subsequent adoption, adaptation, and impact on the system. At the point of adoption, at the level of the production unit, and in terms of the experience of that unit, it was new. Thus we do not analyse here those technologies that, essentially unchanged, continue to play a part in the system of production.

In this profile of Technological Change our first objective is to inventory the range of new (exogenous) or extended (endogenous) technologies. This effort has revealed a remarkable diversity, perhaps attributable to special circumstances operating in Machakos. The second objective is to investigate selected technologies in greater depth. Target questions addressed to each are (1) its source, and pathway of diffusion, (2) its spatial distribution in relation to ecology, (3) its adoption according to users' evaluations, and (4) its economic costs and benefits. Our achievement of these targets, and especially (4), has necessarily been limited by the information available, since this study did not set out to collect new primary data. We construct a chronological framework of technological change, as far as our incomplete sources of information allow. Such an attempt is justified, since it is implicit in any evolutionary theory that timing is important. Premature innovations (that is, technologies promoted at a time when prevailing conditions of population, land and labour supply, and market access did not justify them) have been known to fail to disseminate.

The lessons that can be learnt from each of the production technologies selected are related to the driving forces of promotion, farmer experimentation, population growth and market penetration. The options of intensification and commercialisation - i.e., more food and/or more income from the same land resource - were always constrained by the fact that the substitutability of food production and income is strictly limited by an overriding priority to meet the subsistence needs of the household.

2. INVENTORY OF PRODUCTION TECHNOLOGIES

The literature on Machakos District documents a wealth of production technologies that in one way or another have contributed to the observable changes in primary production systems. An inventory of these technologies is offered in Table 1. Mention in the literature is no guarantor of their significance. Their importance varies, and there is no means of arriving at a ranking. The sources provide no internally compatible and comprehensive data on past or present levels of adoption (with a few exceptions); neither are the dates of first mention necessarily significant.

Table 1: **Inventory of production technologies**

1. CROPS

Field crops

1.1	Maize	-	Taboran
1.2		-	Katumani Synthetic II
1.3		-	Kitale hybrid 511/512
1.4		-	Katumani Composite B
1.5		-	Makueni Composite
1.6	Cotton		
1.7	Wheat		
1.8	Sisal		
1.9	Castor		
1.1	Sorghum, improved*		
1.11	Finger millet, improved*		
1.12	Pigeon pea, improved (NP 670)*		
1.13	Cowpea, improved (M66, K80)*		
1.14	Greengram, improved (N26)*		
1.15	Sunflower		
1.16	Beans, improved types*		
1.17	Sweetcorn		
1.18	Coriander seed		
1.19	Tobacco		
1.20	English/Irish potato		

Vegetables and fruit

1.21	Peppers chillies
1.22	French beans
1.23	Tomato, improved
1.24	Cabbage
1.25	Onion
1.26	Cucumber, courgette
1.27	Carrot
1.28	Egg plant (Brinjal)
1.29	Peas
1.30	Loofah
1.31	Karella
1.32	Pineapple
1.33	Pawpaw (Solo)
1.34	Spinach
1.35	Strawberries

Trees

1.36	Coffee
1.37	Citrus (Orange, Lemon, Tangerine, Lime, Grapefruit)
1.38	Avocado
1.39	Apple
1.40	Macadamia nut
1.41	Peach

2. TILLAGE

Tools

2.1	Victory mouldboard plough
2.2	Hindustan plough
2.3	Bukura multipurpose tool bar
2.4	Tractor plough
2.5	Forked jembe

Agronomy

2.6	Row planting
2.7	Ridging, tie-ridging
2.8	Dry planting
2.9	Irrigation
2.10	Pit planting

3. FERTILIZATION

3.1	Boma manure
3.2	Inorganic fertilizers
3.3	Composting
3.4	Residue incorporation
3.5	Rotations, including fallow
3.6	Agroforestry

4. CROP PROTECTION

4.1	Herbicides
4.2	Pesticides
4.3	Grain silos

5. LIVESTOCK

5.1	Grade or crossbred cattle
5.2	Grade or crossbred goats
5.3	Grade or crossbred sheep
5.4	Grade or exotic poultry
5.5	Dipping

6. FEEDING SYSTEMS

6.1	Pasture privatisation (enclosures)
6.2	Rotational grazing (paddocks)
6.3	Fodder production
6.4	Stall feeding or zero grazing

7. TRANSPORT

7.1	Ox-sledge
7.2	Ox-cart
7.3	Motor transport

* Available according to Muhammed, et al. (1985), but level of adoption not known.

Sources: Various, including for Section 1: Bottrall (1969); Muhammed et al. (1985); Gomez (1982); where (if in doubt) a crop or tree is excluded if it has a vernacular name, according to Gomez.

The technologies have been grouped into seven 'families', corresponding to major components of the production systems: crops, tillage, fertilization, crop protection, livestock, feeding systems and transport.

Given the information available, and the need to be selective, major technologies will be analysed from five 'families' only, excepting crop protection (4) and transport (7). From these technologies, enough can be distilled to discern the main lineaments of change over six decades.

3. CROPS

3.1. Katumani Composite B maize

3.1.1 Maize and food security

The analysis of cropping choices during the period 1930-90 takes place against the background of a long term shift from sorghum and millet to maize, among both the Akamba, and Kenyans at large. According to Peberdy (1958:250), maize became popular from the 1920s, when employees on European farms were paid partly in maize or maize flour. It is easy to grow, less susceptible to disease than sorghum, and requires less labour for bird scaring and threshing. Farmers today confirm that child labour for bird scaring is scarce, given the high priority placed on education. Maize involves the women in less grinding. Famine relief programmes, and commercial imports in drought years, reinforced the trend to maize (Owako, 1969:202-203). The decline in the supply of milk (milk was an important ingredient of sorghum and millet porridge), which accompanied the diminution of cattle holdings, may also have contributed to the preference for maize.

In 1930, maize was estimated to occupy 42% of the cropped area, and sorghum and the millets together, only 21% (Lynam, 1978:218). The latter figure declined to 10% in 1960 and 2% in 1970. But Ecosystems (1985, Vol.2:3.6, 3.35) reported that 3.6% of the cultivated area was under sorghum alone in 1985 (no millet was identified). Among farmers in five sampled villages in 1975 (Onchere, 1976:33), from 31% to 85% said that they grew sorghum. In 1979-80, 11% of a sample grew sorghum and 22% grew finger millet, though 66% and 43% had grown them before (Rukandema et al., 1981:33). They are, therefore, minor but still significant crops.

Low producer prices provide little incentive for the adoption of inputs. There has been no significant increase in fertilizer consumption over the last decade, and no upward trend in maize yields since 1975, in Kenya as a whole (Wyckoff, 1989).[1] The growth in domestic production has come (according to this argument) entirely from area expansion, both as maize substitutes for other crops and livestock, and as

[1] This argument does not appear substantiated in Machakos. See Production Profile.

migration to semi-arid areas occurs. The low yields and frequent failures encountered in marginal areas worsen food security, both locally and nationally. Maize breeding to minimise such losses should be both relevant and acceptable to farmers, if this thesis is correct.

3.1.2 Antecedents

It is mistaken to believe that until the release of Katumani maize varieties in the 1960s, the Akamba grew 'traditional' varieties. The crop itself is new, though how new it is not clear since maize was being sold to the Railway in 1902, a year before the arrival of the first European settlers. A few years later, in 1908, the Administration, in an effort to improve seed quality, which was seen, with low rainfall, as a cause of low yields, issued imported maize seed along with beans and groundnuts (Peberdy, 1958:2). From 1932 onwards, the Agricultural Department carried out trials on ten or more imported varieties, at least one of which was bulked up for sale in the District, on about ten Kenyan varieties, and hybrids. Only yellow maize offered improvements over local varieties, whose number, according to Peberdy (writing in 1958) was 'infinite', owing to importations in famine years, and farmers' own selections for hardiness over 10-20 years.

It seems certain that this experience of experimenting with new varieties of maize prepared the ground for the reception of the Katumani varieties after 1956.

3.1.3 The breeding challenge

The analysis of rainfall distribution offered in Section A of the Environmental Profile shows that in most of Machakos District (the hills excepted), the two main agroclimatic challenges posed to crop husbandry are the shortness of the growing seasons and the frequency of droughts. With regard to the growing season, the length of the long and the short rains in AEZ (Agro-Ecological Zone) 4 is 60-70 days and in AEZ 5/6, about 50 days. With regard to drought, only in the central hill areas (AEZ 2/3, with the highest parts of 4) can rainfall be expected to exceed 300 mm per season in 60% of years (Jaetzold and Schmidt, 1983). The pattern of rainfall reliability is similar in both the long and the short rains.

The breeding problem was to allocate priority to drought escape and drought resistance; it is difficult to meet both objectives in the same genotype. According to Fisher (1977), most drought-resistance mechanisms require some quiescence during dry spells, after which they can resume growth without permanent injury, whereas drought-escape mechanisms require rapid development to maturity. Shortness of season, therefore, calls for a crop that can develop quickly so that by the time the rains end, it has completed those developmental stages most sensitive to water stress. High probability of drought (including within-season drought) calls for a crop that yields well under drought conditions.

According to Mbithi (1967), the success of the Katumani varieties was due to a change in breeding strategy from selecting for drought resistance to selecting for drought escaping properties, or early maturity.

3.1.4 The Katumani varieties

The National Dryland Farming Research Station at Katumani was opened in 1956. In 1957, over 500 varieties were collected, and selected for earliness. The first improved variety released was Taboran (a member of the Mexican race Salvadoreno, imported from Tabora, Tanzania), which took 63 days to 50% silk, compared with 76-79 days for local Machakos White (Table 2).

Table 2: Maize varieties released from the Katumani breeding programme

Variety	*Year released*	*Days to 50% silk*	*Yield (tons/ha)*	*Remarks*
Machakos White	-	76-79	1.8-4.0	Late flowering
Taboran	1961	63	1.83	
Katumani				
Synthetic II	1963	65	2.66	
Composite A	1966	65	2.82	Colour problems
Composite B	1968	65	3.0-4.0	Good husk cover
Makueni Composite	1969 (?)	55	2.5-3.5	Outyields Katumani varieties at <250mm rainfall

Source: National Dryland Farming Research Station.

Katumani Synthetic II offered a substantial yield improvement in roughly the same maturation time. Further breeding eventually yielded Katumani Composite B (KCB), released in 1968. KCB takes 120 days to reach full physiological maturity at Katumani (AEZ 4), but only 100 days at Kampi ya Mawe (AEZ 5), where the mean annual temperature is 5°C higher (Nadar, 1984). Later, Makueni Composite was released for areas with less than 250 mm of seasonal rainfall.

3.1.5 Promotion

From 1963, the new maize varieties were actively promoted by the extension services, along with associated technologies, and in particular, early planting recommendations. A study of the adoption of the new maize varieties completed before the release of KCB (Mbithi, 1967) showed that in four villages, farmer adoption described a 'S' curve from less than 20% to more than 80% in only three years. It appeared to mirror the success of hybrid maize in western Kenya between 1963 and 1973 (MoA, 1980).

Multiple methods were used for promoting the new varieties:

> *The departments which were involved in the field extension campaigns were the District administration, the Agricultural Department, and Community Development. Agents were appointed by the Agriculture*

Department in co-operation with the administration; the Information Department got out publicity; and the chiefs were used to round up farmers for barazas. Initially, free seed for the first acre was issued. Farmers who wished to establish demonstration plots received also free fertilizer and free DDT dust.

After the initial enthusiasm waned, and it became necessary to extend the programme to the less co-operative farmers, the establishment and maintenance of demonstration plots became the yardstick for measuring agricultural staff effort (Mbithi, 1967:14).

Later, the emphasis shifted to demonstration plots. In 1965-66 a maize planting campaign was supported by loans in kind, but repayments were disappointing. Annual 'maize tours' took place to 'good' and 'bad' farmers. But in 1971, it was felt the messages were still getting through slowly, and extension efforts were focused on the 'unconverted' farmers. However the campaigns were not helped by seed shortages, nor by the refusal of the Maize and Produce Board to buy the maize!

3.1.6 Adoption

In the short rains of 1975, it was estimated that only 44% of the maize area was planted to Katumani varieties (Kenya National Archives: DoA File 154/Maize/II). Lynam (1978:177) reported that 89% of farmers in Makaveti, and 71% in Kampi ya Mawe and Kalawa, used them. In 1983-84, 79% of a sample of 211 farmers used KCB, though 93% knew it by name (Muhammed et al., 1985:34-36). But only 30 tons of seed were sold annually in the District. According to Carr (1989:75.6), the drought-escaping varieties have enjoyed limited acceptance because they are particularly sensitive to moisture stress under erratic rainfall distribution. In particular, silking is delayed until after pollen shedding, so 'there is little pollen available to fertilize the ova, which results in poor seed set'.

The rate of adoption also varies among the ecological zones. In AEZ 2/3, Kitale hybrid 511 or 512 maize is often preferred to KCB, having been bred for somewhat wetter and cooler conditions. The highest percentages of farmers using Katumani maize are found in AEZ 5, although Makueni Composite is better adapted to conditions there.

Katumani's policy of producing open-pollinated composites enables farmers to save seeds from their own harvests and sell to each other. Farmers tend to renew their composite seeds only after every third season, or a crop failure. For example, Onchere (1976:52) reported that 20% of his farmers had planted seed from the previous harvest - a practice that was not then recommended with the new varieties. Furthermore, there has been extensive on-farm crossing, so that the local varieties are now considered to contain some Katumani strains. The estimates just quoted therefore understate the real impact of Katumani varieties. By 1985, extension messages had adapted to local practice and recommended purchasing KCB every other year.

This low investment, low risk strategy is suitable for composite variety such as KCB because the frequent crop failures will lead to some fresh seed input regularly (Muhammed et al., 1985:36).

3.1.7 Farmer experimentation

There is some evidence (Onchere, 1976:52; Rukandema, 1981:18) that seed shortages deterred farmers from using Katumani varieties in some years. But at least as important a reason for the incomplete adoption of KCB is farmer ambivalence, rooted in on-farm evaluation of the performance of local and improved varieties under conditions of uncertain rainfall. Before the release of KCB, it was apparent that while Katumani maize gave higher yields when the rains were poor, local varieties could outyield it when the seasonal rainfall exceeded 300 mm (de Wilde et al., 1967:101). Some 33% of Rukandema's farmers, and from 35% to 60% of Onchere's, believed that local varieties are as good. In 1983-84, 80% of KCB users gave early maturity as a reason for adoption, and only 25% gave high yield (Muhammed et al., 1985:36). This ambivalence is perhaps surprising in view of optimistic estimates of expected income improvements from the use of the new technology by Heyer (1967) and Lynam (1978) - by 50% on farms of 3 ha and by 70% on farms of 5 ha in AEZ 4.[2]

Group and farmer interviews conducted in five locations in 1990 throw some light on user rationales. In Mbooni (AEZ 3), KCB is grown along with a quick maturity type known as Kangundo (obtained since 1978, from Kangundo) that outyields it, though KCB does better in drought. In Kangundo, one local variety (Kinyalili) has been dropped owing to its purple coloured seeds (Kenyans' aversion to non-white maize is well known), but another local variety, Mulaba, is still used. In Masii (AEZ 4), KCB maize is preferred owing to its drought-escaping properties. In Makueni (AEZ 4/5), during the 1940s and 1950s, settlers tried out various seeds available to them, including a yellow variety (probably imported as food aid: it proved inferior to local white). Early adoption of Taboran maize was a logical response to rainfall conditions there. Later, KCB was adopted in its place, but some have reverted to the older type because KCB is more susceptible to weevil damage. Local varieties, however, are still in use. In Ngwata (AEZ 5), KCB is grown along with Kinanyana, a local variety, and (surprisingly) Kitale 512. Of 40 farmers interviewed in the five locations, only a third used Katumani varieties exclusively (sometimes more than one), whilst another third planted Katumani along with local or hybrid varieties, and a third were not using Katumani seed at all. It is unlikely that cost was deterring them.

Farmers' experimentation is not confined to evaluating alternative varieties, but extends to adaptive selection and crossing. One woman farmer explained how she planted KCB and her local seeds in blocks - with Katumani on the windward side - so that cross-pollination would occur. She then selected the best cobs from the middle to use as improved seed stock, retaining the seed from the outer lines to repeat

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2 According to Lynam (p.175-6), KCB permitted the growth of the population in AEZ 4 and induced accelerated migration into AEZ 5.

the cross the following year. The crossed seeds, she claimed, were both earlier maturing than the local seeds, and higher yielding than KCB. Some farmers have been formally involved in the maize breeding programme, through hosting on-farm trials and in providing varieties for testing. Selected seeds from a farmer's Mwalavu variety, for example, proved to have better cob placement (higher and less susceptible to pest damage) and similar yield potential to KCB, although maturing five days later (Kasewa, personal communication).

3.1.8 Lessons from the Katumani maize story

The crucial question with regard to KCB maize is whether it has improved food security by increasing the reliability of yields in below average seasons. Experimental results appear to suggest such a conclusion, but representative farm level data are lacking. Relevant for its bearing on the question is the nearly universal preference of farmers for mixed strategies, combining improved with local varieties. This suggests that something less than a 'green revolution' is occurring. Carr (1989:75-77) argues that farmers used a drought-tolerant, rather than drought-escaping variety, and moreover, one that yields well if planted late, owing to the labour constraint that usually ensures only a small proportion of farmers' fields can be planted early.

It cannot be known with any certainty what percentage of farmers use KCB, how much of the maize area is planted with it, or what proportion of total output it contributes. What is known is that its adoption is incomplete, and is likely to remain so. From a 'green revolution' standpoint, such an outcome appears to qualify the success of the breeding programme. But from the standpoint of the goals of small farmers, it is a measure of some success, for three reasons.

(a) The observed levels of adoption, sustained over two decades, show that KCB is perceived to contribute positively to meeting the primary objective of smallholder agriculture, namely securing household subsistence by maximising yields under the constraint of a variable semi-arid rainfall regime.

(b) KCB strengthens, rather than undermines the flexibility or adaptive choice that is essential for coping with such a regime and with the range of micro-environments found in the District. That is to say, it extends rather than replaces the menu options.

(c) Its open pollinating characteristic is consistent with smallholder experimentation, which is a major resource of the farming system, and releases the farmer from total dependence on external sources of seed.

In the Production Profile, evidence is presented that food security has improved, notwithstanding an increase in the population, and migration into agroclimatically riskier areas, though large-scale imports are still necessary after prolonged drought. The view that low yields and frequent failures, resulting from extending maize cultivation into drier zones, threaten food security, might predict a 'green revolution' into KCB. Such has not occurred. The manner of its adoption into a cropping system characterised by varietal diversity, strategic flexibility, and adaptive experimentation, though perhaps unexpected, suggests that the system is less vulnerable than had been supposed.

During the 1980s, breeding policy at Katumani aimed to improve yield without sacrificing earliness and adaptability (MoA, 1983:10). Breeding for the best phenological match between plant development and expected rainfall distribution (Nadar, 1984) has been relatively successful. Keating et al. (1990) conclude that there is little to be gained from further breeding for altered phenology at Katumani (AEZ 4), and only very modest gains at Makindu (AEZ 5). They argue that improving nitrogen supply should be the next major target for research.

3.2 Cotton

3.2.1 The search for a lowland market crop

Some Akamba farmers were selling maize, bananas, sweet potatoes, beans, sugar, tobacco, millet, *mtama*, and *wimbi* to the Railway in 1902, and in 1912 the District Commissioner reported an increase in the area of cash crops (Peberdy, 1958:2,4). The Administration was promoting the cultivating of cash crops long before the posting of the first agricultural officer (AO) to the District in 1932. The problem, as always perceived, was to find suitable crops: for the cooler, wetter hills (zones 2/3), and for the hotter, drier lowlands (zones 4 and 5). Coffee and cotton, respectively, eventually emerged as officially preferred candidates, the first after European farmers' opposition to African cultivation had been overcome, and the second after the failure of sisal.

Cotton replaced sisal in government policy for the lowlands. Sisal 'used to be the lifeline of the dry areas' (Mbithi, 1967:7) when the price was high in the early 1950s. It was grown as a hedge plant on farms, and officially encouraged as a slope stabiliser. It was decorticated by hand or at a factory in Machakos. Falling prices forced the factory to close in the 1960s. At 25 cts/lb, washing and decorticating at home were uneconomic labour for the women (*ibid*).

3.2.2 The promotion of cotton

The first government proposal to grow cotton in the District was made in 1926, but was not followed up because its production would have needed supervision by government staff, who were not available. Its effective introduction took place in 1933 (Peberdy, 1958:230-3). According to Peberdy, the cotton programme was started at the wish of the Administration in order to provide cash incomes in an area prone to famine. After fairly successful experiments, commercial planting of 800 ha took place in a crescent of locations, extending from Mukaa through Nzaui to Kibauni - all on the dry fringes of the hills in AEZ 4 except for Kibauni, which is more marginal, and was dropped later owing to fears of soil erosion. Planting in the short rains was preferred because they were considered more reliable. Nevertheless, large-scale failures occurred in 1936, 1937 and (on the trial plots) in 1940. In 1941, therefore, the effort was abandoned, output and yields having fallen from 262,000 bags (grown on about 1,200 ha) in 1937 to 88,000 (on 800 ha) in 1941. A ginnery was provided at Nzui (in Nzaui Location) in 1938. But low prices (10 cts/lb for Grade A), the long growing season (spanning both rains), stainer infestation, and drought seem to have demoralised the producers: 'the people did not like the crop and therefore never tended it properly; they had to be goaded to harvest it and even then nearly a fifth of the crop was still left on the shambas, they always prepared their land late' (Peberdy, 1958:231). Quality declined, and cotton 'died a natural death' (Mbithi, 1967:11), while sisal took its place in official preference.

It was reintroduced in 1960, with energetic promotion by the administration, and the cultivated area expanded quickly to about 1,500 ha, though yields were rather low (at 400 kg/ha) and nearly half the cotton harvested was second grade (according to de Wilde et al., 1967:109). But official statistics (see Production Profile) show far lower yields - 220 kg/ha or less - and both the area under cultivation, and output, fluctuated widely from year to year. There was a peak of 1,900 tons from 11,000 ha in 1966. Cultivation was concentrated, as before, in the southern settled fringe of the Reserve, and in the newly settled areas, where relatively large amounts of land were available, and the entrepreneurial drive of the Makueni settlers could be directed into its production (Owako,1969:263). The Government opened a ginnery at Makueni.

Coercion nearly killed cotton a second time, according to Mbithi (1967). In order to improve supervision, in the interest of quality, cotton blocks were advocated in place of individually farmed plots (of 0.3-1.0 acre). Contract ploughing, weeding, and spraying were financed by loans to the farmers. An obligatory crop of green grams or Mexican beans had to precede the cotton on newly cleared land. The Marketing Board made deductions from both crops to repay the loans. But farmers planted food crops instead of the obligatory pulses, and the Board could not recover its loans. Droughts decimated the cotton crops. Farmers defaulted, or were forced to continue growing cotton to escape from ever-increasing debts. Chiefs used all sorts of tactics to increase its cultivation, including (in one location) withholding famine relief unless cotton was planted by beneficiaries (Owako, 1969:268).

After 1976, cotton entered its third period of expansion, output averaging 5,000 tons from 1977 to 1984. A new priority was given by the Machakos Integrated Development Plan (MIDP) to revitalising cotton cooperatives, input delivery, and marketing from 1979 (ODI, 1982). According to MOA annual reports, the cotton area increased from 1,137 ha in 1974 to 7,848 in 1977, 27,387 in 1981 and 30,175 in 1983 (ADEC, 1986:Table 4.21). (These figures may be compared with 1,200 ha and 11,000 ha claimed for the peak years - 1937 and 1966 - of the first and second periods of expansion).[3] But after peaking at 7,600 tons in 1985, output collapsed to 1,400 tons in 1987. It must be assumed that the cropped area fell accordingly. In 1990, cotton was considered to be a diminishing but important source of income in Masii,

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[3] Doubt is cast on the figures, but not the trend, by a lower estimate of 5,976 ha under cotton in 1981 by Ecosystems; however this estimate uses a different method. (See Ecosystems, 1982; 1985, vol.4:2.11). Ecosystems recorded an increase to 15,000 ha in 1985 - an increase of 23% per year.

Makueni, and Ngwata (AEZ 4 and 5) among the interview locations, but not so in Mbooni and Kangundo (AEZ 2/3).

3.2.3 Factors affecting adoption

The factors affecting farmers' adoption of cotton include ecology, labour and input costs, financial returns, and marketing.

Cotton is agro-ecologically suited to AEZ 4 where land was not considered to be scarce until recently. The distribution of cotton acreages in 1966-67 - in the second period of expansion - reflected this (Owako, 1969:264). Subsequently, cultivation increased in the newly settled areas.

With regard to labour, cotton competed directly with maize, (Heyer, 1966:135; Owako, 1969:263-5). Early planting is required for both crops. Cotton is planted in the short rains and harvested after the succeeding long rains. Maize is grown in both seasons. Given adequate manuring, cotton planting took 15 man-days per acre; without manuring, only three. The priority usually given to the subsistence crop led to cotton being planted late. Cotton also requires replanting, and at least two thinning and weeding operations early in the season. The labour required for picking and grading is even more, but extends for a longer period at the end of the long rains.

With the prevailing prices of the 1960s, average returns from food crops in dry zones might be almost double those from cotton, at 50 Ksh/acre. (Our estimates from District production and sales data for 1961-66 in Owako (1969:261-262); and see Heyer, 1967: Table 8). In 1977-78, returns to labour (net of purchased inputs) ranged from 200 Ksh/acre in AEZ 4 and 5 to 440 Ksh/acre in AEZ 3, still half those from maize and sorghum (Consortium; Hash and Mbatha, 1978: Appx.I). By 1982, the value of cotton production per acre had risen to 830 Ksh, but with labour requirements of over 250 man-days, and fairly costly chemical inputs (especially sprays), this represented returns to labour of only 255 Ksh/year. This figure was still less than that from food crops, at local market prices (Neunhauser et al., 1983). These consistently low returns from cotton were accentuated by lower than average yields or quality, caused by droughts, pests, diseases or labour shortages.

Marketing problems have dogged the cotton industry. In the 1960s, farmers often had to carry the cotton long distances to buying centres, and agents might fail to report on appointed days. Crops deteriorated in storage, attracting lower grade prices or even being refused by the agents (Owako, 1969:266). The Machakos Cooperative Union started buying cotton in 1976, but had no control over storage and transport operations, so heavy losses were made in the first five years (ODI, 1982). In 1981, with an interest-free loan from the MIDP for transport and radio equipment, collection time was reduced from seven to four months, and the Union made a profit of Ksh 1 million. But from the mid-1980s, a trend towards late payments from the Marketing Board to the Union (up to six months' delay or more) caused farmers first to neglect their crops and then, in increasing numbers, to abandon cotton altogether (ADEC, 1986). Interviews in 1990 indicated that many farmers have abandoned cotton owing to late payments, though the high cost or scarcity of sprays, and labour costs, are also influential. The Makueni ginnery was closed owing to losses. Low profitability and marketing difficulties may yet bring the third chapter of Machakos cotton to an end.

3.2.4 Lessons from the cotton story

Notwithstanding reservations expressed by Peberdy (1958:231), who thought that cotton is risky, and should take second place to food crops, the later experience with cotton shows that farmers in AEZ 4 and 5 have been willing to incorporate into their farming systems a technology (crop) that, however suitable for drier environments, has many drawbacks. These drawbacks include (1) the input costs, (2) labour competition with food crops, (3) low financial returns and (4) marketing difficulties.

Consequently, not withstanding its agro-ecological potential, the production of cotton has lurched through three phases of expansion and decline since the 1930s. Cultivation was driven, in the early days, partly by political pressure, and more recently, perhaps, by a lack of alternative incomes.

Cotton competes with the food crops for the factors of production, and labour in particular. Therefore it will continue to be given a low priority, in order not to increase the riskiness of subsistence production. A low priority means inefficient production at low financial returns per hectare. Low returns serve to further marginalise a crop already affected by price changes and marketing inefficiencies. The minimisation of these remains the best policy option. However, it can be argued, with as much validity in the 1990s as in the 1930s, that the production and storage of grain would be less oblique to the attainment of food sufficiency.

3.3 Coffee

3.3.1 The growth of coffee production

In contrast to cotton, coffee is a high value crop suited to AEZ 2/3, between 1,500 and 2,000 m, with an average annual rainfall of 750 mm or more and dark, friable soils with good moisture retention. Some Akamba were employed on European coffee farms and had learnt to grow the crop, but in 1938, the Government expressly forbade native coffee growing in order to protect European producers' interests. This policy was eventually reversed, in response to persistent and organised pressure from farmers.

In 1947, the councillor for Kangundo, with others, attended a meeting in Machakos to negotiate for coffee, after which elders were selected to go to Chagga in Tanzania to see African coffee farms (personal communication, former Councillor, Mr. Thiaka). In 1950, coffee trials were set up on bench terraces at Ngelani, the Government farm, and farmers requesting permission to plant were told to await their outcome; the trials were extended to Kangundo and Matungulu in 1952; training of agricultural instructors was begun; and demonstration plots were set up in 1953. In 1954 farmers were allowed to plant for the first time. Influential in the reversal of government policy was the realisation that coffee was a suitable component of rehabilitation programmes, being both profitable, and consistent with conservation objectives (T. Hughes-Rice, 1951: Kenya National Archives: Machakos Coffee File).

Planting was at first confined to selected areas in Kangundo and Matungulu Locations, extending to Mbooni in 1955, to Iveti and Mitaboni in 1956, and to Kilungu in 1957. By the end of that year, there were 1,824 growers in the District with 144 ha planted (Peberdy, 1958:204). Six years later, at independence, there were over 17,000 growers with 2,668 ha planted (Owako, 1969:256). Coffee farms were small - 99% were less than 1.6 ha and 90% were less than 0.8 ha in size, (*ibid*:249).

The Department of Agriculture regulated planting, production and processing closely, under the Coffee Rules. Nurseries provided seedlings for planting in the short rains. Planters had to belong to cooperatives; all coffee had to be grown on terraces; and standards were enforced by the inspectors, with regard to spacing, manuring, mulching, pruning and windbreaks (Peberdy, 1958:222-223). Grading was carried out at the factories, where the first coffee was pulped in 1959. Loan capital for the factories was raised by the cooperatives themselves.

Close supervision of both cultural methods and processing achieved higher grades, on average, than coffee from any other district; but after 1960, under political pressure, the Department of Agriculture transferred primary responsibility to the growers' cooperatives, and the proportion of coffee in the first three grades fell from 75% in 1959 to 34% in 1962, though it recovered to 55% in 1962-65 (de Wilde et al.,1967:105; Owako, 1969:252). Producers were paid a flat rate, irrespective of grade, but the cooperatives were paid by grade. This was a disincentive to producer quality, but forced loss-making cooperatives eventually to improve supervision.

According to Owako (1969:249), notwithstanding the International Coffee Agreement of 1963 which led to a ban on additional plantings, with Independence there was some relaxation of the Coffee Rules' enforcement and an increase in 'illegal' planting (unauthorised by the Agricultural Department). The coffee boom continued till the 1980s (see Production Profile); official statistics claim an increase in the planted area after 1974 to 14,000 ha in 1982, stabilising thereafter. Ecosystems (1985, Vol.4) however reported a decline in the area of smallholder coffee from 1981 to 1985 at a rate equivalent to 4.3% per year.

3.3.2 Factors affecting the adoption of coffee

Estimates of the potential coffee area in the District vary between 24,000 and 40,000 ha (Peberdy, 1958:219; Owako, 1969:248). Only 11% of the lower figure had been planted by 1965 (Owako, 1969:247). Agro-ecological conditions were not, therefore, limiting, in AEZ 2/3. In 1975, however, 90% - 100% of the farmers in three villages in northern Machakos were growing coffee (Onchere, 1976:33).

The labour and other input requirements of coffee are considerable, and conflict with the needs of food crops (Owako, 1969:250f). Planted, according to the Rules, in deep manured holes, the bushes had to be regularly weeded or yield was forfeited. Pruning, picking and drying, and crop protection required labour during the growing season of the food crops. Labour hiring and input purchases increased the costs of production. The plants' need for land, manure and mulches competed directly with other crops. Such competition set limits to the coffee area per holding.

However, returns to coffee were high until recently. Revenue was estimated to be about 850 Ksh/acre (for 240 days' work) in 1962-64 (Owako, 1969:251 note 21, 256). This may be compared with estimated returns of 150 Ksh/acre (per labour unit/year) for food crops (Heyer, 1966:135; 1967:7-14). The estimate for coffee ignores establishment costs and purchased inputs, however, and assumes full production (fifth year from planting). In the mid-1970s, the average coffee grower still earned about 850 Ksh/acre/season (Onchere, 1976:38-39), though maize prices had risen four-fold in the decade.

3.3.3 Decline

A declining trend was observed after 1980 (ADEC, 1986:4-39; Ecosystems, 1985, vol.4:2-11). Although poor rainfall took the blame in some years, many farmers were neglecting husbandry practices. In 1990, according to interviews, coffee producers in AEZ 3 remained heavily committed to the crop. But the recent decline in world prices has been quickly passed on to the producers, some of whom now threaten to abandon coffee. Lower producer prices are partly attributable to the high costs of Kenya's processing and marketing infrastructure. Abandoned or neglected coffee is reported to be common in some areas. Farmers are not allowed to uproot their coffee and this, together with its establishment costs, deters farmers from transferring land to other crops. However, land is extremely scarce in the coffee growing locations, and there are reports of uprooting.

Already in the 1960s it was apparent that the practice of paying producers a flat rate, regardless of quality, provided little incentive for good husbandry. Grading was done after the coffee left the factory and it was the cooperative that benefitted. Under conditions of buoyant prices, and dynamic leadership, such benefits might be passed on to the wider community in various ways. Under falling prices and indifferent leadership, producer demoralisation seems inevitable. Delayed payments from the Board, which is short of cash, to the cooperatives have added to the producers' difficulties. Cooperative factories are working below capacity. In such conditions, large-scale producers are more strongly placed than smallholders, however numerous.

3.3.4 Lessons from the coffee story

(a) Coffee shows how demanding standards of husbandry, and requirements for inputs (especially labour), need not deter the popularity of a profitable crop (in terms of the percentage of farmers adopting it in potential coffee zones).

(b) Smallholder coffee producers were unable (or unwilling) to specialise in coffee, and notwithstanding its comparative advantage in the higher potential areas, it shares land, labour and capital resources with food crops, other cash crops, and livestock. This is consistent with the multiple objectives of the farming system.

(c) Finally, it shows that marketing structures must maximise producer incentives, even under conditions of high prices : for it appears that declining standards of husbandry from 1963, which were related to the flat rate of payment, sowed the seeds of future depression when the world price fell. Now it has become clear that Kenya's ornate marketing system can no longer be supported by the crop.

3.4 Horticulture and Fruit

3.4.1 Origins

Given Kenya's export oriented farming sector, strongly developed urban market, and technical resources it is not surprising that interest developed early in marketing perennial and annual fruit and vegetables.

Travelling Akamba have brought back seeds and seedlings from Kikuyu country. Small-scale, intensive production of hand-cultivated fruit and vegetables is well suited to some micro-environments found in the hill areas of Machakos, and the Northern part of the District was well within reach of the Nairobi market. Strawberries, introduced by the African Inland Mission to Mbooni, and Egyptian onions were popular in 1935 (Peberdy, 1958:14). Pineapples were first introduced about 1930, but grown in commercial quantities from 1952 using imported suckers (Peberdy, 1958:26, 235, 247). Missions introduced the mango to parts of Mbiuni as recently as the 1950s (Gielen, 1982:37). According to our informants, missionaries and Asian traders were active in introducing horticultural crops to Kangundo. Coriander, first recorded as a District export in 1943 (Peberdy, 1958:229), and cited by our informants as a significant market crop in several drier areas in the 1940s, may have been introduced and bought by Asians. Other Asian vegetables were introduced in the same way. The method continues to be used; for example, with French beans and spinach.

3.4.2 Promotion

Agricultural officers stationed in the District had few resources to direct into the multi-faceted fruit and horticulture sector, but there was a seed farm at Machakos, and at the horticultural section of Ngelani farm in Kangundo; variety trials on 22 fruits and nuts and 16 vegetables were in hand or planned in 1959 (Peberdy, 1961). The fragmentation of the sector - in terms of crop varieties, markets, techniques and locations - imparted a completely different character to research and extension efforts. Among 22 vegetables tried successfully in the District by 1958 (Peberdy, 1958:187, 283-287), the most valuable (per acre) were egg plant, onions, cucumbers, English potatoes, lettuce and tomatoes. All could be grown twice yearly, which made them attractive to farmers.

The Agricultural Department's interest in the promotion of horticulture led to the appointment of a horticultural crops officer in the District, and the incorporation of vegetable fruit crops in the District Development Plan for 1969-74, though some of the planning targets were criticised as arbitrary in a government report (Bottrall, 1969). The Department was active in seeking market outlets. Its activity has diminished in recent years - or there is less evidence of it - and in nursery provision for fruit tree growers, it has not been effective. Some 11 ministry nurseries were supplying seedlings to a mere 3% of farmers sampled in 1986, and all of them ran at a loss, notwithstanding a strong demand for seedlings (ADEC,1986). This demand was being met by private sector nurseries.

3.4.3 Adoption

There are two ways of measuring the adoption of fruit trees: the percentage of households growing, and the average numbers per household, or per growing household. The early popularity of fruit trees is shown by some estimates of their numbers in four AEZ 3/4 locations in the southern hills (Kilungu, Kalama, Mukaa and Okia) in 1959 (Table 3). The average numbers per household (growing and nongrowing), computed from the 1962 Census, are shown in the second column. They add up to 4 fruit trees per household. These estimates were arrived at after several months' work by an agricultural officer and were thought to 'act as a good guide and as a basis for future workings'.

Table 3: Fruit trees inventory, Kilungu area, 1959

	Number	*Per household*
Mango	11,700	1.0
Oranges	9,600	0.8
Pawpaw	6,046	0.5
Lemons	5,368	0.5
Pineapple	4,595	0.4
Guava	3,395	0.3
Loquat	2,859	0.2
Custard apple	1,624	0.1
Apple	1,213	0.1
Pomegranate	629	0.1
Fig	349	<0.1
Limes	266	<0.1
Peach	251	<0.1
Passion fruit	201	<0.1
Avocado	185	<0.1
Grapefruit	147	<0.1
Mulberry	143	<0.1
Tangerine	133	<0.1
Plum	48	<0.1

Numbers per household: the population of 104,133 in 1962 is divided by 9 (the average size of household according to interviews) to estimate the number of households (see Institutional Profile)

Source: Kenya National Archives: DoA Kilome HORT/1/20 (29 September 1959)

Village surveys carried out in Northern Machakos in 1974 and 1981 provide data on the adoption of fruit trees by household (Tables 4 and 5). The first column of Table 5 is comparable to the household estimates in Table 3. Very considerable increases in the overall number of fruit trees per household are implied, even though the Kilungu survey omitted bananas (the most popular). Since both sets of villages included a range from AEZ 2/3 to AEZ 5, the differences cannot be put down to ecology.

Table 4: Percentage of households growing fruit trees

	Mbiuni, 1981[a]	*Northern areas, 1975*[b]	
	AEZ 3,4,5	*AEZ 3*	*AEZ 4*
Banana	69	89	35
Mango	62	70	66
Pawpaw	51	57	50
Citrus	53	47	22
Macadamia	nr	53	4
Guava	33	20	12
Passion fruit	2	28	2
Mulberry	5	nr	nr
Custard apple	4	nr	nr
Cashew nut	2	nr	nr
Loquat	nr	7	0
Apple	nr	4	0

Notes: (a) Gielen, 1982:33
(b) Onchere, 1976:33, 40, 43
nr: not reported

Table 5: Numbers of fruit trees per household

	Mbiuni, 1981[a]		*Northern areas, 1975*[b]	
	AEZ 3,4,5		*AEZ 3*	*AEZ 4*
	No. per household	*No. per growing household*	*No. per growing household*	
Banana	25	25	25	5
Mango	4	4	3	2
Pawpaw	4	4	5	2
Citrus	3	4	16	4
Guava	0.8	3	3	2
Macadamia	nr	nr	7	1
Passion fruit	nr	nr	3	1

Notes: (a) Gielen, 1982: 35-41
(b) Onchere, 1976: 33, 40, 43
nr not reported

Ecosystems (1985, vol.4:Table 2.15) reported that in the District as a whole, the number of fruit trees increased at a rate of 8.6% per year from 1981 to 1985 - notwithstanding a major drought. Only Makueni and Kibwezi Divisions had no increase. A rapid expansion of citrus planting was also reported by ADEC after 1980 (1986:5.5), and also of mango and pawpaw. This expansion is confirmed by interviews held in 1990, and is especially noticeable in AEZ 4. In three villages in Mbiuni Location, 86% of the households grew at least one fruit tree in 1981, though 71% grew less than five (Gielen, 1982:32).

The multiple source nature of innovation is well illustrated in the case of oranges. The Chief of Kiteta location was given some Washington Navel stock about 1950, according to one informant by an agricultural officer. He also acquired the craft of budding, according to other informants from South Africa. He established a nursery and appears to have acted as a centre for the diffusion of the technique; even in 1985 Kiteta was said to be the centre of citrus growing (ADEC, 1986). The first grower of oranges on a commercial scale in Makueni, who planted them in 1972, told us she had gone to Kiteta to learn grafting from the Chief there. Other farmers in Makueni learnt from her success.

The information available on the adoption of vegetable crops is inadequate. Table 6 is illustrative, though possibly incomplete, for 1975. It is believed that the percentage of growing households is now large in AEZ 3, especially in the north, but plots are nearly always small, indicating a low level of specialization, relatively high returns per hectare, and high inputs. Ecosystems (1985, vol.4:2-15) reported average annual increases (from 1981 to 1985) of 35% in irrigated smallholder vegetables and 19% in vegetable gardens and other small plots. These figures confirm that a move into horticulture was occurring on a very significant scale, though these two categories comprised only 1% of the cultivated land in the District.

Table 6: Percentage of households growing vegetables in 5 northern Machakos villages, 1975

Crop	*3 villages, AEZ 3*			*2 villages, AEZ 4*	
Cabbage	67	50	11	0	0
Onion	13	35	4	4	0
Pepper	13	10	0	0	0
Potato (Irish)	60	40	46	4	3
Tomatoes	73	70	15	0	0

Source: Onchere 1976: 33, 40, 43.

3.4.4 Irrigation

Irrigation permits some vegetable crops (and fruit) to be marketed in the dry seasons when there is no glut. Horticultural production, though not originally for the external market, may have been the driving force behind several intricate, hand constructed spring diversion systems in the hills, a technology that is said to go back 200 years, and which may still be observed.

Three minor irrigation schemes were considered for further development by the Department of Agriculture in 1968 (Kenya National Archives: DoA CROP/2/11/235, 9 February, 1968). At one of these - Kyuu Irrigation Scheme in Mbooni - nearly 80% of the District's annual output of 600 tons of tomatoes were grown; at Matuu, a scheme begun in 1967 to use water from the Yatta furrow, 50 ha were planted to irrigated vegetables by 1969 (Bottrall, 1969); the third scheme was at Kyai. Excellent prospects were considered to exist for expanding tomato, onion, and also passion fruit, citrus and banana production for the urban market and the canning industry. There have been no major irrigated developments since.

The Yatta furrow was originally constructed to support grazing in an area where permanent settlement was forbidden. In 1967 a 50 ha smallholder irrigation scheme was constructed at Matuu. Local settlers applied for land, and were organised into intake groups sharing the water for a block. Pump driven sprinklers proved uneconomic, but gravity fed irrigation, first under close DoA supervision, but recently largely self-regulated, continues to support a prosperous enclave of market gardening. Fruit - mango, pawpaw and banana, vegetables - tomatoes, onions, karella, and field crops - maize, cotton - are grown mixed, or in rotations, at the discretion of individual producers.

3.4.5 Outgrower contracts

Outgrower contracts with Kenya Orchards and Kenya Canners (at Ngelani and Thika respectively) were influential in developing horticultural and fruit production. Peberdy (1958:237) believed that Kenya Orchards' buying activities in the 1930s were responsible for thousands of rough lemons found throughout the District. In the period 1959-62, the canners bought on average £9,000 worth of District exports of fruit and vegetables (de Wilde et al., 1967:104-5), and provided seed and advice. Price fluctuations and low grade produce (owing to careless growing, picking or grading) were problems. Fruit that are on record as having been purchased by the canners include: strawberries, cape gooseberries, lemons, Seville oranges, plums (from European farms), peaches, figs, passion fruit, guavas and pineapples. The vegetables include green, haricot and French beans, sweetcorn, carrots and tomatoes.

During the Swynnerton plan period, the Agricultural Department, Settlement Board officers, and the canners worked together to get some of these schemes off the ground, formulating policies for contracts and cooperatives to regulate relations between the producers and the canners, promoting cash crops for the new settlement scheme on the Mua Hills, and no doubt helping to secure reliable supplies for the canners. Contract arrangements have not always worked to the advantage of the producers, and prices have often been low in relation to the labour and other inputs required (for a recent example, sweetcorn, see Ayako et al., 1989). Organised groups of farmers were in a stronger position to negotiate better terms with the canners, who otherwise might dictate terms to the growers, unless the Agricultural Department intervened (Bottrall, 1969:12).

However, growers were not confined to this outlet. Peberdy (1958:193) reported that the prices for green beans at that time were 12 cts/lb at Kenya Canners, Thika; 18 cts/lb at Kenya Orchards, Machakos; and 25 cts/lb delivered to Nairobi. The differences between the prices offered by the canners was attributed to the fact that Kenya Canners exported, but Kenya Orchards sold on the Kenyan Market.

The export vegetable market is now dominated by licensed dealers who have access to air cargo space and market outlets. Attempts by cooperatives to compete have not been successful. Their prices and terms, therefore, tend to dictate participation.

3.4.6 Urban markets

The marketing system for fruit and vegetables (Bottrall, 1969; Gomez, 1982) is fragmented, diversified and uncontrolled with regard to prices. Most of the crops may be partly consumed at home (about half the mango and pawpaw crop is so estimated) or sent to markets within the District if other outlets (Nairobi, Mombasa, Thika) are unprofitable. The Horticultural Cooperative Union bought quality produce for export, though at low prices. Asian vegetables from Tala were reputed to be better than those from Machakos, and had access to better retail outlets (Asian vegetables did not pass through wholesalers).

In an uncontrolled and distant market, variable prices, transport problems, perishability and the need for information provided strong inducements for group marketing initiatives. Coffee cooperatives in the Tala area diversified into vegetable and fruit marketing and were supplying both Kenya Canners (Thika) and the Nairobi market in 1969. In the Kangundo area a group system, an offshoot from the cooperatives, organised transport and finance on behalf of producers. In Mbooni, groups of buyers cooperated to supply the more distant Mombasa market with tomatoes - highly perishable, and so sent in staggered consignments to avoid flooding the market. At Matuu, group activity focused on transport which was scarce. (See Institutional Profile.)

3.4.7 Factors influencing adoption

Ecology

The influence of ecology is clear from Tables 4, 5, and 6. The level of adoption of both fruit trees and vegetable growing was lower in AEZ 4, but especially vegetables. Even where fruit trees were grown, they were fewer in number per farm. Even in AEZ 3, rainfall variability causes major fluctuations in output from season to season. Owako (1969:258-260) quotes a range from K£3,400 to K£23,000 in the value of fruit, and from K£9,300 to K£76,200 in that of vegetable exports from the District between 1955 and 1965.

The planting of citrus (especially oranges) has extended beyond AEZ 3 into drier areas of AEZ 4 and even 5. The mango thrives in drier areas below 1,500 m, and fruits out of season for the Nairobi market (Peberdy, 1958:240-1), but it is not known to what extent improved varieties have supplanted the local ones. Bananas and pawpaws are also grown on a large-scale in AEZ 4, thanks to the technology, first reported in 1948, of growing in pits, in diversion channels and at the back of terraces where water is within the reach of roots. In 1981 (Ecosystems, 1982, vol.1b, table 78) the average density of bananas in the District was 12/km^2; the highest density was in Northern Division (40/km^2), but even in Makueni a density of 8/km^2 was recorded. Adoption patterns, therefore, have reversed ecological expectations, though the scope for development, except by irrigation, is certainly more restricted in AEZ 4.

Labour

Information on labour requirements is scarce. But it must be assumed that short season rainfed vegetable production competes with food crops, though such competition may be minimised where plots are small. Fruit trees, as usually cultivated, require little labour, except for harvesting, and this may contribute to their popularity. For example, a mango tree may produce 4-600 fruit and requires little maintenance; on the other hand, bananas need pitting and mulching.

Market

Only 21% of farmers sold fruit produce in Mbiuni in 1981 (Gielen, 1982:34), most commonly mango and lemon. Interviews carried out in 1990 indicate that produce is often consumed in the village, but sale was more common in the 1980s than it had been in the 1960s. According to Hayes (1986:214), the notable increase in fruit tree planting that took place after 1980 was driven by the need of women in the household for disposable income. Women need little start-up capital or education in order to plant trees. The mango was found to be the most popular marketable fruit (*ibid.*,221).

Producers' margins in vegetable production have probably been attractive throughout the period, though production and marketing risks were high. Owako (1969:259) compares returns of Ksh 1,400 - 1,800 from a half-acre (0.2 ha) tomato plot at Mbooni, compared with Ksh 900 - 1,200 under coffee and less than Ksh 100 under maize.

Since efficient marketing is of critical importance, traders' margins are also of interest. According to Bottrall, (1969), at Tala, Mbooni and Matuu, these then ranged from 2 to 25 cts/lb, depending on the crop, and they were considered on the evidence available, not to be excessive.

3.4.8 **Lessons of the fruit and horticulture story**

There are important differences between fruit trees and vegetables. Vegetable and field fruit production require much more labour and purchased inputs than tree crops (perhaps excepting the banana). Vegetables are mainly annuals, and fruit trees are perennials. In relation to intensification in a land-scarce farming system, fruit trees offer a high return per hectare with low inputs of labour, and horticulture offers a higher return per hectare with high inputs of labour.

It is their marketing that they have in common. Therefore the history of their promotion and adoption is largely the growth of the urban, canning and export markets, and of marketing channels adapted to the diversity and variability of both products and markets. Both coffee and cotton required government interventions in extension, the provision of inputs, supervision of production, grading and marketing of output. They have recently run into marketing difficulties, and these can be traced to rigidities in pricing and marketing, which are controlled by state-run monopolies. By contrast, horticultural and fruit crops, developed with far less government involvement (and expense), are sold through more fragmented and less controlled channels, and have been more dynamic over time. Adaptation and innovation are characteristic attributes of Akamba agriculture. With little or no official pressure, the performance of the sector, even in the drier areas, is in sharp contrast to that of cotton. In the long run, horticulture may turn out to be more stable in the District than coffee.

The generally high value per hectare of vegetable production for the market, when not reduced by drought or other factors, permits optimal use of micro-environments with a favourable moisture balance. High value per hectare also minimises the entry cost in terms of food grain production foregone. Similarly, fruit trees offer women farmers both sources of food and disposable income, without a major reduction in the area under food crops. This is because they are grown scattered on arable land, representing a form of intensification (Hayes, 1986).

4. TILLAGE: THE OX-PLOUGH

4.1 History of Adoption

In view of the reputation later acquired by the Akamba for resistance to change in agriculture and livestock husbandry, the early adoption of the ox-plough, if limited in scale, is astonishing. According to Peberdy it was introduced in 1910, and this "undoubtedly led to the District Commissioner's statement in 1912 that 'the Akamba are beginning to cultivate larger areas and disposing larger quantities for cash (crops) than in former years'. This might also have been caused by decreasing yields in the hills due to overcropping and the fact that shifting cultivation must have been reduced by the rapidly expanding population" (Peberdy, 1958:4). The first European settlers arrived in the District in 1903,and though they must have used ox-ploughs, and attracted trade suppliers, seven years was a short lead-time for the innovation to have such a significant impact on the Reserve. Its early association with cash cropping is also noteworthy.

Smallholders in Kangundo are reported to have started buying ploughs, and training their own oxen, by the late 1920s (our interviews). In 1933, the Agricultural Officer reported that draft implements (ploughs and cultivators) were widespread in the District (DoA, 1933); then about 600 ploughs were in use (Carter Commission evidence: Kenya Land Commission, 1934). Although this would have been less than 3% of households, the ox-plough's popularity was actually beginning to worry the Administration, for fear that the natives would plough more land than they could properly manage, resulting in lower yields, and soil erosion (DoA, 1935).

Perhaps because of these misgivings, there is no record of systematic promotion of the ox-plough by the Agricultural Department in Machakos. However, interviews have yielded evidence of one introduction by an agricultural officer (and there may have been more). This case is recorded below as it throws light on the link between livestock ownership and ox-ploughing, and the early evolution of the farming system, as well as on the adoption process:

> Mr Thiaka can remember 'affairs of the world' from about 1915. Bush clearance was accomplished in this previously unsettled and heavily wooded area (Muisuni, near Kangundo) by means of burning and *pangas* made by blacksmiths from locally smelted iron. Digging sticks were used for planting. Around 1920, land rotation ('shifting cultivation') began to cease as a result of advice from local AIM missionaries. There was no manuring, though abandoned house sites were recognised as fertile places for cultivation. On grazing land, woody regrowth was controlled by burning.
>
> After marrying in 1928, he began to hire a plough and oxen in Machakos, at a rate of 50 cts/ridge, spaced a yard apart, irrespective of length. Some people in Matungulu had enough cattle in the 1930s to hire out or operate three ploughs. The oxen - four or six if breaking new land - had been trained by Indians to draw ox-carts, from 1923-4. He could now plough larger areas and produce more grain and cash crops for sale.
>
> In 1943, he bought his own plough, and oxen. There were two trade models on the market : the Tiger and the 'Ochui'. In 1946 the AO introduced a new type which sold for Ksh 40. This plough was not popular, being very large and heavy in beam and mouldboard, and requiring six oxen or eight when on grassed land. At this time the AOs were promoting contour ploughing, heaping stalks on the contour to stop erosion, and planting sisal on boundaries. They were also promoting row planting of maize and beans, using strings, which replaced irregular sowing with *jembes* (which had by then replaced digging sticks).
>
> With the extension of the cultivated area, the grazing areas became smaller and cattle fewer. The plough he uses today is the lighter one (Victory plough) introduced during the 1940s, which uses two oxen. Its advantage is that in needing fewer oxen it can be supported with less grazing.

> Compost making was introduced around 1945, as taught by the AOs (domestic rubbish and residues rotted in a pit near the house, where water is admitted). Boma manure however is preferred by all cattle owners. Bench terraces were introduced to the area in 1943-44; and to his farm in 1947-48. These were *fanya chini* terraces, and the AO ordered that cultivation without them should be prohibited. The *fanya juu* method replaced them in 1953.[4]

Since the late 1940s, an Agricultural Mechanisation Service unit based at Makueni has promoted ox-technology, ox-training and cultivator courses. Two NGOs, AMREF and ActionAid have recently assisted in these programmes.

It is likely that the innovation curve was virtually complete by the late 1970s, in terms of usage. Rukandema (1981) reported that in Mwala Location, 78% of farmers owned ox-ploughs and 72% owned oxen. In Makueni in 1975, 91% of farmers owned ploughs and 76% two or more oxen (Heyer, 1975).

Muchiri(1979:198) considers that poverty is likely to be the main reason for less than 100% adoption (ownership) in the semi-arid areas of Kenya. Rukandema found that non-ownership was related to economic differentiation. In Nzaui, while average farmers owned a pair of draft oxen or bulls together with one mouldboard plough, a third owned no draft animals, and were found to be cultivating a smaller area than the average (Rukandema, 1981). Farmers owning oxen or bulls generally planted on time, but other farmers were unable to do so. In Mwala, similarly, non-owners had smaller farms, and had to borrow or hire. Sharing or borrowing are reported where one or more of the components (plough and two trained oxen) are lacking.

Ecology however also influences ownership. Interviews conducted for the present study suggest that in the lowland locations of Masii (AEZ 4) and Ngwata (AEZ 5), most farmers are said to own ploughs; in Kangundo (AEZ 3), about half; but in the hills of Mbooni (AEZ 2/3), many farmers are obliged, by reason of their small and intricately terraced holdings, to use the forked *jembe* (itself an innovation, widely marketed only after 1960). Use of the ox-plough is more general than its ownership. Thus ADEC (1986) found that in the District as a whole, 62% of sampled households owned ploughs. Ownership is more frequent in AEZ 4 and 5 than in 2 and 3 with smaller farms within AEZ 4 and 5.

4.2 Development of Types

The Victory mouldboard plough is often considered to be 'traditional', but it is clear from the account given above that it was preceded by heavier types. Many types of plough have been marketed and promoted under different names over the years, and it is not possible, with the information we have recovered, to construct a technical inventory or a clear chronology of types. The early ploughs were very heavy, and there are reports of up to 12 oxen (in Masii) being required for draft. In 1935, a smaller Hindustan plough introduced by the Department of Agriculture was said to be becoming popular. The lighter mouldboard plough came into

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4 Interview with Mr. Thiaka (b.1906) at Muisuni on 23/1/91, by courtesy of Mr. Peter Muasya.

use in the 1940s, introduced by traders (according to the interview quoted above). It used only one pair of oxen and was more easily manageable, though farmers say it is less strong than the early ploughs.

The significance of the transition to lighter ploughs lies in their compatibility with reduced livestock holdings, smaller grazing areas, and the less frequent need to break new ground as cultivated areas stabilised. It is compatible with increased participation of women in ploughing work. Also, it may be supposed that teams of several span were difficult to manipulate on the terraces that became increasingly common from the 1950s, and on the small fields of the uplands.

The mouldboard plough, however, was not officially judged to be well suited for Machakos conditions. Early planting is essential in order to make optimal use of the rainfall. A district agricultural officer's appraisal in the 1960s considered that it required a tractive effort greater than badly trained and underfed oxen could supply at the end of the dry season (de Wilde et al., 1967:104). Correct adjustment was often not understood, or spare adjusters were not available; the share broke the soil but failed to bury trash; the same eight-inch furrow was used for primary cultivation, seedbed preparation and weeding (Alexander, 1975). For example, sixty percent of farmers in Makueni used ploughs for breaking new land, 83% for first cultivation, 79% for planting and 88% for weeding (Heyer, 1975). The mouldboard plough failed to produce a cloddy structure (for infiltration) and to control weeds, as well as being unsuitable for dry ploughing (and planting) before the rains begin (Johnston and Muchiri, 1975).

Attempts to improve the technology centred on multi-purpose equipment adaptable to the different farm operations performed hitherto by the mouldboard plough. A single tool-bar modified from the Indian Desi plough can be used for chisel ploughing before the rains, opening planting furrows, and weeding (Muchiri,1983; Muchiri and Gichuki,1982; Muchiri and Mutebwa, 1979). The weeding equipment requires 5% of the man-hours per hectare required in hoe weeding, according to experiments (Muchiri, 1980).

On the basis of this work, the MIDP, in 1979, introduced a multi-purpose tool bar which it was hoped would be able to break hard ground prior to the rains, and serve for land preparation, planting and weeding. However, uptake was slow, several hundred units were unsold, and most users preferred their old ploughs, finding the MIDP equipment too heavy for their draft oxen (ODI, 1982). An evaluation report concluded that the problems of the mouldboard plough had been overestimated. The mouldboard plough, slightly modified and available in different sizes, is the one principally used in Machakos today.

Improvement efforts, however, continue. In 1984, the MIDP was involved in promoting conservation tillage systems and equipment, in collaboration with the Rural Technology Development Unit of the Ministry of Agriculture, based in Katumani. The Bukura Mark II plough was widely promoted through on-farm trials and by local manufacturers. In 1985, they conducted on-farm trials on the effects of different mechanical planting and weeding control on maize production. The equipment tried included ploughs, sweeps and ridgers.

4.3 Reasons for Adoption

4.3.1 Technical advantages

Heyer's farmers in Makueni mentioned the following advantages of the ox plough: it is cheaper and more available than a tractor; it saves labour and time; it requires little skill; it gives a good depth of cultivation, and quick germination; it retains soil fertility; and is suitable for most topography and poorly cleared sites. Its disadvantages however (in comparison with hand and tractor cultivation) were: it is slower, requires more labour and can cultivate less land than a tractor; it is susceptible to cattle disease, theft, and shortage of grazing; it calls for extra weeding; and (with oxen) it is expensive.

Interviews conducted for the present study indicate that the following reasons are influential in farmers' changing to ox-ploughing: (1) its superiority for loosening the soil; (2) its rate of work; (3) the saving of labour time and drudgery; (4) better timeliness of operations; and (5) improved crop yields.

This evidence, taken together, leaves no doubt why adoption (in terms of use, if not ownership) is very high; but little work has been done to quantify or prioritise these benefits under smallholder conditions.

4.3.2 The plough in economic history[5]

Given the technical, economic and social (prestige) advantages of plough ownership, it is worth asking what were the likely sources of investment funds during the history of plough adoption. Early in this history, cattle ownership was greater per capita than now, though possibly no more widespread in the community. Large-scale herders could afford to sell animals to buy ploughs. In the 1940s a plough cost about Ksh 30, roughly equivalent to the cost of a cow. In the early 1930s, ploughs and teams were hired at the rate of one cow, two he-goats, or about Ksh 35 per acre. These relativities would have ensured rapid adoption of the technology.

Another reason for early uptake, which accelerated during the period 1930-64, was the experience of plough operation gained on European farms by those who worked on them, and the proximity of such farms to the Reserve. During this period, some farmers earned revenue from selling horticultural produce to Kenya Orchards and Kenya Canners. The short-lived cotton boom of 1936-40 set a premium on plough ownership in the drier areas.

Ploughs were available from dealers in Machakos and Nairobi. During the famine years of the 1940s, the Government provided ploughs (and dam scoops) for conservation work: dams, terraces, and scratch ploughing for grass planting. After World War II, soldiers who had seen ploughs in India, Burma and Ethiopia returned with the funds necessary for purchasing their own.

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5 This section owes much to J.R. Peberdy (personal communication, 1991).

During the 1950s general agricultural prosperity, and a high level of Akamba employment outside the District, made investment funds available. Credit was provided by Asian traders in grams, lentils and onions, and much of the Governments' supervised credit was used for ploughs and ox-carts. Coffee (after 1950) and cotton (from 1960) brought in cash.

In the mid-1970s Lynam, working in AEZ 4, found that only a farm size of five ha or more yielded an adequate return to investment from an ox-team (1978:163). Nevertheless, the hiring market was poorly developed. But given that the major factor affecting yields (and incomes) is the ability to plant early, the ownership of ploughs is more widespread than might be expected on purely economic grounds. The factor now limiting its ownership and use is oxen ownership.

4.4 Associated Practices

Dry planting

Animal power had a considerable impact on cultivation practices. From the 1960s, extension workers advocated dry ploughing and planting (particularly for the Katumani maize varieties). Ox-ploughs enabled farmers to take this up. However, early planting means that stronger oxen are needed for breaking hard ground, when fodder is more scarce; two cultivations of the seedbed are necessary; there is a higher risk of seed loss; and weed growth is more dense. Thus by the mid-1970s, acceptance of dry planting was mixed. Its rates of adoption by farmers in Makaveti (AEZ 4) and Makueni (AEZ 4/5) were 78% and 61% respectively, but in Kalawa (AEZ 5), it was less than 25% (Lynam, 1978). Dry planting is now fairly widespread, according to our interviews, but depends on the rainfall pattern and conditions of animals in a given year. To spread risks and save time, many farmers plant both before and after the rains. Those who do not own oxen are at a disadvantage.

Row planting and inter-row weeding

Row planting and inter-row ox-weeding were promoted by extension workers from the 1950s. In 1963 (Heyer,1967) few of the farmers in Masii were practising it. According to our interviews, women farmers in Embui did not learn inter-row weeding until after 1960. By the mid-1970s, however, much of the lowlands were ox-weeded (in the first weeding), up to 86% of farmers in Makueni weeded with oxen (Heyer, 1975), and 90% of the cultivated area surveyed by Lynam (1978) was so weeded.

Ox-weeding reduces labour requirements at a peak time, from 17 to 11 man-days/ha according to Lynam (1978). This was an advantage, especially where farmers had extended their cultivated land in the drier, land-surplus areas. Also, timely weeding conserves moisture by limiting weed competition, reducing run-off and increasing infiltration. These advantages are fully recognised in some ox-weeding systems (for example, Neunhauser et al, 1983:32-3). According to Lynam, the relatively recent adoption of inter-row weeding was due to the prevalence of 'broadcast' sowing before 1960 and the greater control over the oxen that was necessary, among other reasons.

4.5 Lessons from the Ox-Plough Story

The ox-plough has proved to be both a durable and a flexible technology. First adopted as a means of extending the cultivated area, to produce cash crops and more food for a growing population, its significance later, as landholdings became smaller through subdivision, was for saving labour in a process of intensification. Early adapted to opening new land, with teams of six or eight oxen, it later evolved into a two-oxen instrument suitable for work on small, terraced and permanent fields. At the same time the average cattle holdings declined and an increasing shortage of grazing dictated a transition to more intensive feeding systems. Today, the need to maintain a viable plough team provides the 'bottom line' keeping many farmers in cattle ownership.

The plough diffused early with little government promotion, notwithstanding the Akamba reputation for conservatism. Given its technical and economic advantages, and social acceptance, within the constraints of the Akamba farming system, the most important question to be answered about its adoption is the sources of investment capital. These sources changed through time, and have been intimated above. The 'oxenisation' of Akamba agriculture was, in a measure, a triumph of capitalisation in a capital-scarce, risk-prone and low productive farming system.

The Victory mouldboard plough is criticised as inefficient in several respects, and for being inefficiently used. Yet attempts by the government and other bodies to intervene in promoting improved technologies have not had a significant impact in the District. Especially unsuccessful was the MIDP's tool-bar. One study (ODI, 1982) concluded from this that expert assessment of the mouldboard plough had been overly pessimistic. An imperfect technology, in the hands of skilful users, is better than a poorly tested innovation, whose adoption, furthermore, calls for major new investment.

The history of the plough in Machakos District is full of paradoxes which support the view (McIntyre et al., 1989) that ox-ploughing is an imperfectly understood technology in tropical Africa. In Kenya, according to Muchiri (1983) there was no definite policy on ox-ploughing before 1975. This is reflected in a sparse research literature, which even now is dominated by technical issues, rather than those of economics or management.

5. FERTILIZATION

5.1 Management Options

The need to intensify agriculture to permanent fields, with cultivation twice a year, brought about a transformation of the regime of fertility management. What has been achieved falls short of sustainable productivity everywhere, but the direction of change is clear nonetheless.

The soils of the District are deficient in nitrogen and phosphorus (see Environmental Profile, Section C). Early planting, which is practised in order to take the best advantage of the rainfall, also secures for the crop the benefit of the nitrogen flush that occurs in the first rains.

But where phosphorus is seriously deficient, even nitrogen fertilizer may not improve yields significantly.

There are four main soil improvement options: (1) inorganic fertilizers, (2) the extended use of boma manure; (3) alternative organic systems (compost, mulches, green manure); and (4) the extended use of nitrogen fixing legumes as intercrops, rotations or farm trees. Probably none of these alone provides a complete answer to the loss of plant nutrients under cultivation. But in the historical experience of the District, it has been the increased use of boma manure that has provided the main theme in fertility management.

5.2 Boma Manure

5.2.1 Early promotion

Official policy favoured boma manure from the start. The third Reconditioning Committee (1944-55) considered that it was 'dangerous to put too much reliance on fertilizers, as they were not real substitutes for farmyard manure and proper rotational measures' (Peberdy, 1958:21). Behind this Better Farming propaganda, which aimed overtly at intensive mixed farming, may have lain an awareness that the cost of inorganic fertilizers would not recommend them to resource-poor smallholders. Also, where rainfall is unreliable, inorganic fertilizers are not only a risky investment, but may increase water stress in a dry season, damaging rather than assisting the crop. Manure improves the structure of the soil, minimising damage from water splash and improving water retention.

The Department of Agriculture used its model smallholding to demonstrate the advantages of mixed farming. It promoted manure, compost, crop rotations and planted fallows. A Chief's Act was used to encourage the use of manure. At the time of the de Wilde study (1967:102), recommendations for manure production and use were given great stress by the Department. Nitrogen fertilizer was recommended for coffee, but repeated trials with food crops had shown poor and erratic responses. Phosphate fertilizers had given more definite and reliable responses with maize, but these were unspectacular. Manure appears to have had a more marked effect on yields. Experiments at Makueni, for example, gave improvements of 50% in return for a moderate dressing of five tons of manure per acre (DoA, 1953).

5.2.2 Adoption

It is of some importance to establish when the use of boma manure became widespread. There are reports of the use of manure as a general practice by 1940, but Peberdy (1958:18) comments that 'when examining these early reports in the light of present practice, it appears that they must have been over-estimated, because it was not until 1950 that widespread manuring became apparent in Kangundo and Matungulu, while in some areas it was still the exception rather than the rule'. In 1946, the Agricultural Officer reported that 80% of a small sample of 26 fields in Kangundo and Matungulu Locations were manured, and the differences between manured and unmanured plots were remarked upon by their owners (DoA, 1946).

There was a local trade in manure, and Akamba farmers had also been selling it to nearby European farmers for some years. This implies that a turning point may have been passed in these northern locations some time in the 1930s, though general acceptance of the practice came later.

The information that is available on the adoption of boma manuring in different areas suggests that its use is still spreading. In 1956 it was estimated that 70% of farmers in high potential areas used it, compared with only 2% in semi-arid areas (DoA, 1956). In Masii (AEZ 4) in the early 1960s, manure was used only on some of the nearer fields (Heyer, 1967). In Northern Division in the mid-1970s, more farmers used boma manure in the hill locations than in the plains (Onchere, 1976). But by the 1980s, adoption had reached 90% of farmers in some areas (for example, Yatta: Neunhauser et al., 1983); they were spreading manure over whole fields, in lines or in selected patches. In Mwala, about 66% of farmers were using it; in Nzaui, about 50% used it on maize, 33% on beans and fewer on cotton (Rukandema, 1981). The ADEC sample survey (1986:6.34) reported that 87% of farmers used boma manure on crops, and 3% were selling it. Only 10% did not collect it. These figures imply that in terms of the percentage of users, the adoption curve is almost complete. By contrast, [inorganic] 'fertilizer use is minimal', the bulk of it on coffee (ADEC, 1986:7.6).

The percentage of adopters, of course, tells us nothing of the rates of application, which are known to be highly variable in space (from field to field and within fields) and time (from season to season).

5.2.3 Factors influencing use

The use of boma manure is influenced by (1) yield expectations, (2) rainfall risk, (3) supply and (4) labour and transportation. With regard to expectations, most reports suggest that the best returns from the use of boma manure (especially if it is purchased) can be obtained from coffee, cotton, and improved maize. However little information has been found on farmers' choices. The residual effects are also recognised.

With regard to risk, the probability of losing a crop through drought deters farmers from using manure (and perhaps other) inputs. Also, it is known that manure may burn the crop, or accentuate water stress, under dry conditions. It is possible that reduced drought risk helps to explain the higher incidence of manuring in the hills of AEZ 2/3. However, as shown above, manure use has extended steadily into the drier zones, according to the historical record.

Manure supply on the farm is obviously constrained by the size of livestock holdings, which diminished considerably during the period covered by this study, though partly compensated by improvements in the efficiency of collection brought about by stall feeding. Demand has exceeded supply, in some areas, ever since the 1940s, when farmers were buying manure at Ksh 1 for 7-10 bags in Matungulu (DoA, 1946). Of those farmers in Mwala who were not applying boma manure around 1980, most cited a lack of livestock as one of their main reasons (Rukandema, 1981). In 1990, 40 farmers interviewed in five locations, in all agro-ecological zones, reported problems of obtaining sufficient manure from their animals, and of cash for purchasing it (or fertilizers). The only ones who said they had few problems in maintaining soil fertility lived in the newest settled location (Ngwata). The better off farmers buy manure supplies from livestock owners, sometimes Maasai in Kajiado, who do not use it. But at around Ksh 300/ton, the price is now becoming prohibitive.

Labour inputs in manuring have undoubtedly increased with the acceptance of boma management as the normal method of keeping livestock for at least part of the year. Probert et al (1990) report that farmers knowingly delay in moving manure from boma to fields, because they are busy with early planting. With regard to transportation, a shortage of carts and (in hilly areas) difficult terrain may impede the distribution of manure. Transportation problems were cited by some farmers in Mwala as one of the main reasons for not using manure (Rukandema, 1981). They may have been referring in oblique form to a labour problem.

5.2.4 Manure and nutrient cycling

Manure supplies a range of plant nutrients, most critically nitrogen and phosphorus. Field samples from cultivated terraces show that manuring has a marked effect on available phosphorus, which may be limiting even in the presence of nitrogen fertilizer (Okalebo et al., 1990). Ikombo (1984), on the basis of experiments at three sites in Machakos and Kitui Districts, found that while higher applications gave better maize yields in good seasons, a rate of 8 t/ha of farmyard manure gave relatively high and consistent yields in all seasons. Inorganic fertilizers depressed yields in poor seasons.

Assuming that boma manuring yields 1 t/year/livestock unit, an average livestock holding of 2.4 oxen, 7.7 cattle, 8.1 goats and 1.3 sheep (8.7 units), kept on 5.1 ha of grazing, could provide an application of 2.5 t/ha/year on 3.4 ha of cropland, containing 50 kg of nitrogen and 9 kg of phosphorus (Probert et al., 1990). This would support a maize yield of not more than 2 tons/ha, assuming that all residues are recycled as manure, and all nutrients are fully utilised by the crop. Land holdings of this size are, however, generally found only in AEZ 4/5.

But the manure used in Ikombo's experiments was of better quality, and the boma system, as it is operated on the majority of farms, is relatively inefficient. The quality of the manure is poor, owing to the incorporation of soil from the floor of the boma. The earth floor also permits the loss of nutrients into the soil beneath. Losses of nitrogen occur through volatilisation, and by denitrification (when the manure is waterlogged). Application to the crops is prone to be left late, and most farmers can only manure a few of their fields each year (Probert et al., 1990).

Improving the efficiency of the boma system should be a target for research. But there will never be enough manure under the constraints of this nutrient cycling system.

5.3 Composting

Composting, as a closely related technology, was also promoted hard in the 1930s as part of the Better Farming Propaganda (Peberdy, 1958:15-19). By 1937, there were reported to be 10,698 compost pits constructed, and over 1,000 farmers had tried the technique. It is not known what became of these compost pits. Since dry bedding and uneaten crop residues are normally incorporated in boma manure, it appears possible that the early reports were referring to manure production under a different name. Today, farmers having no livestock are said to make compost. Farmers owning livestock cannot, as a rule, afford to use residues for this purpose.

Compost making is being promoted again by NGOs, notably the Kenya Institute of Organic Farming (KIOF).[6] In the Makaveti area there are 56 participating farmers (women and men) organised in five groups. Each group meets twice weekly to provide labour for its members, especially for water carrying. The method consists of filling a pit about 2.5m long, 1.5m wide and 0.7m deep with alternate layers of *Lantana camara* or other shrubs (*Cassia* spp., *Croton* spp., and sisal waste are suitable), dry grass, boma manure (which includes bedding), red soil (which includes micro-organisms), green shrubs, wood ash, and water; these layers may be repeated in cycles until the hole is sealed with more soil and protected by branches from chickens. Water is admitted through post-holes. A long stick is inserted at an angle to test for dampness; when dry, water is added, and when cold (damp), the compost is turned for better aeration - usually after two to three weeks. It is ready for use in two to three months. One drum (44 gallons) of water has to be carted in from the river for each turning.

Application is similarly labour intensive. The compost is applied, in handfuls, to each crop stand in the last season's furrows, and buried with the seed by turning in the adjacent ridges with the plough. Considerable quantities are required per hectare.

Compost is preferred to using manure alone because (1) it doubles the quantity of organic matter available; (2) it reduces the problems associated with insects such as cutworm; and (3) it does not burn the crops when rainfall is deficient. The first and third of these reasons have the utmost relevance to AEZ 4 and 5, where arable areas are larger than in AEZ 2/3, the soils intrinsically less fertile, and the risk of drought greater. Given that livestock holdings cannot increase, in view of the smallness and continuing subdivision of landholdings, and that low fertility is the major constraint on productivity and farm incomes, the large labour inputs that these farmers are willing to invest can be understood.

Compost making may compete for some of the plant materials normally used for feeding livestock. The use of *Lantana camara*, which has few alternative uses, but grows uninvited along roadsides and on abandoned land, and other wild shrubs and hedge plants, sidesteps this potential limitation. The new technology, therefore, represents both an improvement in the efficiency of nutrient cycling, and a further step in labour intensification, in the system.

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6 The sources for this account are Rose Maweu and Agnes Mulandi.

5.4 Lessons from the Fertilization Story

This review has paid little attention to the first and fourth management options listed in Section 5.1 (above). Inorganic fertilizers, though applied profitably to commercial crops, compete for scarce capital which will always limit their usefulness. The medium and longer term nutrient requirements of arable soils cannot be met with inorganics alone. These considerations justify paying more attention to the other three options.

Leguminous crops (and trees) already have an established place in the system, but not much research appears to have been done on extending their contribution. They can correct deficiencies of nitrogen, but not of phosphorus.

The experience in the use of boma manure and composting is entirely consistent with an historical imperative of labour intensification, on holdings diminishing in size, generated by a growing population and increasing land scarcity. In a context of capital scarcity, additional labour inputs are preferable to the use of purchased inorganic fertilizers.

One primary constraint operating on the use of boma manure is supply (livestock holdings). The substitution of compost for manure not only increases the quantity of organic material generated from the boma but also brings into the managed nutrient cycle various fugitive sources such as *Lantana camara*, representing a significant increase in its biological efficiency.

The second primary constraint on the use of both manure and compost is labour, especially for transportation (transportation equipment is also sometimes scarce). A general increase in population does not connote an adequate supply of labour on every farm. Manure making and distributing is organised at the household level, but it is significant that the KIOF's composting scheme is predicated on collaborative inter-household use of labour and equipment. Such institutional arrangements achieve increased efficiency in the use of labour and capital in the farming systems as a whole. This is the price of biological efficiency, and adoption patterns in the future will tell if it is considered to be payable.

Having accepted the need for (if not commanding adequate supplies of) boma manure, as an essential component of the farming system, the Akamba farmer is, in 1990, on the threshold of a transition to a yet more labour-intensive, but biotechnically efficient, use of natural resources.

6. LIVESTOCK

6.1 A Change in Values

A fundamental change has occurred in the social value of cattle. At the beginning of our period of study, cattle were the 'leading edge' of the Kamba economic system - a repository of investment funds, indicator of socio-economic status, and dominant consumers of natural resources. Now, their investment function is secondary to other forms of savings, their possession no longer exclusively determines wealth or status, they are frequently bought and sold, and their access to biological resources has become subsidiary to the demands of farming. A major reason for owning cattle is now the maintenance of a plough-team. Small ruminants have perhaps changed less, but less is also known of their management.

6.2 Grade and Crossbred Cattle

6.2.1 Promotion and adoption

In 1948, Faulkner (then Director of Veterinary Services) considered that it was useless to improve the genetics of cattle in the District until management and disease control had been correspondingly improved, since the livestock would fail to reach their genetic potential under 'the intensified and mismanaged form of agriculture practised [sic] by . . . the Akamba who persist in retaining large numbers of stock but do not utilize them for the production of manure . . . We know that the local indigenous Akamba cattle are those best suited to the area, it is they which have survived the local conditions of feeding, management, disease and climate and which have successfully adapted themselves to those conditions.' (Faulkner, 1948:1-3). Only in Makueni, where an intensive system of mixed farming was being introduced under strict control, might there be a case for introducing the Sahiwal breed, should the system prove viable after 5-8 years.

Artificial insemination (AI) was introduced to Kenya (after basic research in the 1930s) in 1946-48, primarily to control sexually transmitted disease, and only secondarily to introduce grade cattle (D. Brown, personal communication). In Machakos, the Department of Agriculture's livestock breeding programme began during the 1950s with the establishment of AI and bull centres. The minimum requirements that had to be met by farmers were set out. Direct participation in the breeding programme was slow, but Sahiwal blood was diffused into several local herds, as in Yatta, where farmers grazed their animals on the improvement schemes, which were stocked with Sahiwal. If heifers were sent for 18 months, an owner might get the benefit of two improved calves for a grazing fee of Ksh 15. 'Although the Kamba disliked the fees the scheme was quite popular' (Kimambo, 1970), not surprisingly.

According to Peberdy (1958:123), the Sahiwal was preferred to European breeds because, while as good in terms of milk production as Europeans maintained in African conditions, it is hardier and more tolerant of heat. After the first diffusion of Sahiwal blood it might be desirable to bring in European breeds. However, it is possible that the use of crossbreds rather than pure stock alters the strength of this argument. Friesian and Ayshire crossbreds are quite common today in the District.

By the 1970s, the Ministry of Agriculture had built up a fairly successful AI service in such locations as Kangundo and Matungulu, with over 1,000 inseminations per year (Onchere, 1976). However, in the District as a whole, only 15% of farmers were using AI in the mid-1980s. This was considered to be because the services were not widely available, or irregular (see Production Profile); at least half of the farmers not using it expressed a wish to do so (ADEC, 1986). The number of improved cattle was estimated to be 30-50,000; but another 1980s study (ODI, 1982) estimated only 10,000. These figures represent 7-14% and 2-3% respectively of a total cattle population of 350-450,000 (see Production Profile). The District Development Plan estimated 8% grade cattle in its sample survey. The number of grade cattle is difficult to determine, because estimates did not disaggregate numbers by breed.

6.2.2 Factors influencing adoption

Both the logic of intensification and the realities of maintaining animal health point to the likelihood of a higher rate of adoption in the cooler and wetter areas, and this is so. According to Jaetzold and Schmidt (1983:vol.2c), about 20% of the cattle kept in the high potential zones (2 and 3) were of improved stock in the early 1980s, compared with only 7% in the lower potential zones (4 and 5). According to our interviews, 80% or more of the cattle in Mbooni are thought to be improved stock, but 10% or fewer in Masii and Ngwata. However, a major exception to this ecological pattern is Makueni, where more than 50% of farmers are said to have crossbreds. Such a high level of adoption is facilitated by the presence of the AI and bull centre, and the early innovatory attitudes of the settlers. Nevertheless, crossbreds are generally preferred to higher grade animals. An exception is the Wamunyu Friesian dairy herd (Mutiso, 1990), where management more than compensates for the disadvantages of a location in AEZ 5. This is not the only grade cattle operation in the dry lowlands. But its large-scale and capital intensive management restrict its relevance for livestock production on smallholdings.

Farmers value improved animals for their superior milk and manure output and higher market value. Milk output for household consumption was always an important determinant of livestock decisions, more important than feeding the calf according to Peberdy (1958:123). The recent deregulation of prices has helped the profitability of livestock production, and the market for milk is increasing rapidly (Potter, 1990) with improving prices (see Production Profile).

But the costs of buying and keeping grade cattle are much higher than for unimproved animals. According to recommendations current in the 1950s, these costs included fencing fodder reserves, shelter, sprays, record keeping, grass leys, water supply, castration and calf nutrition. Although management did not adhere strictly to these standards, farmers are motivated by the size of their investment to manage the animals more carefully than their unimproved zebu stock. Some observers have claimed that 'green strips' of intensive farming follow the AI runs in the District. In Masii, interviewed farmers gave the cost of buying feed as their reason for not keeping grade cattle on their small holdings.

There is a greater risk of mortality with improved animals. At Makueni (AEZ 4/5), grade cattle introduced in 1973 all died prematurely, it is reported. Even in Mbooni (AEZ 3) grade cattle are difficult to maintain in good health. The economic loss of death is correspondingly greater for grade animals. AI is to produce crossbred. It is debatable, therefore, whether the low utilisation of the AI service is due only to its limited availability, or partly to farmers' preferences for lower grade cattle and their more flexible management requirements.

Although some authorities consider the indigenous zebu to have little real production potential, having a low milk producing capacity even under good management (Tessema et al., 1988), Potter (1990) argues that it has not yet received a fair trial, and stresses its physiological adaptation to the environment. Many farmers appear to confirm the first view. But their evaluation of comparative performance may be clouded by the different level of care given to their costly grade animals. It is clear that 40 years of AI and improved bull services have brought about a slow and limited conversion. Poverty and environmental stress may be chiefly responsible. Efforts to improve indigenous cattle may yet pay dividends.

6.3 Dips

Dipping livestock on an extensive scale in small holder areas of Kenya began with large donor-assisted programmes in the 1960s. Initially there were no fees charged. The objective was to control East Coast Fever (ECF) and other tick-borne diseases. Regular dipping was a condition of survival, not only for exotic cattle, but also for crossbreds containing 50% or more exotic blood (D. Brown, personal communication). The prevailing orthodoxy at that time aimed to eliminate ECF from national territories by 100% dipping and strict control of movements.

Dipping services are commonly cited by farmers as the most valued service provided by government in the livestock sector. They are available to most types of livestock and all classes of owner, throughout the District. In 1985, 74% of cattle, 63% of sheep and 61% of goats were said to be dipped weekly (ADEC, 1986:6.39); conversely, only 7% of cattle owners, 17% of sheep owners, and 18% of goat owners said they never used dips. These figures are improbably high, especially for sheep and goats, not least because 30% of dips may be out of action at a time (Potter, 1990). Thorough dipping is more probably spasmodic, influenced by owners' resources, and disease outbreaks.

Of the dips used, 64% were operated by the Government, 20% privately, and 16% by cooperatives. Dips are not cost effective for individual farms, except the largest, and running costs are fairly high. Proposals to transfer management to self-supporting committees, if accompanied by increased fees, may have negative effects on levels of use.

This rather unsung area of technological improvement has probably been of greater economic benefit to the livestock sector as a whole than the stock improvement programmes. However, a loss of immunity through two or three generations of dipping, in an environment where ECF is still endemic, creates a dependency on dipping and a large addition to the costs of animal husbandry. Vaccines may soon offer a cost-effective alternative to dipping.

6.4 Lessons from the Livestock Story

Dipping, and improved breeds of cattle, have both been promoted for three decades or more in the District. They form parts of the same package, since grade cattle cannot survive without regular dipping in an environment where ECF remains endemic. But of the two technologies, dipping has achieved the higher level of adoption by a wide margin. There can be little doubt that its value for existing livestock is responsible for this, whereas grade animals compete with indigenous animals for fodder.

A grade animal is a high risk, indivisible investment in the rainfall and disease environment of Machakos District, though potentially profitable. Its riskiness is inversely related to quality of management. It is no longer thought to be suited only to the high potential zones. But patterns of its adoption (though little known) suggest that capital-intensive management units do not have a monopoly of grade animals. Ordinary livestock smallholders try to keep one or two among a mixed herd, and to increase the proportion of grade animals as the size of their cattle holding diminishes through time. In other words, grade livestock may be regarded in a manner similar to KCB maize - as a system where diversity is king.

Dipping is a divisible (low cost per capita) investment that reduces risk at low levels of productivity. Paradoxically, in view of the government's preoccupation with destocking at the beginning of our period of study, it was a technology that helped preserve the lives of livestock that contributed most to the welfare of stock owning households. Unfortunately, the level of dipping that reduces risk from ECF to an acceptable level for indigenous cattle falls short of that which could secure elimination of the disease. This increases the risk for grade animals and, by removing partial immunity from second or third generation dipped animals, for indigenous cattle as well.

Finally, a lesson may be learnt from the adaptability of the livestock producers themselves. The transformation of social attitudes, and in attitudes to economic management (noted in Section 6.1) reconciles the present realities of access to resources with the traditional status of cattle. The forces that brought about such a change can only be speculated, but education must be one of them.

7. FEEDING SYSTEMS (See also Production Profile)

7.1 Livestock, Feed and Farm Sizes

The role of livestock in the production system has been fundamentally affected, not only by arable expansion *per se*, but also by first, the demarcation and second, the registration of private land holdings, which reduced common access grazing areas to a residual category. Notwithstanding an increased supply of crop residues and fodder on the farms, a reduction in the average size of livestock holdings has been unavoidable, owing to the subdivision of landholdings into progressively smaller units. Nevertheless, according to Potter (1983), the smallest holdings in semi-arid areas retain some grazing land, not in highlands, even though the cultivated area may be insufficient to feed the family. This is a reflection of the continuing importance of owning some livestock.

The alternative sources of feed are: (1) natural grazings, (2) cultivated fodder crops, (3) browse (4) silage, (5) hay, (6) crop residues, and (7) purchased concentrates. The challenge faced on the diminishing Akamba smallholding during the course of its evolution consisted in how to raise or maintain feed resources, without unduly restricting the output of crops.

In parallel with the transformation of fertilization regimes on arable land, the progressive scarcity of grazing land has driven a revolution in livestock feeding systems which, similarly, is yet incomplete. One may see in close proximity, on the one hand a degraded and eroded vestige of common grazing, and on the other, intensive stall feeding of grade cattle.

7.2 Individual Title and Grazing Management

Critical in this revolution were the demarcation, enclosure and registration of grazing lands that were formerly open to common access. Mobile flocks and herds used to graze, unregulated, both near the homestead and in more distant rangelands. Sometimes, goats and fire were used to control bush growth. Otherwise, management was minimal. The failure of the Administration's attempt at compulsory destocking, with the famous march to Government House in 1938, lent impetus to a new policy to bring about individual tenure in the Reserve.

Live fencing with sisal or other plants was promoted for conservation purposes from the 1940s, and the economic value of sisal as a commercial crop (in the 1950s), or as a raw material for rope, mat or bag making, encouraged this trend. Registration of individual title to land, begun in the 1950s, has still not been completed throughout the District. In some areas of the south (AEZ 5), unregulated grazing across farm boundaries is still reported, but usually, grazing fees are payable on a monthly basis for the use of a neighbour's farm.

The accepted orthodoxy is that the demarcation and, later, registration of individual landholdings has forced livestock holdings into line with carrying capacity, and induced more sustainable forms of management. One farmer, interviewed in Masii, explained how, after buying a very degraded and steeply sloping piece of grazing in 1952, he destocked it (by sending his animals elsewhere) to allow natural regeneration to occur. Notwithstanding the droughts of the 1970s and 1980s, it is reported to be in better condition now than it was then, and still supports some stock. A major factor in his thinking is his need to provide viable inheritances for his two sons.

Rotational paddocks were promoted for soil conservation and better management of grazing land. However, as farms became smaller and cultivated areas increased, paddocks were no longer feasible on the majority of farms. In all the locations in which interviews were carried out in 1990, irrespective of ecology, it was said that only a few large farmers can still afford to operate this system.

7.3 Fodder Grasses and Trees

Major Joyce began testing varieties in 1932, and government trials on eight fodder plants, including Napier grass (*Pennisetum purpureum*), were carried out under the Reconditioning Programme in 1932-33. Napier, planted in contour strips in 1934 to provide stock feed in shambas, died however (Peberdy, 1958:14-19). But the drive continued: by 1937, 337 acres of Napier had been planted in half-acre plots on farms. The Department of Agriculture was still promoting it in the 1950s. 'The plant is a very hardy one, it is perennial and high yielder . . . In 1955 much propaganda was done to encourage people to plant it in dongas and streams with a fair amount of success, unfortunately the people are still too lazy to feed it to the cattle using the excuse that it is too far from the boma. It is now intended to encourage it as a shamba crop to be planted next to the cattle boma' (Peberdy, 1958:174). Sudan grass [*Pennisetum americanum (typhoides)*] also had good potential, Guinea grass (*Panicum maximum*) was considered a possible candidate for drier areas, and a number of other plants were evaluated if not subjected to trials.

Napier was strongly promoted in the 1960s as a dual purpose grass for fodder and conservation, and by the 1970s and 1980s, the fodder value of grasses planted for stabilising terrace banks, drainage ways and in gullies was fully appreciated on ever-diminishing smallholdings. *Panicum makarikariensis* has assumed a similar role in the drier zones (AEZ 4/5). It is thus impossible to consider the move into farm fodder production in isolation from the progress of conservation.

Competition between fodder and other crops, both for land and labour, has influenced their adoption. In the densely populated highlands, planting is restricted to terrace banks and tends to be close to the cattle boma, to ease the demands on labour for cutting and carrying the grass. Nevertheless the advantages are recognised. Some farmers buy in grass, and non-owners of livestock find it profitable to grow and sell fodder grasses. The terrace bank has provided a niche for growing fodder grasses that does not conflict with the needs of other crops. There is scope for improvement in the effectiveness of fodder production and use (Potter, 1987).

Trials of fodder trees (including some exotics) were made by the Veterinary Department in the 1930s, and several were reported in 1939 as growing well. *Acacia seyal* pods were found to be very acceptable to cattle, and significantly raised milk yields when in season on Major Joyce's farm (Peberdy, 1958:173). A plan to plant indigenous and exotic trees on farms, in half-acre plots, had achieved 220 acres by 1937, mainly in western and southern hill areas (Peberdy, 1958:19). It is not clear how much effort was put subsequently into promoting fodder trees, how many were planted on smallholdings, nor for that matter how many indigenous fodder trees grew spontaneously on farms. Browse is an integral part of the resource on grazing lands, especially for goats, and trees are managed accordingly (Gielen, 1982; Neunhauser et al., 1983).

7.4 Stall Feeding

Stall feeding (zero grazing) consists in keeping livestock in purpose-built enclosures, usually shaded, for part or all of the year, feeding them on a cut-and-carry basis and collecting the manure for use on the farm. All types of livestock may be so kept, but small ruminants may be more easily kept tethered on the farm during the daytime. The system is possible even on farms with little or no grazing land, provided that the amount of residues, fodder and (if necessary) purchased feed is sufficient.

In Kangundo, stall feeding was practised for at least a part of the year from the 1950s. It has since become quite common in the older settled areas. Much interest is expressed in the method, as it appears to offer the only way forward for livestock husbandry on farms threatened with more subdivision and conversion to arable.

Stall-feeding makes use of fodder and natural grasses and crop residues. Maize stalks and bean haulms are particularly important and universally used for this purpose. Stall-feeding, although labour-intensive, disposes of the problem of where to put livestock during the cropping season.

In 1985 the ADEC household survey (1986:6-37) obtained the figures about feeding systems shown in Table 7. The figures show that more livestock owners were practising stall-feeding (with or without grazing) than those who were not.

Table 7: Systems of feeding livestock (percentage of owners)

System	*Cattle*	*Sheep*	*Goats*
1. Zero grazing (hand-feeding) only	6	3	3
2. Hand-feeding and grazing in herds or flocks	53	50	47
3. Tethered grazing	10	9	15
4. Grazing only	31	35	34
Total	*100*	*97*	*99*

Source: ADEC 1986: 6-37.

The link between stall-feeding and fodder production is a close one. Ecological influence, and that of land supply, are noticeable upon the adoption of both (our interviews). In Kangundo and Mbooni (AEZ 2/3), almost all farmers are said to plant fodder, and stall feeding is the most common feeding system. In Masii (AEZ 4), only a few plant fodder or practise stall-feeding. In Makueni (AEZ 4/5), while some plant Napier or Rhodes grass, stall feeding was earlier tried, and abandoned. In Ngwata (AEZ 5), no farmers do either, according to reports. The ecological gradient thus correlates with the intensification of feeding systems, as expected. This sounds like our sample, not ADEC. Data on smallholdings in the upland and lowland ecozones in 1982 showed that the upland farms were smaller, produced more fodder, and had less grazing, than the lowland farms (Jaetzold and Schmidt, 1983:Vol.2c).

The Department of Agriculture saw the production of fodder crops, in conjunction with stall feeding, as the key to maintaining smallholder incomes at an acceptable level (Peberdy, 1958:172). European farming experience showed that fodder crops upheld milk yields in the dry season. Manure applications at 1-2 tonnes/ha were considered necessary to improve the fertility of the cultivated shambas. And only by means of fodder crops could the livestock population of the Reserve be supported without causing soil erosion on the grazing areas. This view has been largely accepted by Akamba farmers, though only a minority are in a position to apply manure at such levels.

7.5 Lessons from the Story of Feeding Systems

The challenge of supporting a minimal viable livestock herd on a diminishing landholding has dominated the evolution of feeding systems. This evolution from extensive grazing in the 1930s, through increasingly labour-intensive methods, to the growing popularity of stall-feeding in the 1990s, is consistent with a general trend towards agricultural intensification, driven by population growth and land scarcity.

The transfer of grazing land to cultivation has added impetus to the trend noted above, and reflects a fundamental shift in the relative priority of cropping and livestock enterprises in the farm system, in favour of the former. This has required a redefinition of the role of livestock in which nutrient recycling is increasingly important. Stall feeding and fodder crops further the integration of crop and livestock enterprises on the family holding. Intensive mixed farming appears capable of supporting more livestock units per hectare than its extensive grazing precursors. At the same time, it is fully consistent with conservationary objectives.

Individual title to land, expressed in the demarcation and enclosure of grazing areas, was a necessary condition for the intensification of the feeding systems on smallholdings. Its importance for the evolution of livestock husbandry cannot be overstated.

There is a marked divergence between the paths taken in the uplands (AEZ 2/3) and in the lowlands (AEZ 4/5). But although the upland environment appears to offer better possibilities than the lowland for sustainable productivity, lowland mixed farming, even in AEZ 5, has been shown to be more sustainable (in economic terms) in severe drought than specialist livestock husbandry in a similar environment. Lower proportionate losses, in time of drought, were attributable to the supply of crop residues, smaller herds, better market outlets and superior animal condition (Mukhebi et al., 1991).

8. CONCLUSION

This synthesis of experience in production technology in Machakos District over a period of 60 years has been necessarily fragmentary and incomplete. Its compelling justification is the fact that after a five-fold increase in population, natural resources that were either denuded and devegetated (in the Reserve), or inaccessible (on Crown and European land), are now found to be under productive smallholder management. The farming system understood to be in a crisis of evolution in the 1930s and 1940s (overgrazing and declining yields), is more sustainable now than it was then. The material is rich in policy implications, but only three general points are made here.

8.1 Sources of Innovations

The Machakos experience provides strong support for the idea that technological innovations originate from multiple sources, in geographical space, in time, and in the institutional sense (Biggs, 1989). The role of the farmers themselves is pre-eminent. Rather than being 'passive recipients of technologies developed by other people' they should be seen as 'active problem solvers who develop for themselves most of the technology they use' (Parton, 1990). Among the many examples that could be cited, farmers' experimentation with alternative varieties of maize, and adaptation of the ox-plough to terraced smallholder agriculture are outstanding. However, as both of these examples illustrate, farmers did not work in isolation. Government plant breeders (as we argue above) diversified the options available to maize growers, and the undocumented activities of traders and European farmers provided the plough and start-up experience. To these three sources must be added travelling Akamba (bringing back ideas from as near as Kikuyu or as far as Burma), commercial fruit and vegetable buyers, and, lately, NGOs. Others could be added.

Given a multiplicity of sources and promotional agencies, technological change is in 'continuous disequilibrium' (Biggs, 1989) amongst an assortment of interest groups. Interventions in the management of such change cannot sidestep the political economy of these interests, any more than it can avoid the technical implications of the low and erratic rainfall or the properties of the soils.

8.2 Intensification and Capitalisation

The thesis that technological change in smallholder agriculture is driven by population growth, via labour intensification, receives support from the transition to permanent cultivation (multicropping) on terraced fields, the evolution of fertilization regimes, and of livestock feeding systems, and the change that has occurred in the relative importance, functions, and integration of the cropping and livestock enterprises in the farming system. It is consistent with the adoption of coffee, fruit and horticultural production, and of grade livestock, in land-scarce areas, and of cotton where holdings were larger. We have not been able to find time-compatible data on labour inputs per hectare to substantiate the thesis, but the indirect evidence is compelling.

However, the experience of Machakos shows that labour intensification cannot be isolated analytically from capitalisation. Labour was both hired, and supplied from family and communal sources. Although no data have been found, it is widely reported that hired labour is used increasingly today. Not only does capital substitute for labour, but in several of the technologies having critical importance for intensification, it supplements it. For example, terrace construction required tools: effective manuring and composting require ox-carts and water drums; grade livestock require frequent dipping; coffee and vegetable crops need purchased inputs.

In a study of 16 innovating farmers, carried out in Machakos, Kitui, Embu and Meru District in 1986-87 (Ockwell, et al, 1990), it was found that the farmers could be divided into three groups on the basis of the innovations they had adopted. The first group were labour-intensifying practices (manuring, fodder cropping and terrace maintenance). The second group were yield-enhancing innovations (pre-rain land preparation, and improved maize and bean varieties). The third group were capital-intensive (ox-ploughing and the use of storage chemicals). Such a classification suggests a labour-to-capital continuum that is consistent with the observation that capital both substitutes for and supplements labour in productivity-enhancing technological change.[7]

8.3 Market Penetration

Also receiving ample confirmation from the Machakos experience is the thesis that market development drives technological change in agriculture. This is obvious with respect to crops produced wholly or partly for the market. The ups and downs of cotton (in the lowlands) and coffee (in the uplands) indicates a total dependency on marketing institutions and prices. It has also been argued above that fruit and horticultural production, though undertaken partly for home consumption and sale in local markets, is driven by long-term urbanization in Kenya, which has turned out to be more reliable than that for coffee or the industrial market for cotton, at least as mediated by their respective marketing institutions. It is also exported. In the livestock sector the growing market for milk is analogous, being relatively free from controls and driven by long-term social and demographic trends.

However markets do more than offer outlets for farm produce. The need for capital to invest in agricultural intensification or conservation, as well as recurrent income for paying for school fees, health and other services, taxation, consumer goods and food, precipitated every household into a deeper involvement in the cash economy. Occupational diversification and spatial mobility are well established. Intersectoral transfers occur at the household level - income from cash crops is spent on school fees, while migrant earnings are spent on terraces or ploughs, for example. Successful manipulation of the market economy - both within and without the District - is the key not only to wealth accumulation, but also to the capitalisation of land, which is the road to sustainable productivity. Today, farmers generally see capital scarcity as the major constraint on technology adoption.

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7 However, these authors' assertion that the three classes represent a continuum from least to most widely adopted receives no support from our study.

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Fax: 071-487 7590
Telex: 94082191 ODIUK