

The Australian Centre for International Agricultural Research (ACIAR) was established in June 1982 by an Act of the Australian Parliament. Its primary mandate is to help identify agricultural problems in developing countries and to commission collaborative research between Australian and developing country researchers in fields where Australia has special competence.

Where trade names are used this does not constitute endorsement of nor discrimination against any product by the Centre.

ACIAR MONOGRAPH SERIES

This peer-reviewed series contains the results of original research supported by ACIAR, or material deemed relevant to ACIAR's research and development objectives. The series is distributed internationally, with an emphasis on developing countries.

© Australian Centre for International Agricultural Research
GPO Box 1571, Canberra, Australia 2601.

Lee, Brian 1993. Escaping from Hunger: research to help farmers in semi-arid Kenya to grow enough food. ACIAR Monograph No. 23, 52p.

ISBN 1 86320 093 2

Design and production by BPD Graphic Associates, Canberra
Photos provided by dryland farming project staff and author
Printed by Goanna Print Pty Ltd, Canberra.

Escaping from Hunger

*Research to help farmers in
semi-arid Kenya to
grow enough food*

Brian Lee



*Australian Centre for International
Agricultural Research
Canberra 1993*

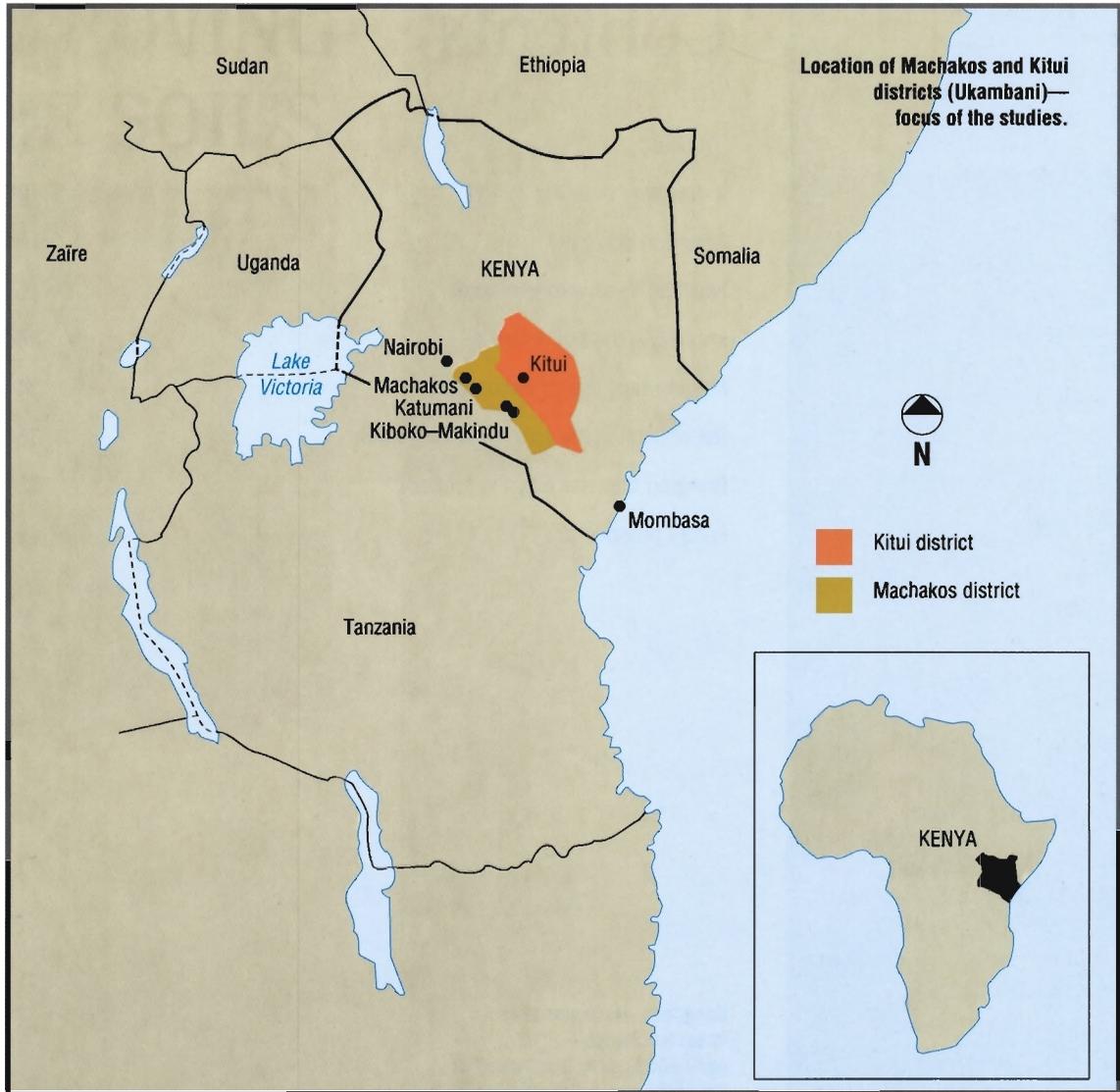




Contents

Foreword	5
A new way of doing things	6
A land in decline	10
Farming in an erratic climate	16
Improving the soil's fertility	26
Making best use of the rainfall	34
Rehabilitating the farm's grazing land	38
Bringing the new ways to farmers	43
Future prospects	48

**Kangundo, Machakos district
in eastern Kenya—
semi-arid farming land typical of
the study area covered in this book.**



Foreword

The population of Africa south of the Sahara is rising rapidly. In 1985 it stood at 460 million. By 2010 or earlier it will have topped 1 billion. More than half of this tropical region is semi-arid. Rain falls only in the 'rainy' seasons, and the amount that falls in different rainy seasons varies greatly. Often the rainfall will barely support a crop. Yet most people living in these semi-arid rural areas depend, and will continue to depend, on small-scale farming to grow their food. Production from farms has fallen, and continues to fall, and many farmers find themselves sliding into poverty as their land becomes less fertile.

Until now, more than 30 years of study by agriculturalists have failed to find ways to stop this slide. This booklet presents ideas that may at last help farmers in semi-arid parts of Kenya to slow,

or even stop the fall in the amount of food they can grow on their farms as the seasons pass. It should also be possible to adapt these ideas for farmers in other semi-arid parts of Africa.

The ideas came from a project that ran from 1984 to 1993 in which Kenyan and Australian scientists collaborated closely. Like Kenya, Australia has large semi-arid tropical areas, and Australian researchers have long experience of agricultural research in these regions. So it was hoped that collaboration could be fruitful. The results bear witness to the effectiveness of the cross-fertilisation that occurred as a consequence of the scientists from each country combining their different experiences.

The project has been supported by the Kenyan Government and the Australian Centre for International Agricultural Research (ACIAR), and has involved close collaboration between agricultural scientists

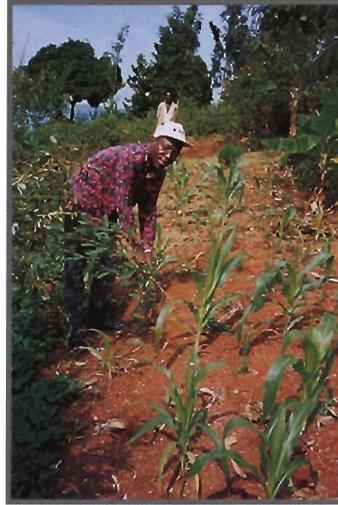
mainly from the Kenyan Agricultural Research Institute (KARI) and the Tropical Crops and Pastures Division of CSIRO, Australia's national research organisation.

This booklet summarises the main findings. The scientific justification for the findings appears in a companion volume entitled 'A Search for Strategies for Sustainable Dryland Cropping in Semi-arid Kenya'. This is the proceedings of a symposium held in Nairobi, Kenya in December 1990. ACIAR has published this as No. 41 in its ACIAR Proceedings series.

ACIAR is indebted to Dr Jeff Simpson, a former project leader in Nairobi, for his initial drafting of many of the sections of this book. Brian Lee recast it in close consultation with project scientists.

G.H.L. Rothschild
Director
ACIAR

A NEW WAY OF DOING THINGS



Simon Wambua inspects crops on a newly developed terrace near his farm.

Simon Wambua has a farm in a hilly area in northern Machakos District, to the east of Nairobi in Kenya. The farm is neither big, nor is it fertile. Also it does not receive a lot of rain. So Mr Wambua has no guarantee that his farm will be able to provide enough food for his family each year. To get extra cash for his family he works as a driver in Nairobi from Monday to Friday. He must leave the day-to-day running of the farm to his wife.

Mr Wambua's farm and his situation are typical of this semi-arid district where the human population pressure is rising rapidly, and the yield of food from the land is falling. Traditional farm practices are failing to maintain the fertility of the land, but the people do not know of a solution they can afford.

Simon Wambua has transformed his farm by judiciously using manure, composts and some commercial fertiliser. His farm grows more than enough food for his family every year, and he has a surplus to sell. He regards himself as lucky because a few years ago he was employed as a driver with a research project being jointly carried out by Kenyan and Australian scientists. He observed what the researchers were doing, and applied their ideas. This project, known as the KARI/ACIAR dryland farming project, was looking at new ways for subsistence farmers in the Machakos and Kitui Districts to keep their lands fertile.

After observing the activities of the project, Mr Wambua began experimenting with soil improvement himself. He became convinced that using limited amounts of commercial fertilisers, along with what manure his cattle produced and some of the trash remaining from his crops, provided the only viable option for maintaining the productivity of

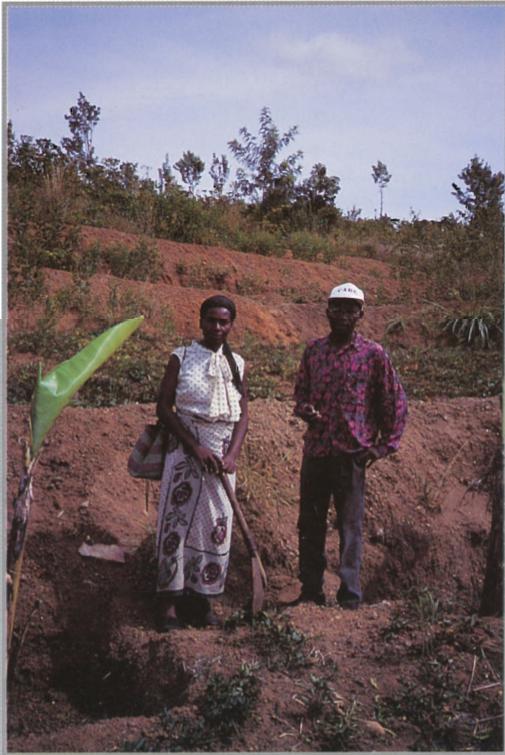
his rather infertile and eroded land. His success has proved him right.

Now, Mr Wambua demonstrates his methods and discusses the options with a local self-help (*mwethya*) group of 106 mainly women farmers, who belong to Kivoto *Mwethya* Group B. He has become a leader of the group. Together they are reclaiming

eroded slopes by building rocks into contour banks and forming arable terraces which are then stabilised by planting bana grass (*Pennisetum* sp.) on the banks. Soil fertility improvement will follow.

The committee of the Kivoto *Mwethya* (self-help) Group B builds a contour bank on an eroded slope owned by an elderly family.





Mrs Sila, secretary of the Kivoto *mwethya* group B, stands with Simon Wambua in front of a recently completed contour bank. A young crop is growing on the terrace, and bananas are planted with compost or manure in pits to collect seepage of water from the terrace above.

Such groups with energetic leadership are gaining the support of the District Agricultural Office and the District Development Committee. They are becoming a focus for dissemination of knowledge through the district and adaptation of the techniques by the farmers themselves.

Mr Wambua summarises the general aim of the self-help group thus: 'to engage people in activities that promote practical and positive attitudes toward local development'. More specifically, in the agricultural context, the immediate aim is 'to protect the soil from erosion, and increase the utilisation of nutrients by crops'. When asked how poor farmers like himself can afford to buy fertiliser, Mr Wambua replies without hesitation: 'Almost all farmers in this place have to buy food each year. Buying fertiliser is cheaper than buying food'.

The project studies Mr Wambua observed took place on farms in semi-arid parts of Machakos and Kitui Districts, on the National

Dryland Farming Research Centre (formerly Katumani Research Station), and on Kiboko Research Station. The area receives some 500–700 mm average annual rainfall over two short growing seasons. Such conditions are typical of some 13% of Kenya's land area. Another 72% of Kenya receives less than 500 mm annual rainfall and usually crops cannot be grown.

The agricultural problems of this semi-arid study area are similar to those already occurring, or likely to occur, in many other semi-arid areas of eastern and southern Africa. It should be possible to adapt the approaches used in the project for other countries.

The project produced valuable information in six main areas:

- why poor farmers farm in their particular way, and how they gain new information and make decisions
- how farmers can manage the variation in rainfall between good and poor seasons



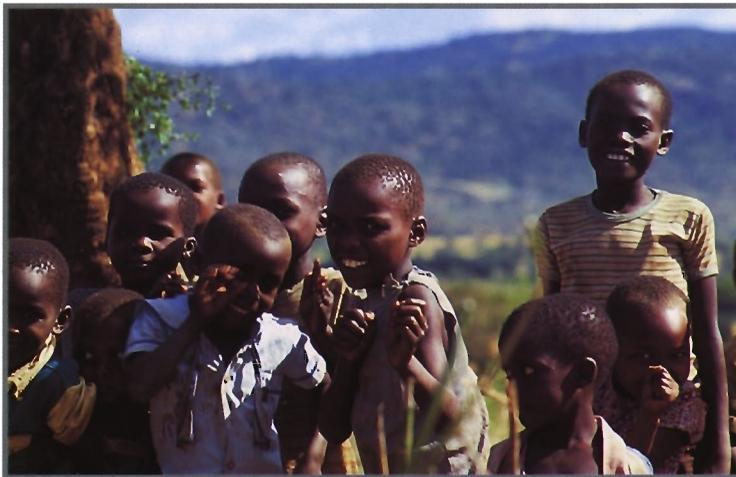
Mrs Sila, and senior members of the committee (front row) show papaws, pumpkins and pigeonpeas grown by group members. In the back row two local headmen, who support the group's activities, Mr Daniel Ngomo, the assistant chief, and Simon Wambua also look on.

- how farmers can reverse the decline in the fertility of their soils through making effective use of manure, grain legumes, and modest amounts of commercial fertilisers
- how farmers can help their crops to make maximum use of rainfall in any season
- how farmers may profitably renovate grazing land that has already lost most of its vegetation, and is heavily eroded
- how farmers can be encouraged to use new techniques that will progressively improve the productivity of their land.

While the project did not last long enough to provide exact recipes on what farmers in particular locations around Machakos should do to keep their land producing, it has yielded valuable ideas, which, as Mr Wambua has found, can certainly help.

A LAND IN DECLINE

The Machakos and Kitui Districts, where the KARI/ACIAR dryland farming project concentrated, and where Mr Wambua and the Akamba people live, is also known by the Kiswahili name of 'Ukambani'—the land of the Akamba. Historically, the Akamba were restricted to the wetter hills of what is now northern Machakos District (named after Chief Masaku) and neighbouring western Kitui. The rival Maasai cattle herders contested control of the surrounding plains and savannah lands.



Towards the end of the 19th century skirmishes between the Akamba and the Maasai subsided. As their population increased the Akamba expanded onto the surrounding plains. Initially, they used the plains for cattle herding, but the need to grow grain brought increasing cultivation around their homesteads.

To begin with the farmers practised shifting cultivation. As each cultivated site became less productive, due to soil depletion, they moved to another site. But, as the population pressure increased during this century, opportunities for shifting cultivation onto new desirable land diminished. The Akamba thus became more intensive cultivators on fixed locations, eventually with fixed land titles. Today the rate of population increase in Ukambani is one of

Akamba children: the population of Ukambani (Machakos and Kitui districts) is rising very rapidly, and new farm management strategies will be needed if these children are to remain well-fed.

the highest in the world, but the productivity of the soil continues to fall.

The social and economic problems of the area have been of concern for more than 70 years. There have been several cycles of rapid population growth, soil depletion and erosion, and attempts to solve the problem. These have included emigration to new settlement areas, terracing to protect the land from erosion, and introduction of an early-maturing maize variety, called 'Katumani Composite', that produces more than the traditional maize varieties in poor seasons. Nevertheless, soil fertility has continued to decline.

Farming risky

As in many tropical semi-arid areas, the variability and uncertainty of rainfall in different seasons present major problems for agriculture throughout Ukambani. Indeed, Ukambani and the surrounding region in Kenya and northern Tanzania have a particular problem

because they have two rainy seasons, known as the long and short rains, in which the rainfall can be very erratic. So farming is a risky business. Droughts during 1982 and 1983 brought crop failures and famine. Distribution of food aid became widespread. The long rains failed again in 1993. Nowadays at least one member of most households supplements the family income through off-farm employment, often in Nairobi or Coast Province in such service sectors as the police, army or private security services.

Farm sizes in the area studied vary, but generally they cover about 5–10 ha. Usually some 2–3 ha are under continuous cultivation and cropping, protected in at least 80% of cases by a distinctive type of terracing known in Kiswahili as *fanya juu* terraces. The terraces are built by hand, by digging trenches along the slopes and throwing the soil upwards to form

Fanya juu contour banks near Machakos. Farmers are making considerable investments in controlling rain-water runoff, and hence soil erosion, from their croplands.





a steep-sided contour bank. Over time, and with regular maintenance of the bank, erosion of the land in the upper part of the terrace down towards the bank produces a fairly level bench terrace. The terraces are expensive to construct, and the terraced land is valuable, restricted in size and normally is cropped twice a year during both rainy seasons. Pigeonpea crops stay in the ground for two seasons or more.

Major crops grown in the densely settled parts of Ukambani are maize and pulses such as

cowpeas, pigeonpeas, beans, and grams. Most farmers depend on a mixed system of growing most of the food needs of their household plus some cash crops (pulses, tobacco, fruits and cereal grain in excess of home needs). Animals are kept for providing draught power and meat for occasional home consumption, for sale to provide ready cash for such purposes as paying school fees, and increasingly for some milk production. Fruits such as bananas, mangoes, pawpaw and citrus are important in favoured locations within some farms.

Farm equipment in Ukambani generally consists of ox ploughs, hand tools and possibly a small cart, wheelbarrow or sledge for haulage over short distances. The areas that can be cultivated and weeded properly are therefore limited.

Cattle, goats and sheep are grazed on any uncultivated land on and around the farm. Grazing land is not protected by terracing since building terraces is not worth the extra cost. So farmers cannot rest their cropland and rotate their crops between the terraced cropland and their remaining grazing land. Most of the residues remaining from crops are fed to the animals in the dry seasons.

Farm equipment generally consists of hand tools, an oxen-drawn plough, and possibly a small cart, wheelbarrow or sledge that can be used for haulage over short distances. People travel by bicycle, public transport or on foot. Farm buildings consist of a homestead, several grain stores and a 'boma'—an uncovered area of perhaps 100 square metres, surrounded by cut thorn bushes

or fences, that is used for restricting and protecting livestock when they are not being herded.

The development of oxen-drawn ploughs has enabled the cultivation of 2–3 ha of cropland each season. This is the biggest area that can be seeded and weeded properly by the labour usually available in the farm family.

Human pressure increasing

As the human population pressure has continually increased, the amount of grazing land available to each farm has gradually become less. Usually the grazing land becomes overgrazed and denuded in the dry season. The soil erodes during the wet seasons, and productivity declines.

Farmers fight the decline in land productivity in different ways. The more progressive farmers use manure from the boma and spread it on the cropland. Because this involves heavy labour and careful timing

between crops, the manure usually stays in the boma for long periods, being removed and spread only once a year—in August–September at the end of the long dry season. While the manure remains in the bomas its nutrient content declines. It loses nitrogen and potassium, and probably some phosphorus. Some farmers are said to purchase manure from poorer farms, which only accelerates the fall in fertility around these farms.

The number of farmers using fertiliser is slowly increasing. A survey commissioned as part of the project showed that 18% of farmers used some fertiliser; only 8% of the same farmers used fertilisers when surveyed 10 years earlier.

Farmers commonly intercrop their maize crops with grain legumes. Pigeonpea is an important drought-resistant crop for eastern Kenya. It is grown in wide-spaced rows, being planted during the short rains and harvested some 9–12 months later during the long dry season.

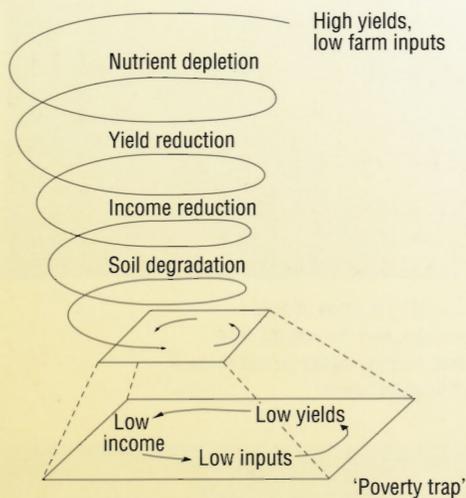


Grazing land is often heavily overgrazed, and the returns from building contour banks do not make it worth farmers' while.



Cattle are confined in 'bomas' (corrals) when they are not being herded. Manure accumulating in the bomas is a valued source of plant nutrients.

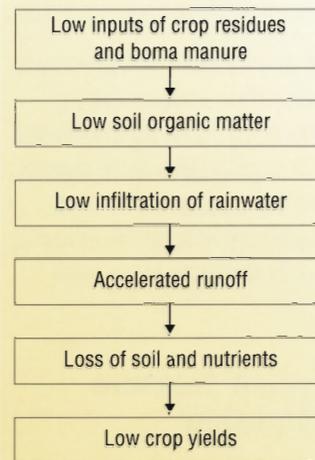
The descent into poverty



As the human population has increased, farmers have had to crop their land continuously, and levels of plant nutrients in the soils have fallen. As the soils have become impoverished, farm yields and incomes have dropped. So farm families have spiralled down into poverty and hunger. If feasible ways can be found for poor farmers to add modest amounts of nutrients to their soils, they may be able to stop the decline, and even reverse it.

Current farming practices cannot maintain adequate levels of organic matter in the soils. As levels fall, less rain-water soaks into the soil, runoff increases causing erosion and soil nutrient levels fall.

The soil degradation slide



farmers do not have enough, or cannot carry it far enough from the boma to fertilise most of their land adequately. For many, as the fertility of their land declines, they enter a spiral into poverty in which their farms yield less and less food, and from which they cannot escape. The KARI/ACIAR dryland farming project has yielded a new perspective on how this spiral may be reversed.

It is always intercropped with maize in at least the short rains (October–January).

If no manure or fertiliser is used, crop yields are generally low, and the soil becomes poorer with every crop. Average maize yields are reported to be in the range of 500-1000 kg per ha, and the remaining standing stalks and leaves after harvest (stover) are completely removed for animal feed. Even when manure is used to improve the soil fertility, most



Manure in a boma: although farmers value this resource, not enough is produced to supply adequate amounts of nutrients to all cropped land.

What the researchers did

The project team began by studying all aspects of the farming systems of the Machakos and Kitui Districts. They tried hard to understand the constraints on typical farm households within the study area, and how these constraints affected their farm management decisions. The researchers studied 18 farms that had been a case study group for an earlier USAID/UNDP project based at Katumani. Some 100 farms, including this earlier study group, were also surveyed with a detailed questionnaire early in 1990.

Field experiments on farms and on research stations measured important features of local maize cultivars as they grew, and recorded their responses to such management practices as planting the maize plants closer together and adding fertiliser, and the interactions between them. Using this information, the researchers adapted a computer model called CERES-Maize to develop a computer model called CMKEN for Kenyan maize varieties and conditions. Soil and weather conditions were carefully documented during each experiment, so that the results from each treatment at each site and season could be used to test and improve the predictions of the maize model.

Also, the research on maize production and simulation included studies on how treating the soil surface in different ways affects water losses after rain, soil erosion and crop growth. The purpose of these studies was to link erosion and the processes by which water moves in soils with crop growth models already in use. Doing this would allow the results of the experiments to be extended to other locations that have different rainfall regimes, soils and cropping systems.

Furthermore, practical experiments, many on farms, were designed to test the value of grain legumes in cropping rotations, to test ways of applying nitrogen and phosphorus fertilisers,

and to assess and improve farmers' use of boma manure.

In addition, the team developed a technique, known as 'Katumani pitting', for conserving and revegetating denuded and degraded grazing lands within farms. The effects of this rehabilitation technique on land productivity, and its possible impact on the economics of the whole farm, were studied at several locations.

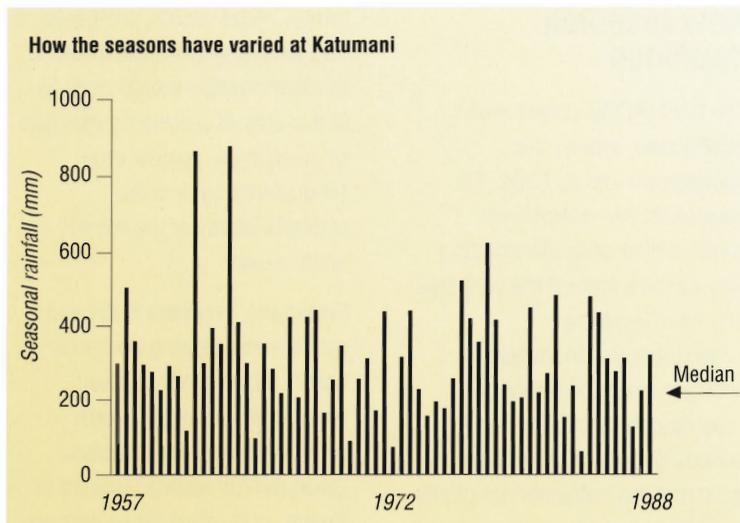
FARMING IN AN ERRATIC CLIMATE



A storm approaches in Ukambani. Variability in amounts of rainfall each rainy season makes growing crops risky.

In Ukambani, as elsewhere in the semi-arid tropics, the amount of rain falling each rainy season varies greatly. In droughts, not enough falls. In other years the total amount may appear adequate, but most of the rain may fall over too short a period for the plants to mature. Or it may fall as heavy storms. So farmers face the twin risks that their crops may not receive rain when they really need it, or that falls are so heavy that they cause erosion.

Farmers in Ukambani have the particular problem that while there are two growing seasons each year in the short and long rainy seasons, the distribution of the rainfall is unreliable for cropping in both seasons. The farmers therefore face a difficult dilemma. If they keep their investment of money and labour in their crops relatively low their chances of producing at least some grain are relatively high. If they invest more, they can produce more grain in good seasons, but the risk that their crops will be poor or fail completely in poor seasons is



Growing seasons around Katumani vary greatly, which makes growing crops a risky business.

also greater. If they are going to try to increase their yields, they have to balance the risk of underinvesting in their crop if the season turns out to be a good one against the risk of overinvesting, and possibly losing the investment, if the season turns out to be bad.

Research on cropping in the semi-arid lands of Kenya has a long history. Over some 30 years

researchers concentrated on understanding how crop growth was dependent on variations in the amount of water in the soil caused by different seasonal rainfalls. As well, they bred new maize varieties better adapted to Kenyan conditions and looked at various management strategies.

The complexity of the whole system, with growth and yield being affected by interactions between seasons, soil conditions and husbandry practices, soon became apparent. Any improvements in crop production through improving soil fertility,



A maize crop fails due to drought.



Heavy storms can cause serious erosion in croplands.

better soil management, better timing of planting, or use of more suitable crop varieties, were restricted and disrupted by the uncertainty of when rain would fall each season, and how much.

Maize breeding, based on crossing the early-maturing Taboran maize from central Tanzania with traditional Kenyan types, concentrated on selecting earlier-maturing varieties that would be less affected by the variable seasons of semi-arid Kenya. Eventually this approach produced the composite of varieties known and now widely used as Katumani Composite.

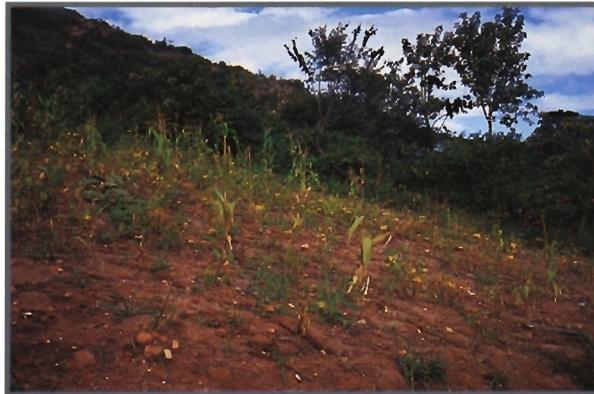
Early research attempted to discover the best way to grow crops in the average season—something that in practice almost never occurs. More recent studies produced a promising technique for assessing each individual season once it was already under way, and then adopting the husbandry practices most likely to produce the maximum yields with minimum costs. So in this system of 'response farming', the farmers assess whether the season is going to be good or bad from the pattern of the early rains, assess the risks of investing in their crops, and then decide on the investment they are willing to make.

New research approach

The KARI/ACIAR project was established against this background late in 1984. To begin with the researchers concentrated on understanding why farmers farmed the way they did, what were the consequences, and where changes might be suggested. They quickly learned that long periods of cultivation without replacing the nutrients that plants need to grow had greatly reduced the fertility of the soil, and that the risk of rainfall during the season being low strongly affected how much labour or money farmers were willing to invest in their

farms. To be useful, any research on increasing the productivity of the farm system would have to find a way of assessing the risks of investing in greater crop productivity against the unpredictability of the rainfall in each season.

Elsewhere, progress had been made in developing computer-based models that allowed researchers to explore farm production in risky climates. Good rainfall records existed in Kenya, and using these with an appropriate computer model could greatly help researchers in assessing the risks farmers must face when deciding what to do.



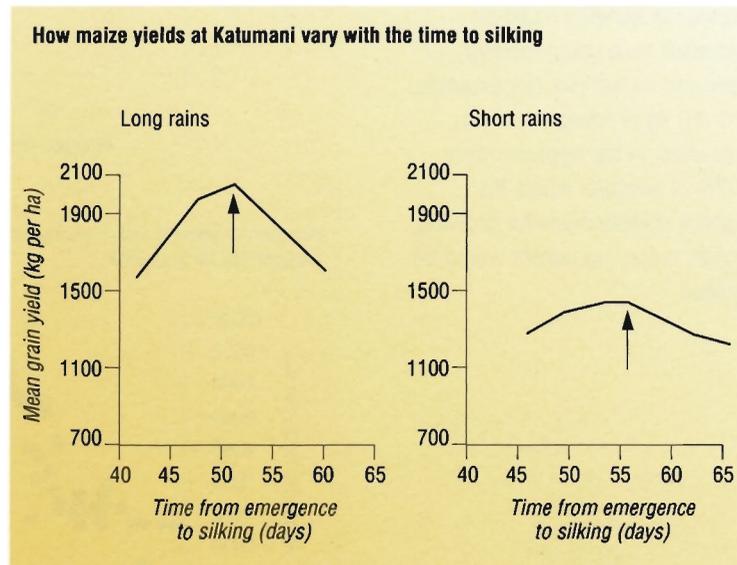
This maize crop on land that has been cropped continuously is failing because very little nitrogen remains in the soil.

Researchers in northern Australia, which is also tropical and semi-arid, had already begun to adapt what they considered to be the best available computer model of maize crops to semi-arid tropical conditions. This was the CERES-Maize model, which was developed for 'high-input' agriculture in North America. An important reason for choosing the model was that it had a submodel that dealt with nitrogen levels in the soil—essential because lack of nitrogen in semi-arid tropical soils often limits growth of crops. Once adjusted to the low-input, erratic-rainfall situation of farming in semi-arid Kenya, this model, renamed CMKEN, became a valuable tool for assessing information from both old and new experiments, and for drawing broadly applicable conclusions.

Use of the model, after testing and validating with experimental results, yielded the observations and conclusions that follow. Conditions experienced at Katumani are used as examples.

Importance of well adapted maize varieties The model showed the relative gains to be made from concentrating on breeding better-adapted maize cultivars compared with other approaches. Its use confirmed that the locally bred maize cultivar Katumani Composite B

(KCB) is well adapted to the rainfall regime around Katumani, so in this area there would be little point in attempting to breed a cultivar that flowers even earlier. For drier areas, breeding earlier-flowering cultivars would give only small gains in yields.



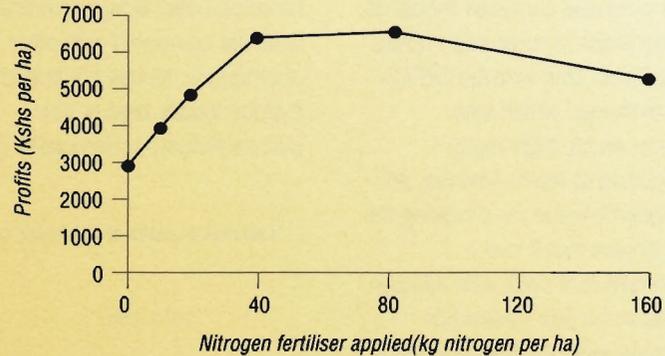
The arrows indicate the time to silking for the currently used Katumani Composite B (KCB) maize. The time to silking for this variety is optimal, giving the highest yields on average in both the long and short rains.

The benefits of using nitrogen

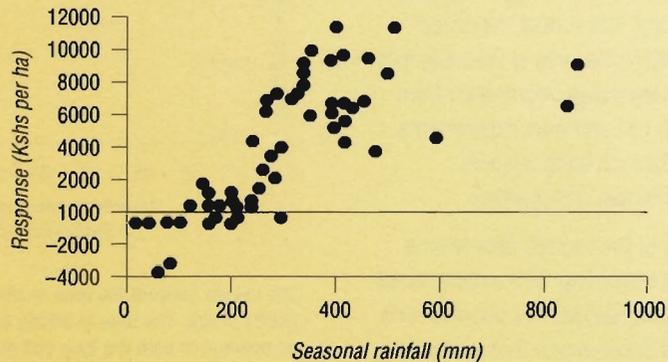
fertiliser Responses to nitrogen fertiliser vary greatly with the season, depending on the rainfall. The model simulated these effects for all seasons in the rainfall records for Katumani. On impoverished soils, typical of croplands in Ukambani, it appeared that substantial economic benefits could be obtained from using modest amounts of fertiliser (for example, 30–40 kg of nitrogen per ha). However, in the approximately 30% of seasons where the rainfall is inadequate for growing maize crops, no benefit would be gained.

Benefits to be gained from applying nitrogen fertiliser to impoverished soils

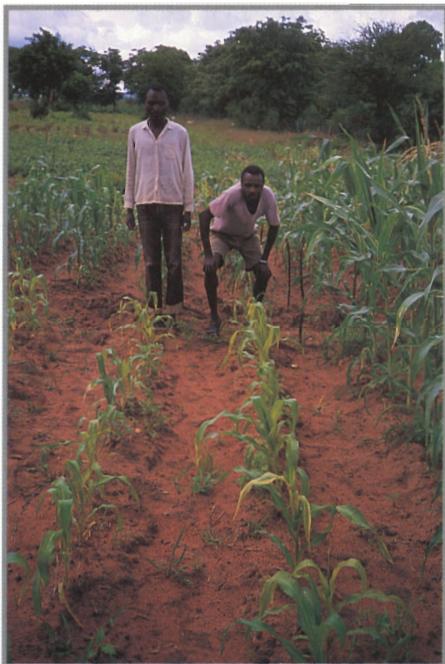
Estimated financial returns from applying nitrogen fertiliser



Variation of benefits with seasonal rainfall when 40 kg of fertiliser nitrogen per ha is applied

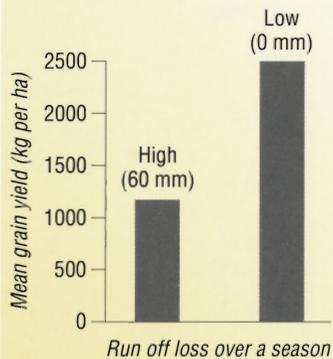


On average, farmers on impoverished soils should profit if they apply 30–40 kg of fertiliser nitrogen per ha. However, they will benefit in only about 70% of seasons, when enough rain falls to grow good maize crops.



Nitrogen fertiliser has been added to the healthy maize (left) on a farm in the study area. The two rows of plants in the centre, which were planted at the same time without fertiliser, remain pale and stunted.

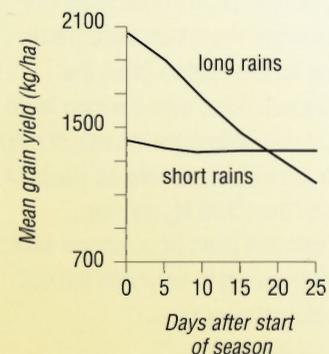
Reducing runoff increases maize yields



The 'high' runoff shown here represents the situation around Katumani in a typical sloping field where there is no protection for the soil. Eliminating runoff should double the average yield.

Making better use of the limited rainfall Using the model, researchers could examine the effects of practices such as mulching or contour ridging that reduce runoff of rain-water. While benefits were shown to vary greatly from year to year, average yields from all seasons in the climatic records were almost double if runoff could be totally eliminated.

Delaying planting reduces maize yields



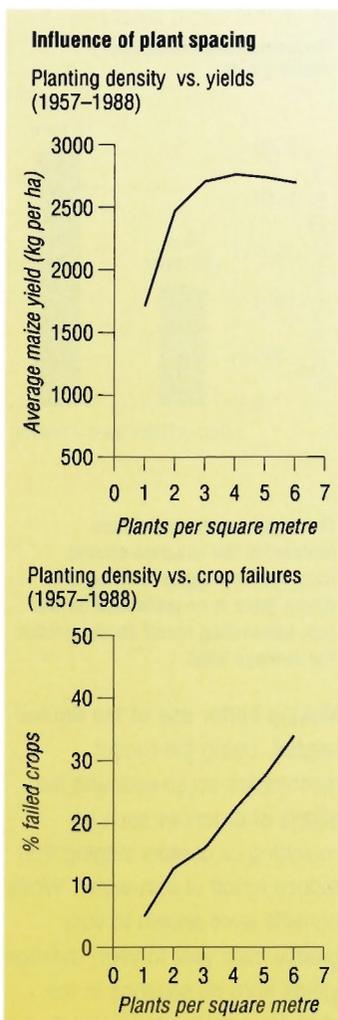
At Katumani, delaying planting by even a few days at the start of a rainy season can greatly reduce the final yield, especially in the long rains. Each 5-day delay gives progressive reductions.

Value of planting early The model showed how important it was to plant as soon as possible after the rains start, particularly with the long rains—as the graph for Katumani shows.

Getting the plant spacing right

The modelling studies showed how planting close together to give high plant populations (for example more than three plants per square metre) gives the highest yields over the long term, but also increases the risk of crop failures (defined here as yields of less than 300 kg per ha). Optimum plant populations were also shown to vary with the soil nitrogen supply.

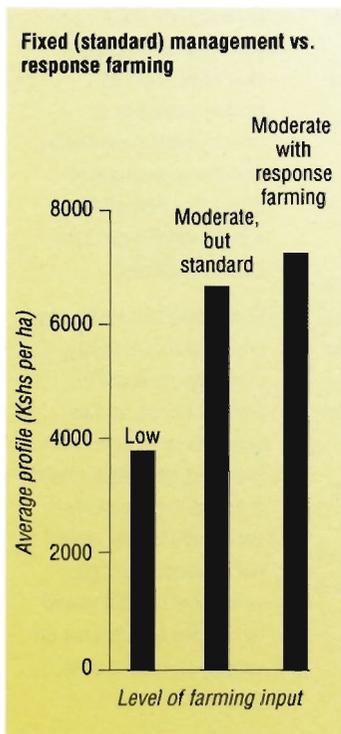
On the Katumani site, optimum plant spacings decreased as the nitrogen available rose with larger fertiliser applications. With no nitrogen fertiliser applied, about two plants per square metre was optimal, but with 20 or 40 kg per ha of nitrogen applied, the optimum rose to 3–4 plants per square metre. Placing the plants further apart decreased the risk of crop failure in drier years, but meant losing the possibility of higher yields in wet years if adequate soil nitrogen was also available.



On average planting closer together gives higher yields, but it also increases the risk of crop failure in poor seasons.

Potential of 'response farming'

The possible benefits from 'response farming', where nitrogen fertiliser applications and plant spacings are varied according to predictions of the seasons, were assessed using CMKEN. The model showed the approach provided reasonably good forecasts of each coming season. However, the additional benefit gained from using this tactical response, even with an ideal forecast, was small compared with the large benefits to be gained just from using a standard modest amount of nitrogen fertiliser (30–40 kg of nitrogen per ha), and a matching plant population (3–4 plants per square metre) regardless of the seasonal forecast. In other words, while on average farmers would be slightly better off using response farming, this would require a high level of skill, judgement and effort on the part of each farmer. The additional effort needed compared with using nitrogen fertiliser and the optimum plant spacing as a fixed farming procedure is probably not worth the additional effort.



Simulations indicated that response farming gives the best returns, but these returns are only slightly better than those achieved by using standard amounts of nitrogen fertiliser and the long-term optimum plant spacing as a fixed management practice every season, regardless of whether it turns out to be good or bad.

Yields that could be achieved

In conditions like those at Katumani, maize crops with the growth characteristics of Katumani Composite B (KCB) could yield on average about 2800 kg per ha if adequate nitrogen is available in the soil, there is little loss of water by runoff, and planting is early in the season at an appropriate plant spacing. At present, yields achieved by local farmers average less than 900 kg per ha without fertiliser.

The CMKEN model indicated that to achieve such a yield, the most attention should be paid to improving the nitrogen supply to the crop and minimising water losses by runoff. However, the prediction assumed that levels of other soil nutrients (particularly phosphorus) were adequate. This is by no means always the case. Finding socioeconomically feasible ways of supplying adequate nitrogen and phosphorus levels in the soil, and minimising runoff by better soil surface management thus became a focus for subsequent project activities.

Use of the model in different agro-ecological zones

The CMKEN model successfully showed the different maize yields that could be expected in various seasons at the climatically different locations of Katumani and Makindu. The researchers also made some preliminary attempts to project potential maize yields at Magarini near Malindi on Kenya's coast, and on the Laikipia plateau at 1800 metres above sea level to the northwest of Mount Kenya. Different types of maize are used at these climatically contrasting sites, and the soils are also quite different. Nevertheless, once the appropriate information about growth and development of the relevant varieties was incorporated into the CMKEN model, it did provide reasonable estimates of the seasonal potential for each site. No doubt these predictions could be improved with further research at these locations.

The CMKEN maize crop model—what it showed

The maize model adapted for use in Kenya is based on CERES-Maize—a model that was developed for high input agriculture in North America. The ability of CERES-Maize to predict maize yields accurately was tested and improved for semi-arid tropical, low-input conditions using information from both old and new field experiments in Kenya. The result was CMKEN. Having CMKEN available allows research in such environments to be conducted more efficiently, and with greater relevance to practical farming.

CMKEN helps research into improving production systems in African agriculture because it can simulate realistically how variable supplies of rain and nitrogen in the soil affect a maize crop, how the distance between plants affects their needs for water and nitrogen, and how different maize cultivars (varieties) perform with different rainfall patterns and nitrogen levels in the soil.

Using this tool makes it possible to make 'what would have happened if?' comparisons of a wide range of practices and strategies for different locations using historical daily rainfall records, which in Kenya often go back more than 30 years. The results provide valuable indications of what might be the best ways to farm in the future, and what might be the most rewarding targets for research and development.

Because the weather varies so much between seasons, results are most informative when expressed as probabilities. Simulating all possible variations of strategies, locations and rainfall in each growing season produces an enormous number of results. General conclusions from analyses for locations in Ukambani include:

- In the long rains, on average, delaying planting even a few days after the rains have started reduces yields

considerably, while delaying planting at the start of the short rains affects yields much less.

- The long-term optimum for spacings between plants in a maize crop can be simulated for different soil nitrogen levels but, inevitably, the variation in actual rainfall patterns will cause these simulated optima to be either too high or too low in some seasons.
- At levels of soil nitrogen typical of farms in Ukambani, application of nitrogen fertiliser to maize as a routine practice would generally be profitable (at 1991 fertiliser prices), but in poor seasons farmers face a high risk of not receiving adequate returns to cover their investment in fertiliser.
- Using early indications of how good a season is going to be to judge how much fertiliser to apply ('response farming') can reduce the risk of short-term financial loss.

- The crop yield increases to be gained from reducing runoff (using structures such as contour banking, or mulch) can be simulated, and the economics of doing this over all the widely varying seasons can be assessed.
- Katumoni Composite, the preferred maize variety currently available in eastern Kenya, is well suited to local conditions. Breeding programs aimed at shortening its maturity period still further would not increase average yields, although it would reduce the frequencies of very low yields in drier seasons.

In summary, the simulations of CMKEN showed that even in the risky environment of semi-arid Kenya, farmers do have the opportunity to improve water conservation and soil fertility on their farms, but doing so requires a high level of management.

Value of the model in other countries Use of the CMKEN model or its derivatives could also be valuable outside Kenya. There are many tropical semi-arid zones in eastern and southern Africa, as well as in northern Australia, where the model could be a valuable research and development tool. Indeed, closely related models developed simultaneously by Australian members of the research team for Australian use have been operational for some time.

Conclusion

In conclusion, the CMKEN model helped the researchers gain insights into many aspects of maize production in the Machakos and Kitui Districts. Modelling studies were always combined with experimental studies so that the accuracy of the model could be tested and improved.

The studies showed that the productivity of the Akamba farming system could best be increased by improving the soil nitrogen supply and reducing loss of rain-water through runoff. Currently used maize cultivars are well adapted to local conditions, and the advantages of planting early are already well recognised, if not always achieved. Often, however, unless the soil nitrogen supply is improved, no other management will have any impact. The spacing of crop plants also needs to match the amounts of nitrogen and water likely to be available in the soil, before the potential maize yield at each site can be achieved.

The studies confirmed that investing in inputs such as nitrogen fertilisers can be risky. The tactic known as 'response farming' had been advocated as a way of raising productivity and reducing risk. The CMKEN model

was able to test the value of response farming over a long period.

With further research, the CMKEN model can be applied elsewhere in Kenya and in other semi-arid tropical countries.

IMPROVING THE SOIL'S FERTILITY

To grow well, plants need a number of different nutrients from the soil. But some of these nutrients, especially nitrogen and phosphorus, are often not present in sufficient amounts.

Much of the nitrogen plants need is held in organic matter in the soil that is derived from previous generations of plants. However, the soils of Ukambani lack organic matter. Even before clearing of the natural vegetation they did not contain much, but when continually cultivated and cropped, the amount declines still further, leading to widespread nitrogen deficiency in the crops. Samples from farmers' fields showed that many of the soils also lack phosphorus.

The major soils are red sandy loam-surfaced deep soils (known as luvisols). Most of the cropland soils are impoverished. As the amount of organic matter in them declines, the structure of the surface soil deteriorates. Crusts form at the surface. These impede infiltration of rain-water, and the soils become more prone to erosion.

Protecting the cultivated land against erosion by *fanya juu* terracing (contour banks) was introduced during Kenya's colonial period. Farmers initially resisted the practice as they thought it an unnecessary cost. Now, after Presidential promotion campaigns and much publicity, more than 80% of farmers, especially those on the steeper slopes and undulating areas, protect their land with these contour banks. Almost all of these valuable terraced croplands are cultivated and cropped continuously, every season.



Newly constructed *fanya juu* terracing: more than 80% of farmers in semi-arid Ukambani protect their land with these contour banks. However, while these banks prevent erosion by controlling rain-water runoff, they do little to help maintain the soil's fertility.

Maintaining the fertility of the croplands when cropped twice each year has become a major challenge for farmers. Three actions they can take are:

- apply manure from their animal bomas to recycle nutrients that have been consumed by livestock
- include legumes in the rotation so that the continuous demands of the cereal crops for soil nitrogen are avoided, at least temporarily
- use commercial fertiliser (preferably in addition to boma manure and legumes).

Use of boma manure

Boma manure both provides nutrients and improves the soil structure by supplying organic matter. Earlier studies in the region had shown that using it can raise maize yields by more than 2000 kg per ha in wetter years. Farmers value their boma manure, but there is not enough to supply adequate amounts of nutrients to all cropped land.



Piles of manure from a boma ready for spreading on a farmer's field: evidence from a number of farms suggests that the manure is not spread very evenly.

Two project staff test manure piles: usually it is of poor quality since it is often mixed with soil, and a lot of nutrients are lost in the bomas before it is removed.

Soil fertility improvement in brief

Ukambani soils lack organic matter, and hence also nitrogen. Also the soils often form surface crusts because of their low organic matter levels, so less rain soaks into the soil, runoff of rainwater increases, and more erosion occurs. Even where terracing improves matters the maize crops do not yield well.

To obtain productive crops, farmers will need to continue the traditional practices of terracing their land to control rain-water runoff, spreading manure from their animal bomas, and growing crops of grain legumes as well as maize. This will help maintain both the soil moisture content and the levels of nitrogen so necessary for growing good cereal crops.

Doing this will not however maintain adequate nitrogen levels, and farmers will also need to add small amounts of nitrogen fertiliser to their land.

Many soils also do not contain enough phosphorus for the best plant growth. However, the phosphorus deficiency is often very patchy, even on individual terraces, so farmers may have to experiment to decide where they need to use phosphorus fertiliser.

Applying phosphorus fertiliser can have a beneficial effect for two or three seasons. Best results from applying phosphorus fertilisers will be obtained where good water conservation measures such as contour banking and mulching are maintained.

The manure is carried from the boma to the cropland by ox-cart or wheelbarrow during August or September each year in the dry season and deposited in heaps before being spread and ploughed in. Evidence from the very variable soil phosphorus analyses found across the cropland on a number of farms suggests the manure is not spread very evenly.

Project staff investigated how three farmers use this valuable organic nutrient source. They showed that the manure being carted to the croplands is of poor quality, partly because it is mixed with a lot of soil that is dug out of the bomas along with the manure. Nitrogen, phosphorus and potassium levels in the manure were only about one-third of those expected in fresh cattle manure. The farmers were applying quite large amounts of manure, but more even application over a larger area seemed desirable.

A lot of nutrients are apparently being lost from the the bomas. It appears that potassium and

calcium are being lost through leaching into the soils under the bomas and are not being recovered in the manure, while nitrogen is being lost as gases.

Some years ago, when the population pressure was lower and larger numbers of animals could be kept, enough boma manure may have been produced to sustain crop production. This is no longer possible, but farmers must continue to use this important resource efficiently to minimise dependence on other sources of nutrients. Undoubtedly farmers could make much better use of the nutrients in their boma manure if suitable management methods could be developed.

Legumes in the cropping rotation

Legumes are plants that have the remarkable ability to use nitrogen from the atmosphere and make it into proteins. So they do not need nitrogen in the soil to grow well. Some may leave a residue of nitrogen in the soil, which can be used by a subsequent cereal crop.

Grain legumes like beans, cowpeas, pigeonpeas and grams are grown widely in Ukambani and provide a valuable source of protein in the people's diet. This protein is obtained largely through fixing nitrogen from the atmosphere, without depleting the soil nitrogen. However, how much nitrogen remains after a legume crop for subsequent cereal crops remains unclear. Earlier studies at Katumani showed that the performance of cereal crops in different cropping rotations was closely related to the amount of nitrogen left in the soil as nitrate by the previous crop.

Project experiments in Ukambani have looked at the effect of two seasons of grain legume crops on the yield and nitrogen content of subsequent maize crops, and compared these with continuously cropped maize alone. Changes in the amount of nitrogen in the soil profile were also measured. The two experimental sites—near Masii and Wamunyu in Machakos District—were both on farms

where maize yields were extremely low due to depletion of soil fertility after long periods of cropping. The results at the two sites were very similar.

At Wamunyu, after removal of the legumes and ploughing in readiness for planting the maize crops, it was found that the amount of nitrogen as nitrate in the soil profile was 37 kg per ha higher than on the control plots that had grown only maize. Maize grown after the legumes benefited from this extra nitrogen, and produced 480 kg per ha of grain compared with 80 kg per ha where maize had been grown continuously.

While such yield increases are a useful boost in productivity, the yields achieved could be much greater. Neighbouring plots that had received applications of nitrogen fertiliser yielded as much as 2500 kg per ha.

On nitrogen-depleted soils, including cowpeas and pigeonpeas in the crop rotation results in a large lift in the total production (1,900 kg per ha was



Cowpeas grow between the maize rows: intercrops of legumes do not need nitrogen in the soil to grow well, and may even leave a residue of nitrogen behind.

harvested as cowpeas and pigeon peas compared with 70 kg per ha as maize).

The experiments did not include intercropping the maize and legumes, which is the usual practice in the region. However, studies from elsewhere suggest that residual effects from intercropped legumes will be less than those obtained from legume crops alone.

The need for supplementary nitrogen

Using of boma manure to recycle nutrients, and also grain legumes can certainly help to sustain grain production on Akamba farms. However, these sources are generally not large enough to satisfy the full nitrogen requirements of the maize crops. So most farmers who wish to increase maize yields have no option but to use commercial fertilisers to augment these other sources. The CMKEN computer model enabled the project researchers to evaluate the feasibility of doing this. Their studies showed that at 1991 fertiliser and maize grain prices using modest amounts of nitrogen fertiliser (20–40 kg of nitrogen per ha) would give increases in maize yields that should be economically attractive to many farmers.

Maintaining the soil phosphorus supply

Unfortunately, other nutrients as well as nitrogen may be in short supply. Farmers will not gain the full benefit of using nitrogen fertiliser if levels of other nutrients such as phosphorus and sulfur are low. By failing to recognise lack of other nutrients they will be disappointed at the response to applying nitrogen fertiliser, and may reject adopting an otherwise sound strategy. There have been very few reports so far of low sulfur levels in Ukambani soils. Many farmers, however, need to correct serious deficiencies of phosphorus.

A survey of 59 cropland terraces on 21 farms in 1990 revealed great variability in phosphorus contents. On 40% of terraces crops would be expected to respond to applications of phosphorus fertiliser because phosphorus levels were so low. Experiments confirmed that on land where extractable phosphorus values were low, application of phosphorus fertiliser was needed before crops

could respond fully to nitrogen fertiliser. In one experiment, maize yields more than doubled when both nitrogen and phosphorus fertilisers were applied compared with nitrogen fertiliser only. Cowpea and lablab crops also responded strongly to phosphorus fertilisers—in some instances the yield of cowpea grain being doubled when phosphorus was applied.

However, while nitrogen deficiency in maize crops is widespread, phosphorus deficiency is patchy. There is considerable variation both between terraces and within individual terraces. Serious phosphorus deficiency causes stunted maize plants with purple colouration in their leaves, but often the deficiency is not sufficiently serious to produce these symptoms, and it is not easy to know if phosphorus is restricting yields. Farmers should therefore be encouraged to experiment on small areas of their crops by applying a little phosphorus fertiliser to find out where they lack phosphorus.

The subsistence farmers in Ukambani have little experience in using any fertiliser. Needing to consider two nutrients (nitrogen and phosphorus) greatly complicates what they need to do to raise their land's productivity. The phosphorus fertilisers available to farmers are diammonium phosphate (DAP) at 18:18:0 (18% nitrogen, 18% phosphorus, 0% potassium) and 20:20:0 formulations. The nitrogen-containing ones they can obtain are the two types of DAP, and calcium ammonium nitrate (CAN), which contains 26% nitrogen, but no phosphorus.

A reasonable recommendation for farmers who cannot apply manure abundantly, and whose land has had a long history of cropping, is to apply DAP at 50–60 kg per ha at planting. This will add about 10 kg of nitrogen and 10 kg of phosphorus per ha. This initial application should be followed by a side dressing of CAN at a rate of 75–115 kg per ha after about 30 days to provide an additional 20–30 kg of nitrogen.



Extreme phosphorus deficiency in these maize plants is indicated by the purple colour in the leaves.



Applying nitrogen and phosphorus fertiliser on this farmer's land has produced a healthy crop (foreground). The maize behind has received no fertiliser.



A farmer applies fertiliser to her field. Only a modest amount is needed.

The researchers examined three ways of applying phosphorus fertiliser to find out how effectively it was used by the crop. These were:

- broadcasting it onto the soil
- placing it in bands 10 cm below the rows of seed
- placing it directly into the individual planting holes.

The results on three farms revealed that placing the fertiliser close by the plants, either by banding or placing it in the individual holes, gave a clear advantage over broadcasting it. However, placing the fertiliser into the individual holes provided no advantages over placing it in bands, so placing it in bands was preferred. An application of 10 kg of phosphorus per ha applied in this way was sufficient to correct phosphorus deficiency at these sites.

The project studies also showed that farmers will get the best response to applying phosphorus fertiliser when they also maintain good soil water management practices such as building contour banks or mulching.

One of the consequences of phosphorus deficiency is to delay silking in Katumani Composite B maize by up to 10 days. Such a delay could expose the crop to greater water stress during the grain filling stage, and so reduce yields.

Residual effects of phosphorus fertilisers

Phosphorus fertilisers usually have much longer-lasting effects than nitrogen fertilisers. Thus phosphorus fertiliser applied to a crop continues to benefit crops in subsequent seasons.

Project researchers found that superphosphate fertiliser banded 10 cm below the seed at planting, and left undisturbed by ploughing when preparing the land for the following season, benefited maize planted again along the

Alternative sources of phosphorus

The International Fertilizer Development Center (IFDC) is studying the possibility of developing phosphate rock sources within Africa. Using local sources, or reducing the amounts of acid used in the production of superphosphate fertiliser may give large savings in the cost of phosphorus fertiliser.

Project staff carried out an experiment to compare the relative effectiveness of three fertiliser materials prepared from the phosphate rock deposit at Minjingu near Lake Manyara in northern Tanzania, which can readily be imported into Kenya. The materials used were:

- commercial single superphosphate prepared in Nairobi from the Minjingu rock
- partially acidulated phosphate rock prepared by IFDC
- powdered beneficiated phosphate rock.

Preparing the acidulated phosphate rock involves digesting the phosphate rock with only half of the sulfuric acid needed for making superphosphate. This preparation is simpler and less costly than the normal fertiliser manufacture process.

The initial responses by maize to single superphosphate and partially acidulated phosphate rock were similar with no significant difference between these two sources of phosphate. The powdered phosphate rock was only about 25% as effective as the other sources on the slightly acidic soil of the trial. A fuller appraisal of the residual effects of powdered phosphate rock in later seasons is needed before conclusions can be reached about its suitability as a phosphate source on these soils.

same row. The residual effects persisted at least into the third season.

Such impressive residual effects greatly improve the economics of applying phosphorus. In some cases, applying phosphorus fertiliser once only every second season could probably be recommended.

MAKING BEST USE OF THE RAINFALL



In Ukambani, as in so many other parts of the semi-arid tropics, the rainfall is erratic. Because the soils are often degraded, considerable amounts of the rainfall can be lost as runoff during downpours. Thus less water enters the soil to be used by plants, crop yields are less than they might have been, and the flow of surface water carries away soil, causing erosion. Obviously, where scarce rain-water limits crop production, as much as possible should be retained in the soils of the croplands.

Heavy storms can cause serious erosion of croplands. Continuous cropping of sandy soils like these reduces their organic matter content. This causes the formation of surface crusts that prevent rain-water from soaking in, and accelerate erosion.

Runoff occurs when the intensity of rainfall exceeds the rate at which water can soak into the soil. The red, sandy luvisol soils of Ukambani have low organic matter levels, so their surface layers are weak. The impact of rainfall disperses the soil particles and the structure collapses to form a water-resistant surface crust.

Mulching maximises efficient rain-water use

Mulching croplands with crop residues from previous harvests improves infiltration of rain into the soil, and thereby reduces runoff and soil erosion.

Farmers in Ukambani feed their residues of maize stalks and leaves to their animals, a use that conflicts with using it as a mulch. By adding fertiliser to their crops farmers can increase production of both grain and residues. They could use the surplus residues as mulch.

By using some fertiliser, and foregoing the immediate opportunity to feed more livestock on the surplus residues, the farmer can reduce runoff and erosion, and in the long run improve the fertility of the farmland.

Current cropping and cultivation practices cause the amounts of soil organic matter to decline further, so the soils become more prone to surface crusting. Unfortunately, the excess water carries away the more fertile surface layers, thus further reducing the soil's ability to supply nutrients. So the cultivated soils become progressively less productive. Controlling runoff and enhancing the organic matter content of the soil are the key to maintaining the soil's fertility. The problem for local farmers is how they can do this when they do not have enough manure.

Experiments at Katumani have confirmed that mulching, by covering the soil with a layer of maize stalks and leaves retained from the previous harvest, or other plant wastes, can greatly reduce the runoff velocity of the rain-water. In time it also provides organic matter. So the mulch assists the water to soak into the soil, delays the collapse of the soil's surface structure and greatly reduces the amount of soil loss.

Local farmers already use terracing effectively to reduce water runoff and erosion. But this does not solve the basic problem of retaining water on the croplands, which is how to increase infiltration into the soils. Mulching is required, particularly on *fanya juu* terraces where the land slopes between the contour banks.

Practicalities of mulching

Unfortunately, farmers in Ukambani have no tradition of retaining crop residues for mulching because the residues are so valuable as livestock feed. Thus there is a conflict between using maize stover as animal feed and as a mulch to protect the croplands.

The demand for crop residues for feed is not likely to diminish much. Therefore, increasing production and using the surplus as mulch provides the only hope that some could be available to protect the soil. If, by using some fertiliser, the farmer increased



A woman and her husband carry maize stover (crop residues) for feeding to their livestock. Stover can also be a valuable source of mulch for the soil.

plant production above what is currently obtained under traditional practices, there would be extra stover that could be returned to the soil as surface mulch—assuming none of the extra was used for stock feed. Thus using fertiliser might not only increase grain and stover

yields directly through correcting nutrient deficiencies, it might also provide extra residues for use as mulch, which would improve water use efficiency, reduce erosion, and further improve the fertility of the soil.

In 1989, the project began a study (which is still continuing at a field site at Katumani) examining the principles and processes involved in controlling surface runoff, the advantages of

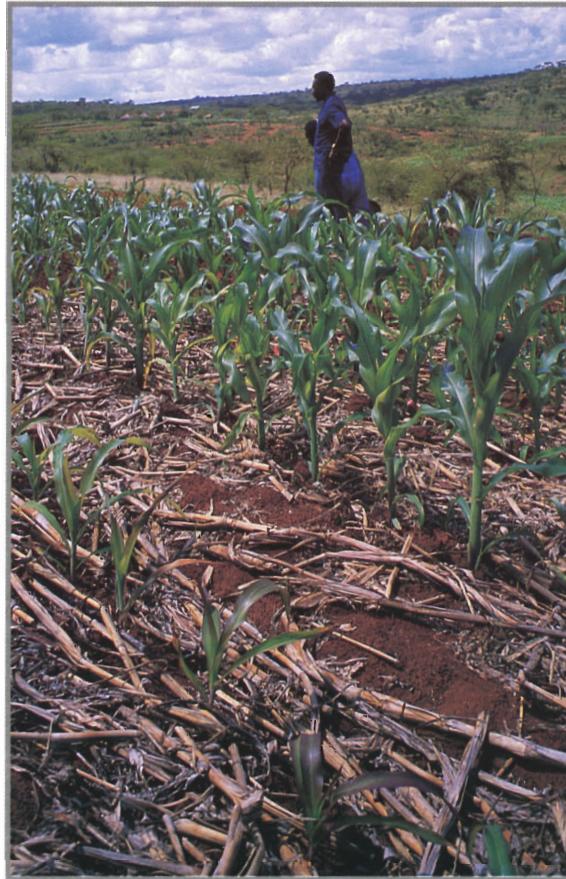
mulching, and the way it affects water use by maize crops. Treatments being studied include:

- traditional farm practices using no fertiliser and no return of residues as mulch
- returning half the maize stover produced without using fertiliser as a mulch
- returning all the extra stover produced as a result of fertiliser inputs as a mulch

- a 'high input' treatment, in which fertiliser is applied in amounts depending on the season and rainfall, and all the stover produced is returned as mulch.

Initial results indicate that in a good wet season when runoff occurs, returning the stover as a mulch in progressively larger amounts does reduce runoff, and greatly reduces soil loss. In one good season the soil loss was reduced from 47 tonnes per ha with no mulch to 7 tonnes per ha when all stover was retained as mulch.

Even in a considerably drier-than-average season, when little runoff occurred on any treatment, crop yields increased where stover had been retained as mulch. This indicates that the crop was making much more efficient use of the available rain-water.

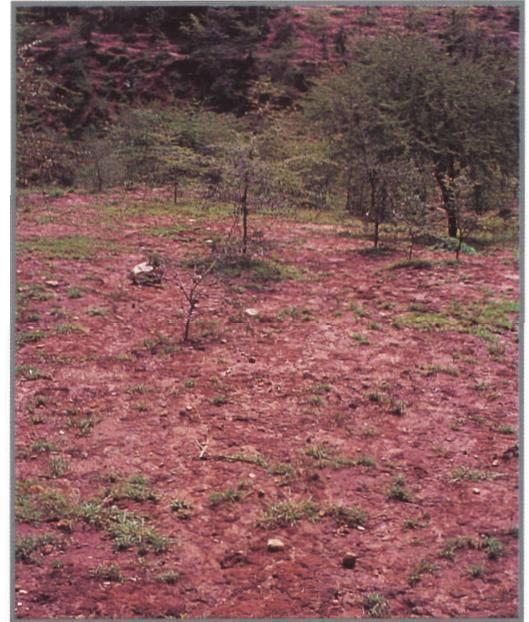


Residues from previous crops form a mulch for maize. Mulching improves infiltration of rain-water into the soil, and hence reduces runoff and erosion. In the long run it improves the fertility of the soil also.

REHABILITATING THE FARM'S GRAZING LAND

Cropped land on farms in Machakos and Kitui Districts is generally fairly well protected from erosion by *fanya juu* terracing. The grazing land on the farms, on the other hand, is often badly overgrazed. Loss of surface cover resulting from overgrazing leads to quite severe sheet and gully erosion, and to a very dramatic decline in the productivity of the land.

Project staff were concerned about this loss of productivity. They were even more concerned about the steady destruction of land that would be needed to produce crops in future years, as the human pressure on the land increased.



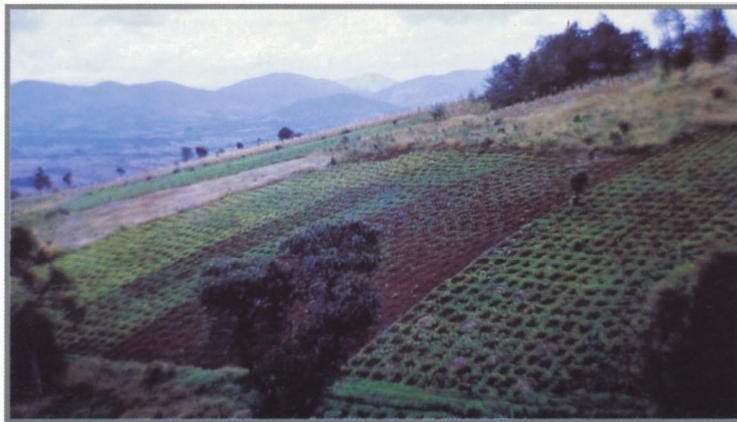
Uncontrolled grazing by farm animals denudes and degrades land that may soon be needed for growing crops.

Fanya juu terracing of the grazing land was not an option. For one thing, the cost and effort would not be justified by the returns from grazing. Also, making the terraces involves piling only the soil from a trench to form a retaining wall. Without ploughing up all the land to increase infiltration of water, massive

uncontrollable runoff comes off the eroded land and breaches the terrace walls at any low points. The project researchers therefore looked for other ideas on how to rehabilitate the eroded land.

Matengo pitting

A chance meeting with Mr Bill Gibbons, leader of the Arid and Semi-arid Land Project in Kitui at the time, drew the researchers' attention to a traditional pitting practice of the Matengo people of southwestern Tanzania. With



The Matengo people of southwestern Tanzania developed this pitting system for farming hilly land during the last century. The dryland farming project modified the system for use on eroded grazing lands in Kenya. The photo was taken by Dr J.E.G.Sutton in 1965.

modification it seemed to offer a solution for the eroded grazing lands of Ukambani.

The Matengo people were forced to retreat to the hills of southwestern Tanzania near Songea in the 1800s. They developed their pitting system, which totally eliminates runoff and soil loss, in response to the need to maximise productivity and to conserve all the soil, nutrients, and water on their land. They still practise the technique today and have achieved sustained farming on quite steep land.

A promising approach

Fanya juu terracing is not suitable for rehabilitating eroded grazing land. The project researchers therefore hit on the idea of modifying a traditional pitting system used by the Matengo people of southwestern Tanzania.

The modified system, known as 'Katumani pitting', successfully eliminates runoff, and hence also erosion. Excellent pastures have re-established after protection from grazing for only two seasons. The value of cash crops of cowpeas grown on the Katumani pitting system during the first season have fully covered costs of constructing the earthworks.

The system was tried on farms, but managed by the researchers. On-farm trials managed by farmers are now needed so that the technique can be modified, if necessary, before being widely recommended to farmers.



Newly dug Katumani pits on a slope on a farm near Katumani: small microcatchments are formed by digging crescent-shaped trenches along the lower boundary and piling the soil from the trench on the downhill side to form a loose retaining wall.

Forage legumes used most successfully for revegetating denuded land using Katumani pits

Species	Cultivar	Suggested seed rate per 2-square metre microcatchment (gm)
<i>Macroptilium atropurpureum</i>	Siratiro	2.0
<i>Macrotyloma axillare</i>	Archer	1.6
<i>Cassia rotundifolia</i>	Wynn	1.0
<i>Stylosanthes guianensis</i>	Cook	1.4
<i>Stylosanthes hamata</i>	Verano	1.4

Katumani pits

In the Kenyan project, the researchers modified the Matengo pitting system to suit eroded grazing lands. They formed small microcatchments on the sloping eroded land that were variable in shape, but approximately 2 square metres in area, by digging a crescent-shaped trench along the lower boundary. They heaped the soil from this trench onto the low side to form a loose retaining wall. This wall retained water within the microcatchment and became the the upper boundary of the catchment next below. Most of the land in each micro-catchment remained undisturbed, so during storms much of the rain-water ran off, to be trapped in the trench at the bottom.

The researchers dug a mosaic of pits, which they renamed 'Katumani pits', about 20% of the land being disturbed in the process. They then planted in each microcatchment a mixture of forage legumes that had shown promise in their earlier studies. The species used appear in the table on this page.

Digging the pits was quite labour-intensive, so the researchers sought a way to recoup these costs by growing a cash crop on the loose soil of the retaining walls. Cowpea proved a very suitable crop as it grew rapidly, fixed its own nitrogen, and produced a grain that was readily saleable at two or three times the price of maize.

Trapping the rain-water in the soil in the trenches right next to the cowpeas on the retaining walls, along with low weed competition on the walls, produced good conditions for the crop. Even though the cowpeas were planted on only the small part of the land covered by the walls, they usually yielded 500–900 kg of grain per pitted hectare. A little phosphorus fertiliser had to be applied on some soils. However, only a small handful (20 gm) was needed per pit (the equivalent of 10 kg of phosphorus per ha).

The pitting was so successful in retaining all rain that fell and any seed that would otherwise be carried away in runoff, that native grasses, planted legumes and

weeds were growing back very vigorously by the second season. For the cowpea crop it proved important to capture the favourable conditions in the first season, because competition for water and nutrients was too intense by the second and subsequent seasons for cowpea to produce acceptable yields.

The pasture legume lablab was so vigorous that it competed with cowpea even in the first season, unless sown only in a small cultivated strip across the middle of the otherwise undisturbed microcatchment. When broadcast, seed of other legumes, particularly *Stylosanthes scabra* and *Desmanthus virgatus*, was washed into the moist trenches where it germinated. Nevertheless, the plants were sufficiently slow-growing for them not to compete with the cowpea.

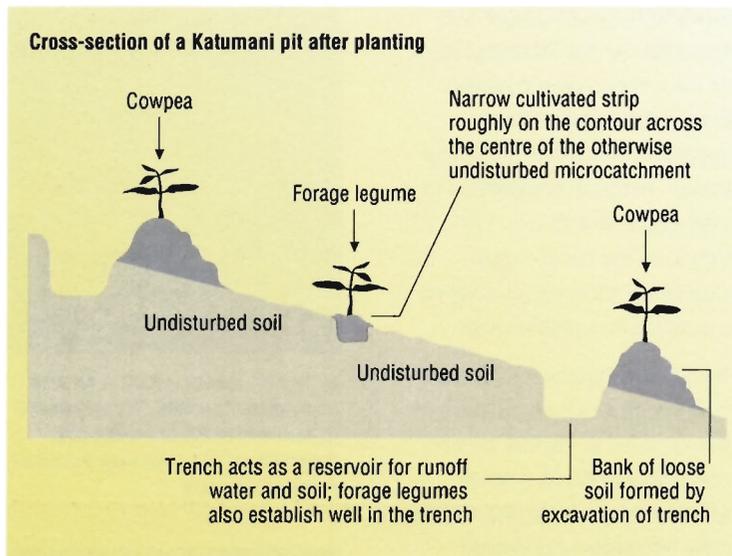
Preparing the land in the long dry season (August to October) seems ideal because it allows the pasture species to establish during the short rains, and to continue growing through the



In the first season a cash crop such as cowpeas is planted in the soft soil of the walls of the Katumani pits. Returns from this cash crop can cover construction costs.



By the second season, forage legumes planted in the Katumani pits during the first season, and native grasses, already provide an excellent cover of vegetation.



The experiments conducted to date, however, have all been managed and implemented by researchers. On-farm trials managed and implemented by farmers are needed so that the Katumani pitting technology can be modified, if necessary, before being widely recommended to farmers.

subsequent long rains between April and June. They are thus well established before the arrival of the long dry season in July. The cowpea seeds can be planted into dry soil at the start of the short rains, or into moist soil at the very earliest opportunity, so that they can gain the most benefit from the available growing season.

The practice has now been tried on five severely eroded farms in Machakos and Kitui Districts with spectacularly successful results. So the research team is confident that the new technology works. Excellent pastures have been re-established after protection from grazing for only two seasons. The economics also look favourable—the labour costs of about Kshs 4000 per hectare were fully recovered in most seasons from the value of cowpea crop.

BRINGING THE NEW WAYS TO FARMERS

The KARI/ACIAR project provided two main benefits. In the CMKEN computer model it provided a powerful new tool for research into the complexities of cropping systems in semi-arid lands. It also showed that it would be profitable for more farmers in Ukambani to use fertiliser, and that doing so should not be dismissed—as has normally been the case. The project thus demonstrated possible technical solutions to some of the agricultural problems of Ukambani. By judiciously using fertiliser, along with spreading boma manure and using land

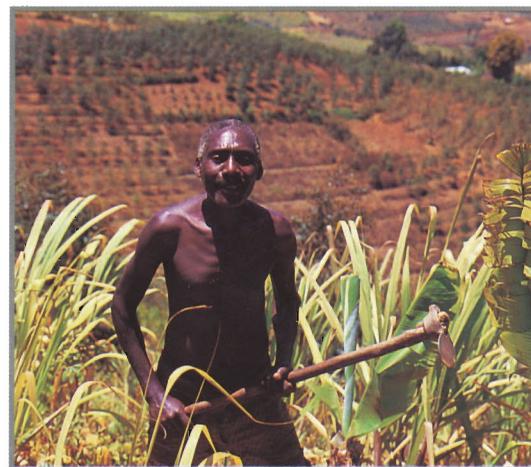
management that minimises rain-water runoff and maximises the rate at which rain-water soaks into the soil, farmers could slow, or even reverse, the decline in crop yields caused by degradation and impoverishment of the soil.

Many in the Kenyan agricultural research community accept the project's conclusions, and the Minister for Research, Science and Technology has made favourable comments in public. Staff of the Ministry for Reclamation and Development of Semi-arid, Arid and Wastelands, have also conveyed their appreciation of the project results.

But achieving such results is only a beginning. The farmers of Ukambani have yet to accept and adopt the 'improved' practices.

Adoption of new technologies can take a long time in any country, rich or poor. While researchers from industrialised countries may view use of chemical fertilisers as a simple technology, it is not.

Using fertilisers needs knowledge and skill. The fertiliser must be purchased with scarce cash, it must be stored, and the rates of application and their timing must be right. Farmers will be able to make profitable use of fertiliser only with careful management: otherwise the risk will be too high.



Many farmers in semi-arid Ukambani have resisted the idea of using fertilisers, but the number using it is slowly increasing. Surveys showed that by 1990 18% were using some fertiliser—10% more than 10 years earlier.

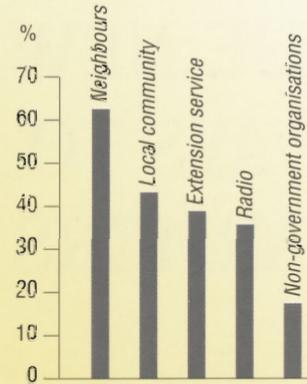


Questionnaires revealed that observing neighbours provides the most important source of information for most farmers. Here Simon Wambua admires a healthy maize crop on his farm with his cousin.

In general, farmers anywhere accept simple technologies much more readily than complex ones. So they will adopt using a new variety of maize or beans, which requires only a small cash outlay, much more readily than the complex package involving the use of fertilisers and overall improvements in management proposed in this case, where the outlays and risks are greater.

Project researchers surveyed the attitudes of Akamba farmers to changing their farm management and taking risks. Their studies suggested that generally the farmers would accept a new technology only if the expected increase in benefits (average gross margins) was greater than half the increase in the risk expected from variations in rainfall in different seasons. These attitudes are very similar to those of farmers in semi-arid areas of India and in various other countries. The researchers calculate that the changes in

Where Akamba farmers get their information



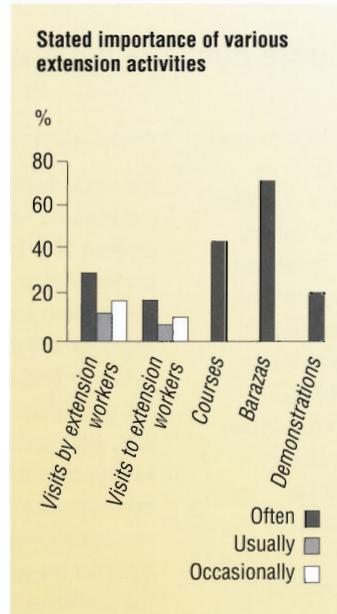
technology they are suggesting for Akamba farmers should meet this risk-return criterion, and therefore be acceptable.

Farmers resist fertilisers

However, the research staff at the National Dryland Farming Research Centre at Katumani have been advocating use of fertiliser for some years. While some farmers are both regular fertiliser users and clearly very successful, most remain sceptical and only a few are using it regularly.

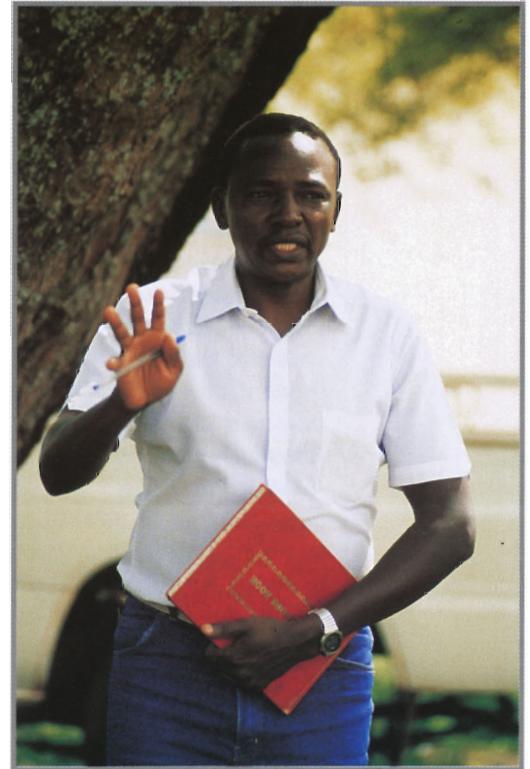
Most likely, farmers perceive the benefits achievable with fertilisers, relative to the risks involved, to be less than those indicated by the research. Also, while the extension services have promoted soil conservation practices such as terracing, using contour grass strips, and other techniques to prevent the physical movement of soils, extension officers themselves are much less familiar with the ideas of managing soil fertility.

Field days have revealed, perhaps not surprisingly, that most farmers of Ukambani do not know how to use fertilisers correctly. Also they do not understand the fundamental difference between the different fertilisers offered for sale. Farmers who are just becoming familiar with fertilisers do not distinguish between DAP (diammonium phosphate) and CAN (calcium ammonium nitrate). They may apply CAN at planting instead of DAP, with disappointing results if their soil lacks phosphate, and their seedlings may be burnt. Many farmers hold the belief that



fertiliser ‘poisons’ or ‘hardens’ the soil—an attitude that is often reinforced by expatriates from Europe and North America with their preoccupation with pollution caused by overuse of agricultural chemicals, including fertilisers.

Likewise, farmers generally do not accept that using manure, rotating crops and applying commercial fertilisers should all be done together. Results vary with each farmer’s



Surveys showed that the agricultural extension services are regarded as important sources of technical information. Farmers stated that local meetings (*barazas*) were their most important official information source. Here Dr Ben Ikombo, of the National Dryland Farming Research Centre, Katumani, discusses the achievements of the project.

Some possible options

Questionnaires presented to a wide range of Akamba farmers in 1990 revealed that 41% had attended some sort of short training course, and 20% had attended organised field days. However, the main sources of information about farming commonly mentioned by farmers were: observing neighbours (63%), from the local community (44%), extension services (38%), and radio and newspapers (36%).

Enhancing the productivity of cropped lands by combined use of manure, improved soil surface management, increased plant populations and both nitrogen and phosphorus fertilisers, as advocated by the KARI/ACIAR researchers, involves a complex package. All the components of the package are interdependent; oversimplifying by using only parts of the package could lead to

disappointing results.

The researchers suggest two approaches to this problem. The first is to get farmers to try out the whole package on only a small part of their cropland. Thus in these trial areas the planting time, plant populations, fertiliser application, weeding and soil surface management can all be kept near the optimum. The alternative is the stepwise approach of gradually increasing fertiliser use and the plant

populations together in modest steps. For example, for environments similar to Katumani, and where phosphorus levels in the soil appear adequate, the steps could be as indicated below.

Whichever approach is taken, the experience and example of the progressive farmers, such as Simon Wambua, who are already using fertiliser, manure, and mulch successfully on maize or various cash crops, are particularly valuable.

Current No fertiliser used, planting usually at density of about 1.5 plants per square metre.

Step 1 Apply 10 kg of nitrogen per ha as fertiliser, raise the planting density (for example to 2.2 plants per square metre) and return as mulch some of the extra stover produced.

Step 2 Apply 20 kg of nitrogen per ha, further raise the planting density (for example to 3.3 plants per square metre), and mulch with the extra stover.

Step 3 Apply 40 kg of nitrogen per ha, plant at an optimum density of 4.4 plants per square metre, and mulch.

circumstances. Appropriate modifications to whole farm management will therefore need designing for different farmers' requirements—according to farm size, livestock carried, labour available, cash crops grown, geographic locations, proximity to markets, and, especially, expectations of rainfall.

Suggested government action

While government extension services and self-help groups can do much to encourage the adoption and use of soil-fertility-improvement methods in semi-arid areas like Ukambani, changes to government policy could do much more. For example, they might subsidise the transport of fertiliser into the rural centres where it is likely to be used. Or they could promote packaging of fertiliser in small bags that farmers could afford to purchase for their first trials. Or they could arrange price incentives for private retailers to stock adequate quantities of the appropriate fertilisers, and have



them available at the start of each growing season.

In Kenya, as well as other countries in semi-arid Africa, the inevitable consequences of not changing land management practices need conveying in a more forceful way. The alternative in the long run is a descent into poverty and hunger. Some farms in Ukambani with sandier-surfaced soils, and where cropping has continued for many years with little addition of nutrients, are already obtaining very poor crop yields. These highlight the tragic consequences

Produce for sale in a Machakos market. Most families have to buy in food at some stage each year. With good management, using fertiliser in modest amounts can make a family self-sufficient, and be a cheaper option.

of neglect, which will drive more and more farm households into poverty from which it will become harder and harder to re-emerge. Despite all the difficulties, farmers must face the certainty that they can reverse the present trend only by investing in improving the fertility of their soil.

FUTURE PROSPECTS

Agriculture as currently practised in Ukambani is leading to impoverished and degraded soils, which in turn contribute to human hunger and create a poverty trap. To date there has been no obviously feasible way either to prevent this process or to reverse it. Central to the KARI/ACIAR dryland farming project has been the idea that if key limiting factors could be identified, it might be possible to slow or even reverse the downward slide by gradually changing the system.



Mrs Ikombo, an outstanding farmer near Katumani, has shown that farm productivity can be built up without outside financial help, even in the risky semi-arid environment of Ukambani.

By the time the project began, it was already known that there were widespread deficiencies of nitrogen and phosphorus in the soils. Yet agricultural experts generally rejected use of fertiliser as even part of a 'solution'. The reason often given was that 'farmers here cannot afford fertiliser', and therefore research on its use would not be relevant.

While the project staff accepted the fact that very few farmers used fertiliser, they were equally conscious that if a lack of soil nitrogen is a major constraint, no other management change could help unless soil nitrogen levels were increased.

The project researchers therefore proceeded on two fronts. Firstly, they made great efforts to gain a better understanding of why so few farmers used fertiliser and, perhaps equally importantly, what were the circumstances of the few that did. Secondly, they began an assessment of the costs and benefits of using manure, legumes, and fertiliser as nitrogen sources.

In a semi-arid climate such as that in Ukambani, assessing the benefits gained from adding nitrogen is particularly difficult because of the variation in rainfall between and within seasons. Responses to added nutrients are high when the water supply is ample, but they are low when lack of water strongly limits growth. Conducting in such an environment experiments that

compare adequately the effects of different management options under all likely seasonal variations would take impossibly long using conventional means.

After validation, the CMKEN computer model provided the means to simulate and compare returns and risks with various investments in fertiliser and other forms of management in a great variety of seasons, and to answer the question of under what circumstances it is economically appropriate or inappropriate to use fertiliser.

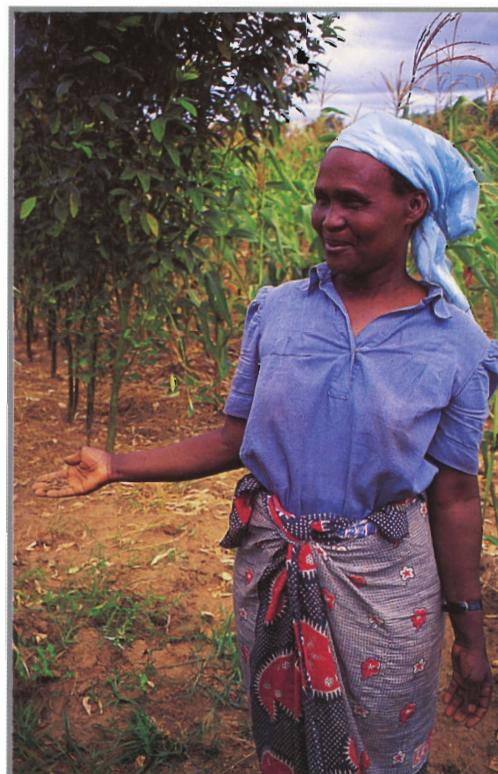
For many Akamba farmers, the benefits of judiciously using fertilisers along with spreading boma manure and using such techniques as mulching to increase the amount of rainfall soaking into the soil should outweigh the risks.

The researchers' studies of farmers who used no fertiliser indicated that their knowledge about fertilisers and their skills in using them were poor, and they regarded doing so as too risky. Their studies of farmers who used

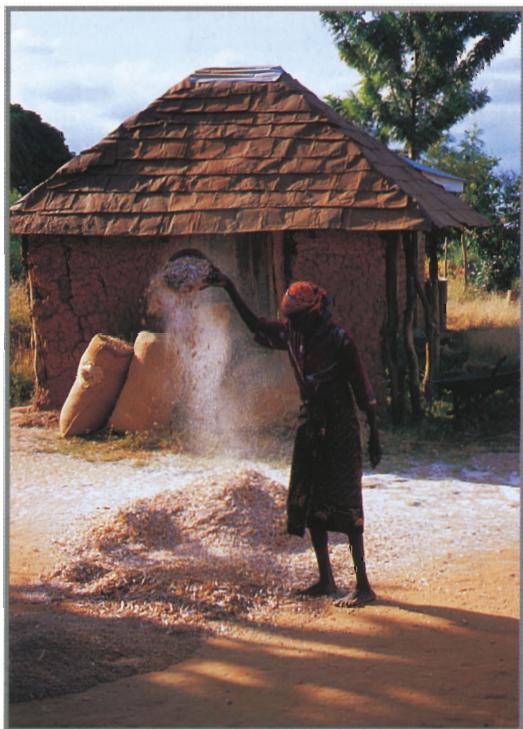
fertiliser revealed that doing so could indeed be very profitable. However, those who were successfully using fertiliser had received 'educational' experience before starting, either through short courses in farm management, or through observation (as in the case of Simon Wambua, the project's driver). Not all farmers can have such 'education'. Nevertheless, the project's surveys revealed that more farmers were using fertiliser than at the time of the previous USAID/UNDP survey 10 years earlier.

Good management succeeds

The experience of the Ikombo family gives hope. Dr Ben Ikombo worked with the project, but the success of his family farm far pre-dated the project. Over several generations his family has invested in education, which no doubt provided the ability to assess and apply new ideas. His family has been using fertiliser on their farm since the early 1970s, and since then they



'This small amount of fertiliser is all you need for each plant', says Mrs Ikombo.



Winnowing at the Ikombo farm. By using modest amounts of fertiliser and good soil management on their farm, the family has avoided needing to buy in food since the early 1970s, despite major droughts.

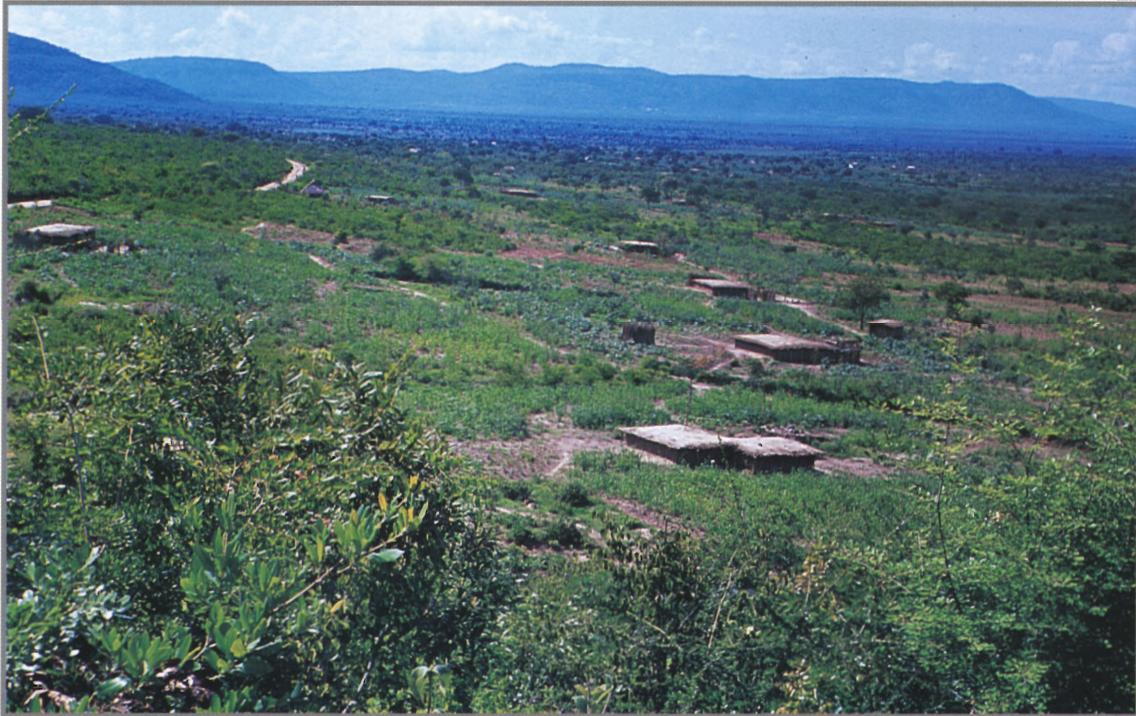
have not needed to buy in food, despite major droughts.

Ben Ikombo's sister-in-law was a farmer who went on a one-week training course near Katumani in about 1970. She received a small bag of fertiliser at the end of the course. Ben Ikombo's mother observed what her daughter-in-law was doing, and began to grow outstanding crops of maize along with cowpeas as intercrops or in rotations. Convinced by her success, other members of the family finally also began using her methods some time later.

Today the family is prosperous. During the 1980s its members felt sufficiently secure to start growing tomatoes and to sell them by the roadside, and then in a shop, with great success. The profits from this venture enabled the family to bring in a bulldozer to build a small farm dam to collect rain-water running off the road, and they have been able to expand into horticultural crops on a large scale.

The Ikombos are exceptional farmers. However, there is nothing exceptional about their land, which is typical of that near Katumani. By using good management, which included use of fertiliser and soil and water conservation, they have, over more than 20 years, built up their farm to its present productivity without outside financial help. By doing so they have shown what can be done even in the risky semi-arid environment of Ukambani. The experience, mentioned at the beginning of this book, of Simon Wambua and his *mwethya* group gives hope that their example can be followed.

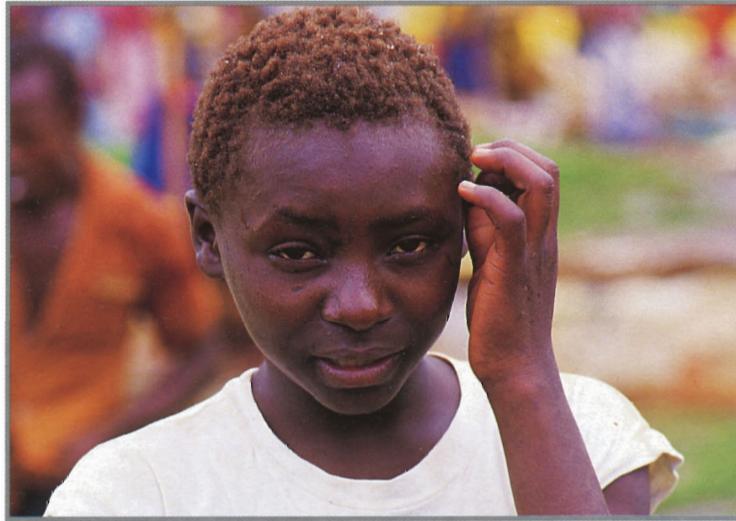
The general approaches of the project are applicable to farmers far beyond Ukambani. They are equally relevant elsewhere in Kenya. The CMKEN computer model has already been used to explore maize production strategies in different conditions at 1800 metres on the Laikipia Plateau, and at sea level on the Kenyan coast. Similar models have been developed for the



harsh semi-arid areas of northern Australia, where there is one short 3-month wet season each year. The researchers of the KARI/ACIAR project are confident that their general approach in

Kenya can be adapted to boost the impact of research on cropping systems elsewhere in the semi-arid lands of Sub-Saharan Africa.

Farming settlement at Chungai in semi-arid central Tanzania. The CMKEN model makes it possible to explore maize production strategies in much of semi-arid Sub-Saharan Africa.



The dryland farming project brought a message of hope: with good farm management future generations need not be trapped in poverty.

Acknowledgements

ACIAR gratefully acknowledges the contributions to the dryland farming project in Kenya of the following from Kenya and Australia.

Kenya

Mr E.M. (Elias) Gichangi
Dr B.M. (Ben) Ikombo
Dr J.K. (Justus) Itabari
Mr D.R. (David) Karanja
Mr S.K. (Samuel) Kitheka
The late Mr P.K. (Peter) Kusewa
Mr J.K. (John) Lekasi
Dr F.K. (Florence) Lenga
Dr F.N. (Fred) Muchena
Mr L. (Lutta) Muhammad
Mr S.N. (Simon) Nguluu
Mr D.M. (Donald) Njarui
Dr J.R. (Robert) Okalebo
Mr E.G. (George) Okwach
Mr M.M.S. (Moses) Siambi
Mr S.C. (Cephas) Simiyu
Mr B.M. (Benson) Wafula
Mr J. (John) Wambua
Mr J.M. (James) Watiki

Australia

Mr S.W. (Steve) Bailey
Mr W.M. (Bill) Beattie
Dr P.S. (Peter) Carberry
Mr N.P. (Neal) Dalgleish
Dr J.P. (John) Dimes
Dr R.K. (Roger) Jones
Dr J.N.G. (John) Hargreaves
Dr P.B. (Peter) Hairsine
Mr R.F. (Ray) Isbell
Dr B.A. (Brian) Keating
Mr A.G. (Greg) Larkens
Dr R.L. (Bob) McCown
Dr A.T. (Tony) Ockwell
Dr K.A. (Kevin) Parton
Dr M.E. (Merv) Probert
Mrs H.E. (Helen) Rodd
Professor C.W. (Calvin) Rose
Dr J.G. (Jim) Ryan
Dr J.R. (Jeff) Simpson
Dr B.H. (Brian) Wall
Dr J. (John) Williams

ACIAR also gratefully acknowledges the enthusiastic support given to the project by Their Excellencies Mr A.G.D. (Geoffrey) White, Mr D.S. (Doug) Campbell and Mr D.C. (David) Goss, three successive Australian High Commissioners to Kenya, and their staff.