THEME

Strategies for Sustainable Crop Production in Semi-Arid Africa

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This is a record of the experience of a research team attempting to identify a development path for a farming system in semi-arid Africa. The farming system is the largely-subsistence production of crops and livestock by smallholders in the Machakos and Kitui Districts in Eastern Kenya. The region is known locally as *Ukambani*- "the place where the Kamba people live". This region has a long history in which the food demands of rapidly growing populations have periodically outstripped the productive capacity of the land and current technology. Today, the population pressure on land and its rate of growth are among the highest in the world, and emigration is no longer a feasible solution. But numerous other areas of Africa are not far behind in population pressures and a more sustainable agriculture in this region is important not only for Kenya. Almost certainly, the problems of agriculture in Machakos-Kitui today represent a future scenario for much of semi-arid Africa.

This article is also concerned with methodology for conducting research on farming systems. While the project was designed according to the concepts of Farming Systems Research (FSR) (Collinson, 1982), the realities of development assistance projects created challenges in implementation. The research also departed from the conventional FSR plan as new possibilities were realized, and with great benefit.

The outcome is a well-founded hypothesis: contrary to much contemporary wisdom, a strategy of augmenting traditional soil enrichment practices with modest amounts of fertilizer is economically feasible for many farmers and provides the best prospects for food security and sustainable agriculture in this climatic zone.

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Background to the farming system

The typical farming household of semi-arid Eastern Kenya owns a small area of land on which crops are produced and which partially supports variable numbers of cattle, sheep and goats. The unreliability of rainfall makes crop production very risky. The mean annual rainfall in the region ranges from 500 to 700 mm. It falls in two short growing seasons, termed locally the "long rains" and the "short rains". Crops, mainly maize and pulses, are produced in both seasons. Crop production plots are generally terraced. Plots are cultivated continuously in the climatically better-endowed areas. In spite of annual application of manure from open bomas (corrals) to selected terraces or parts of terraces, soil fertility is generally and conspicuously low. Few farmers use fertilizer in spite of local retail access to stocks held to service demands of coffee farms in the small areas of high elevation and high rainfall. Cattle, goats, and sheep are grazed on uncultivated areas both on- and off-farm; they are also fed crop residues carried to the boma. Crops provide a variable proportion of family food needs; sale of animals provides timely cash flow to satisfy important family needs. Remittances or wages are an important source of income for most farm households (Rukandema *et al.*, 1981; O'Leary, 1984).

Project design, on-farm diagnosis, project redesign

This project stemmed from another in semi-arid tropical Australia in which a systems approach was used to identify a strategy for sustainable dryland crop production (Jones and McCown, 1984). Ideas were further developed by a consultative process featuring an Eastern Africa symposium of scientists and research administrators, jointly hosted by the Kenyan National Council for Science and Technology and the Australian Centre for International Agricultural Research (ACIAR, 1984).

From the outset, the research approach envisioned was that of FSR as depicted in Figure 1, and described in the context of an Australian involvement in Kenya by Dillon and Anderson (1984). One of the first project activities was to design and implement a study of 18 farms which had been surveyed as part of a much larger sample ten years earlier and used subsequently as pre-extension trial farms for a number of new production technologies. The aim of the study, by a small team of Kenyan and Australian economists and agronomists, was to gain insight to the behaviour of these farmers that might guide the new project's R&D activities (Ockwell *et al.*, in press).

Logically, in this process, one awaits some outcome of Step 2 (Figure 1) before making major commitments to other steps. However, in a project with only a three-year planning horizon, compromises were necessary. Commitments had to be made to begin certain research at the same time as the on-farm diagnostic studies. One of these "best bets" was the evaluation of a range of pasture and forage legumes selected from germ plasm collections assembled in Australia on the basis of probable adaptation to the mid-lands of eastern Africa. The

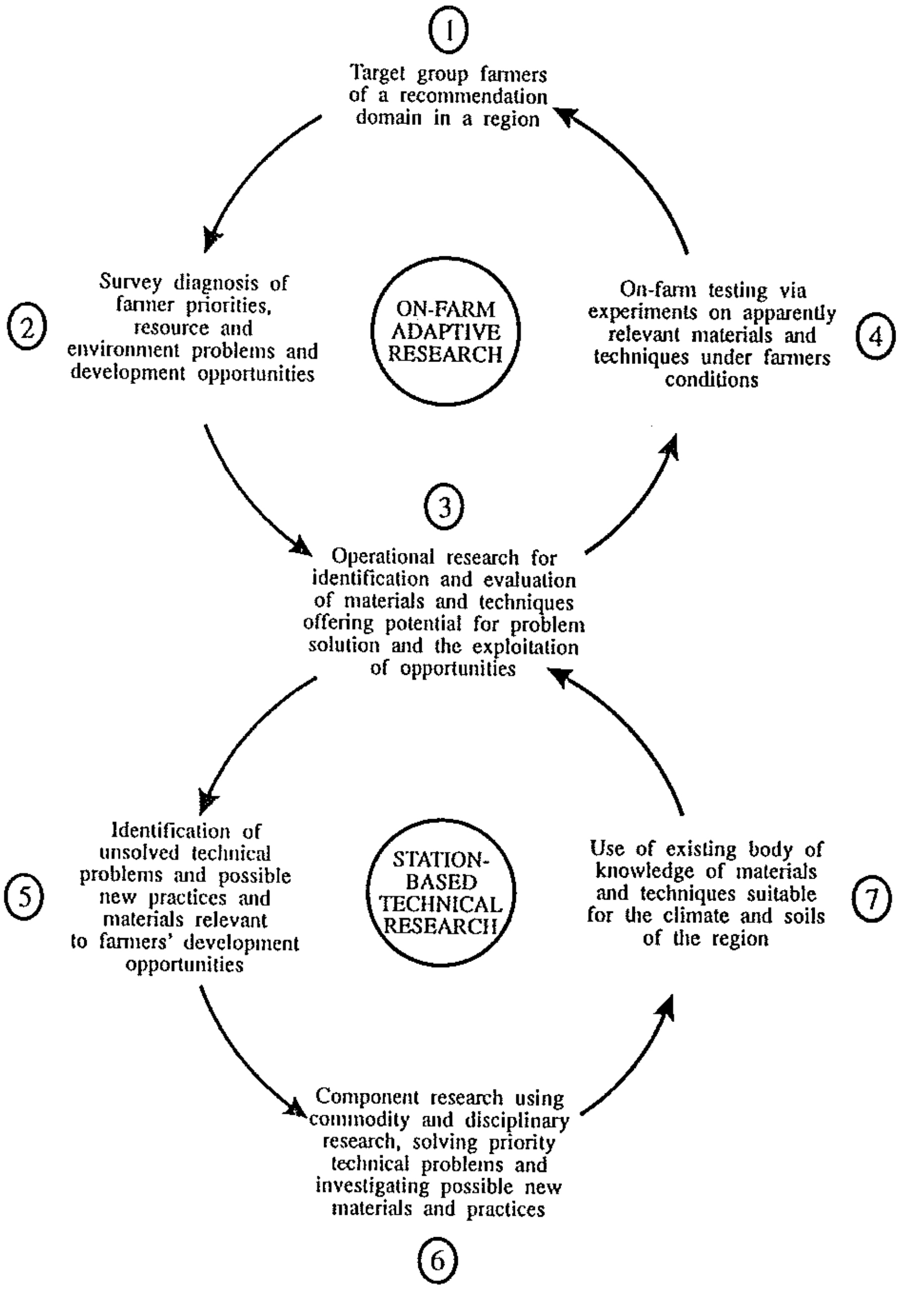


Figure 1 Schematic view of FSR (from Dillon and Anderson 1984, after Collinson 1982).

rationale was that the population pressure on land was rapidly reducing the opportunity for traditional bush fallows to restore soil fertility. For cropping to be sustainable, an alternative was needed. While the legume ley option is often seen as an Australian reflex, others also thought that forage legumes were worth investigating, e.g. Collinson, 1984.

A second best-bet commitment was to develop the capability to simulate maize yields using a computer model. This would enable quantification of climatic risk for the most important crop in the region using historical rainfall records as inputs. There existed at the time a well documented maize model with a soil nitrogen submodel and good daily rainfall records for the region. Research to test and adapt the model for conditions in this farming system seemed to fit the resource and time constraints of this project.

After a year, results from the on-farm diagnostic studies were having a major effect on project thinking. There was compelling evidence of the "involution" described by Ruthenberg (1980) for such systems when population pressure on land results in progressively more intensive mining of soil nutrients, accompanied by decline in labour productivity. While virtually every farm had a manure supply from a boma, only the cultivated area nearest the boma enjoyed significant benefit. While it appeared that more efficient use of boma manure might be possible, it was clear that manure could never be the key to adequate, sustainable production.

The intensity of cropland use was too high for time and space to be given to forage legume production. There was little incentive to improve the diets of animals since relevant economic performance was limited to survival and reproduction and these were rarely put at risk by nutritional limitations. Nowhere, it seems, will farmers grow forage legumes mainly for the soil fertility benefits; the primary requirement is sufficient economic benefit to an animal enterprise (McCown *et al.*, 1988). The forage legume programme was reduced and re-focused on grazing land reclamation (Gichangi *et al.*, in press).

Better understanding of farmer decision-making confirmed the importance of uncertainty about rainfall to farm management. Although some new technologies had been widely accepted, these rarely included fertilizer. The risk of rainfall failure was often given as the reason why farmers were reluctant to invest in fertilizer. Of the several possible explanations, this is the one least amenable to intervention, e.g. by extension. Confirmation (or not) of a climatic limitation as an adequate basis for non-use of fertilizer was seen as essential to sound planning of soil fertility R&D. Testing of the grounds for this hypothesis, using the maize model, became a high research priority.

Operational research in FSR

Dillon and Anderson (1984) used the term "operational research" in describing Activity 3 of Figure 1, referring to both field studies and computer modelling as ways of screening alternative materials and techniques for potential to improve the production system. High ranking alternatives are then tested on-farm. A maize production model provided a tool to quantify the climatic constraint in time and space (Activity 2, Figure 1). It was also needed for research on the efficient operations of existing and potential systems. An experimental programme was designed to provide data to test CERES-Maize (Jones and Kiniry, 1986), a model developed in North America, which, at the time, had not been tested widely in the tropics.

Those of us working in Kenya had little or no experience with either computers or modelling, and expatriates and national scientists learned together, supported by team members in Australia. We had initial doubts about the place for computers on a research station in Africa in 1985. Was this appropriate research technology? Would we find them in some locked cupboard in five years time, like much of the inappropriate research equipment supplied by aid programmes to research stations? Although these were real worries, in the end they were outweighed by the sense of opportunity. The prospect of being able to capture quantitatively the impact of climatic risk was especially motivating as we experienced our first few erratic seasons. With hindsight, our fears were groundless. The original XT computers are still working, despite the dust and uncertain power supply. In the meantime, other donor projects have installed faster, more powerful machines and peripherals, and computers are firmly entrenched in the research environment of the station.

Modelling did not fit easily with established institutional structures, and was seen by many as "academic". The research station had a Farming Systems Section that was distinct from the Agronomy Section and the Soil and Water Management Section. Individuals within a Section were assigned particular responsibilities; in agronomy, someone would look after soil fertility, another plant populations, and someone else agroclimatology. However, our modelling of interactions between nutrients, management and climate served to lower these barriers. Testing of the model was effective in stimulating researchers to address more complex issues of the farming system.

Experiments were set up in contrasting environments. The Katumani site, the National Dryland Research Centre, is cooler because of its altitude (1600 m). Its annual rainfall of 700 mm is more effective for plant growth than the hotter (900 m altitude), drier (600 mm rainfall) Makindu site. Katumani is representative of the intensively-settled semi-arid midlands of Ukambani. Land use at Makindu is largely pastoral, but in active transition to cropping as a result of migration of new settlers from the over-populated uplands.

Our strategy was to maximize the variation in environment and management so as to quickly build up a database of experimental information that could test the predictive ability of the maize model. This involved treatments such as irrigation, nitrogen fertilizers, plant densities ranging from very high to very low, different cultivars and variation in planting dates. In spite of efforts to explain our rationale, our research was controversial. How could a project espousing a FSR approach conduct much of its research on research stations and use irrigation in experiments concerning dryland crop production?

The CERES-Maize model required some modifications to simulate adequately maize growth and yield in semi-arid Eastern Kenya. For example, some of our experimental crops died during poor seasons, and the original model could not simulate this. Changes were also made to the phenology routines to simulate better the temperature response, and effects of water and nitrogen stresses on development rates. Greater flexibility in simulating management was needed. In the original model, the planting date had to be input, and management was constrained to the period of a crop season. Farmers in this region plant in response to the opening rains of a season, and this response needed to be simulated before we could realistically apply the model.

In all, 159 sets of observations were gathered with grain yields ranging from 0 to 8000 kg ha^{-1}. Simulations had a root mean square deviation of 689 kg ha^{-1}. The regression of simulated yields on observed yields has a slope of 0.94, an intercept of 250 kg ha^{-1}, and r^2 of 0.88 (Keating *et al.*, 1991). The model is able to simulate the important interactions between plant population and both water (Keating *et al.*, 1990) and nitrogen supply (Figure 2).

Average grain yield simulated over the 63 seasons using historical rainfall records (1957 to 1988) from Katumani, near Machakos, was approximately 1700 kg ha^{-1} under current management

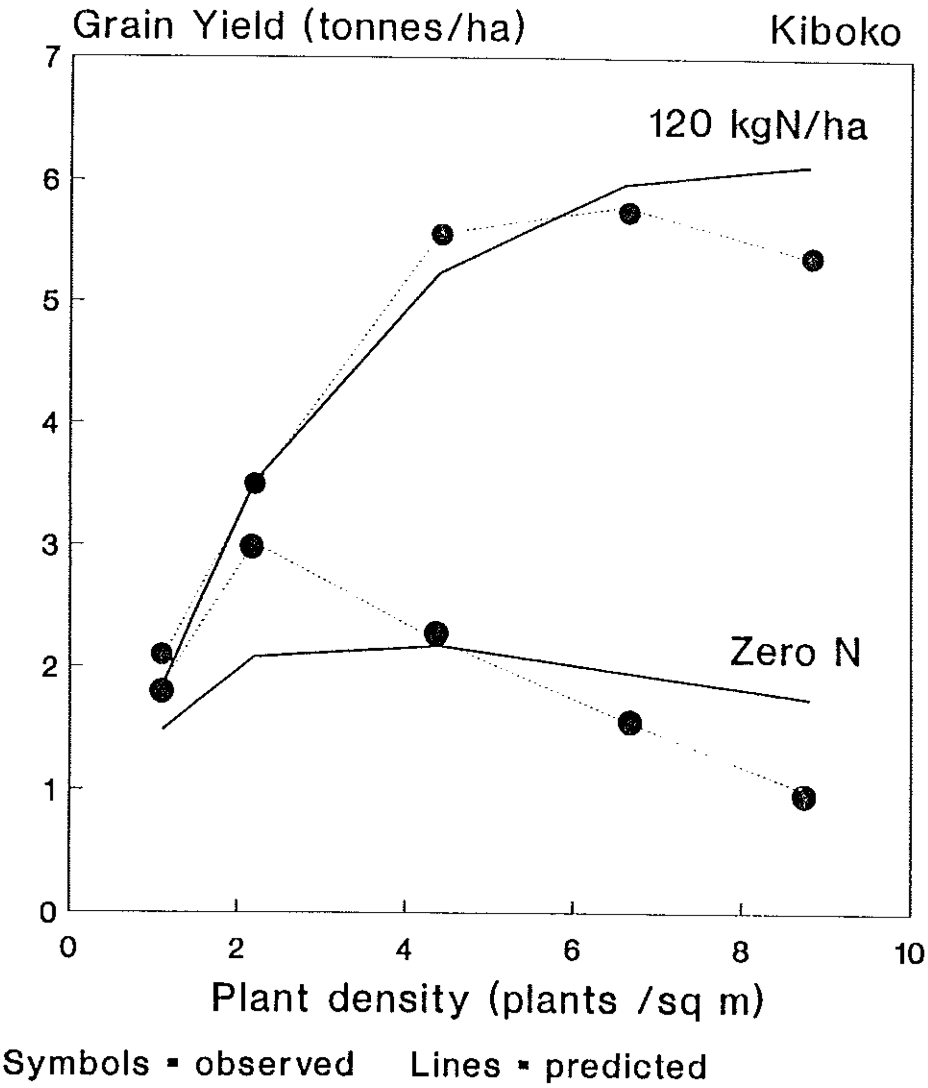


Figure 2 Maize grain yield response to plant density as influenced by nitrogen supply (adequate water). Measured yields indicated by solid points, simulated yields by solid line.

recommendations and moderate soil nitrogen status, compared with 1200 kg ha^{-1} for a similar period at the drier Makindu site. Twenty five percent of simulated crops "failed" (i.e. yields less than 300 kg ha^{-1}) at Katumani compared with 40 percent at Makindu (Figure 3).

Part of the validation data for the model predictions came from farmers' fields. However, it cannot be expected that simulated maize yields for low fertility situations with no added fertilizer, e.g. 1200 kg ha^{-1} for Katumani (Keating *et al.*, 1991) will agree closely with published average farm yields e.g. 750-900 kg/ha^{-1}, (Jaetzhold and Schmidt, 1984). This is because yields in the simulations are constrained only by weather and nitrogen supply, whereas factors including delays in planting, weeds, pests, disease and soil phosphorus deficiencies also contribute to low on-farm yields. The model with these limitations simulates yields needed for evaluation of the potential returns to purchased nitrogen. Consideration of fertilizer input is relevant only when good management in other respects can be assumed. Reciprocally, the less intensive "typical" management when nitrogen is severely limiting, is consistent with the low marginal returns to labour and capital under these circumstances.

The search for a cost-effective soil enrichment strategy for sustainable agriculture

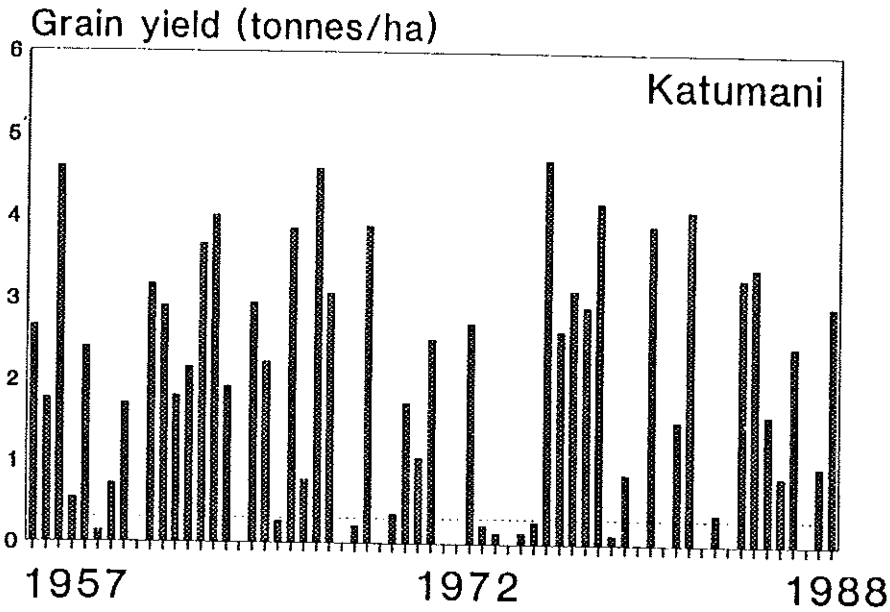
In traditional bush-fallow systems, farmers become skilled in making benefit-cost decisions on when to cease cropping on a given plot of land and (laboriously) develop a new one. Similar judgements are central to any contemporary soil fertility management strategy, although fallowing has greatly diminished as an option. Today, the main options are manure, legumes and mineral fertilizer, and their combinations.

The inadequacy of nutrient conservation/biological strategies

There is no question that fresh manure in sufficient quantities can sustain production close to the potential set by the weather (Ikombo, 1984). However, present efficacy of manure use on farms is low because of nutrient losses during long periods in uncovered bomas before removal and transport to plots. On six farms around Mwala, manure being carted to fields in August 1990, averaged 0.42% nitrogen, 0.14% phosphorus and 90% ash, which is closer to the composition of a fertile soil than fresh manure. Rates of application ranged between 38 and 168 tonnes per hectare, but only a portion of land to be cropped received manure. While farmers said they rotated the applications, soil tests showed the expected pattern of concentration of nutrients diminishing with distance from the boma (Ruthenberg, 1980). Large concentrations of nutrients were found in soil under bomas, indicating leaching, while conditions during part of the rainy season were found to be conducive to losses by ammonia volatilization and denitrification. Manure is transferred from the boma to croplands prior to the start of the short rains. Labour shortage, the limited ownership of carts or even wheelbarrows, and the impediment of pigeon pea crops awaiting harvest all contribute to inefficient transfer.

Opportunities do exist for more efficient recycling of nutrients in manure. The lack of innovation and investment in capturing and storing excreted nutrients in circumstances of serious soil fertility depletion is an enigma to which we shall return in a later section. However, potential supplies of manure are already inadequate. In the long term, they will decrease further as population increases, and grazing areas and herd/flock sizes decline.

The opportunities for a biological



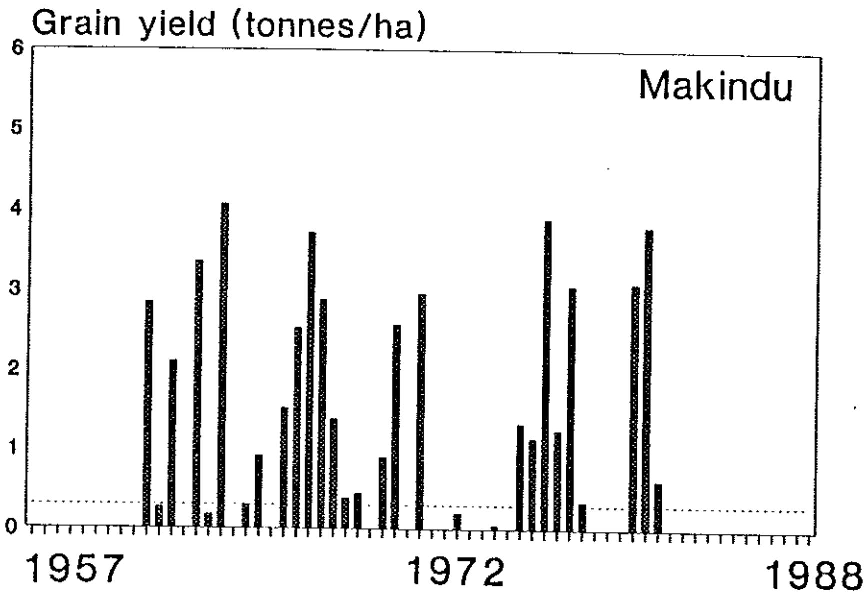


Figure 3 Simulated maize yields for Katumani and Makindu. A 0.3 t/ha threshold is indicated as a crop failure criterion.

nitrogen option are even more limited. While the nitrogen-fixing capacity of the cowpeas, beans and pigeon peas grown in this system gives them immunity to the problem of soil nitrogen deficits, their efficient concentration of nitrogen in grain acts contrary to the needed replenishment of soil nitrogen. At present population growth rates, the opportunity to use legume forage crops or leys to enhance soil fertility appears to be, at best, transient, as Ruthenberg (1980) predicted. The alternative of forage legumes used as intercrops (Collinson, 1984) suffers the problem of competition for time and space with much preferred edible intercrops.

In a recent review of sustainability of African agriculture, Okigbo (1991) concluded that population pressure has generated a rate of depletion of soil nutrients that cannot be supplied by any conservation/biological strategy, and that sustainable, adequate production is achievable only with inputs external to the farm or country, namely mineral fertilizer. Ruthenberg (1980) came to the same conclusion.

A strategy featuring fertilizer augmentation of current practices

It is most important to distinguish a fertilizer-augmented soil enrichment (FASE) strategy from a Green Revolution-type fertilizer strategy. FASE is an enhancement of the current agroecological strategy based on manure and grain/legumes, which is basically sound but quantitatively deficient in its ability to meet demand for soil nutrients. Simply substituting a fertilizer strategy for traditional fertility maintenance practices risks replacing one sort of soil degradation threat with another. On poorly-buffered sesquioxidic soils with depleted organic matter, such as those which prevail in Ukambani, sustained use of commercial fertilizer as a main source of nutrients could well cause soil acidification and related problems (Dommen, 1988; Nambiar and Abrol, 1989). By the standards of the agriculturally-productive soils of the world, even virgin soils of this region are low in organic matter. After a long period of intensive cropping and erosion, organic matter has fallen to very low levels. Restoration of productivity requires substantial inputs of carbon as well as nutrients. Organic matter depletion affects soil behaviour physically, as well as chemically, causing loss of water-stable structure and reduced water conductivity. This effect is most apparent as slaking of cultivated seedbeds, reduced infiltration rates and increased proportion of rain lost as runoff.

There is good scientific evidence that manure is the best amendment. It supplies carbon, prevents acidification, and it generally provides a balance of all nutrients (Pichot *et al.*, 1981; Nambiar and Abrol, 1989). However, manure is seldom available in sufficient quantities on farm, it is bulky to transport and there is no formal market. Fresh crop residues are another possible source of carbon for soil organic matter, but their retention for soil improvement competes with other household needs e.g. animal feed, fencing and fuel. However, with additions of the appropriate fertilizer (containing nitrogen or nitrogen and phosphorus), more residues are produced, and even with previous rates of removal, there is an increasing quantity that could be retained for the soil. This opportunity to "spiral upwards" is enhanced by the improved water conservation that results from the beneficial physical effects of organic materials.

We approached the issue of feasibility of fertilizer augmentation from two directions. The first was to study cases of successful use of fertilizer as well as other cases of non-use to see if more farmers "should" use fertilizer. It is significant that a few farms have a very effective soil management strategy, developed over many years, which includes manure, legumes and fertilizer. What lessons can be learned from such farms and their managerial history? What are the necessary conditions for replication of their experience? Answering these questions is part of the PhD programme of Mr. Lutta Muhammad, University of New England, Armidale, Australia.

The second approach was operational research based on simulation of the effects of fertilizer amount on maize yields, costs of production and risks. This approach allowed us to assess the prospects for fertilizer use in a way that would not have been possible using conventional field experimentation. In fact, earlier workers, including Nadar and Faught (1984), had conducted nitrogen fertilizer trials over numerous seasons, but variability in response associated with variability in rainfall amount and distribution was too large to produce a clear picture emerging on the role of nitrogen fertilizer in this region.

The use of the maize yield model and historical rainfall data for a particular site (e.g. 63 seasons at Katumani in the example presented here), allowed us to assess the probability distribution of gross margin associated with nitrogen fertilizer use at such a site (Figure 4). A strategy involving 45 kg nitrogen fertilizer per crop (F_4) was associated with substantially higher probabilities of gross margins in excess of 3000 Kenyan Shillings (Kshs) ha^{-1} relative to a zero fertilizer strategy (F_1). On a typical soil,

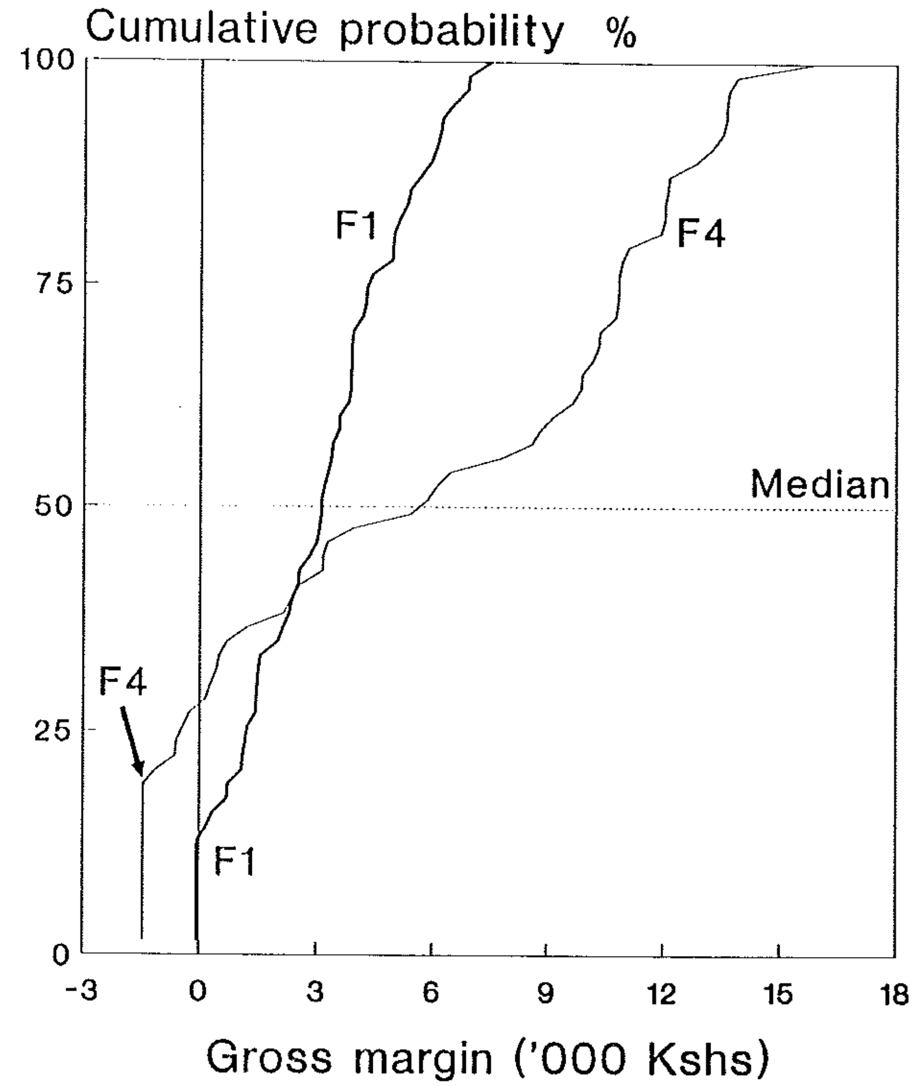


Figure 4 The cumulative probabilities for gross margin (in Kenyan shillings) of maize production at Katumani in relation to nitrogen fertilization.

depleted of nitrogen through a history of continuous maize cultivation, the average benefit of 40 kg ha^{-1} nitrogen is a doubling of the yield and gross margin (Keating *et al.* 1991). However, the probability of negative gross margins increased from 12% in the absence of fertilizer to 28% for the strategy involving fertilizer nitrogen.

While the expected returns to nitrogen fertilizer use appeared attractive, the associated risks were still high. Any means to reduce these was attractive. Such a schema, referred to as "Response Farming" (Stewart and Faught, 1984), had been developed in this area of Kenya. This uses (a) the timing of the onset of the rainy season and (b) the amount of early rain to predict seasonal rainfall and yield. In Response Farming, nitrogen fertilizer is withheld in seasons when onset is late and/or early rainfall is low. It is applied when a good season is indicated by early onset and good early rains. While the concept of Response Farming was appealing to Kenyan R&D workers, it defied evaluation by physical experimentation.

The modified maize simulation model allowed the economic value of Response Farming to be quantified (Wafula, 1989, McCown *et al.*, 1991). If expected returns are expressed as the simulated mean gross margins for the historical weather record, and risks as the standard deviation, the risk-return outcomes of various strategies can be compared in E-SD space (Figure 5). To aid comparison,

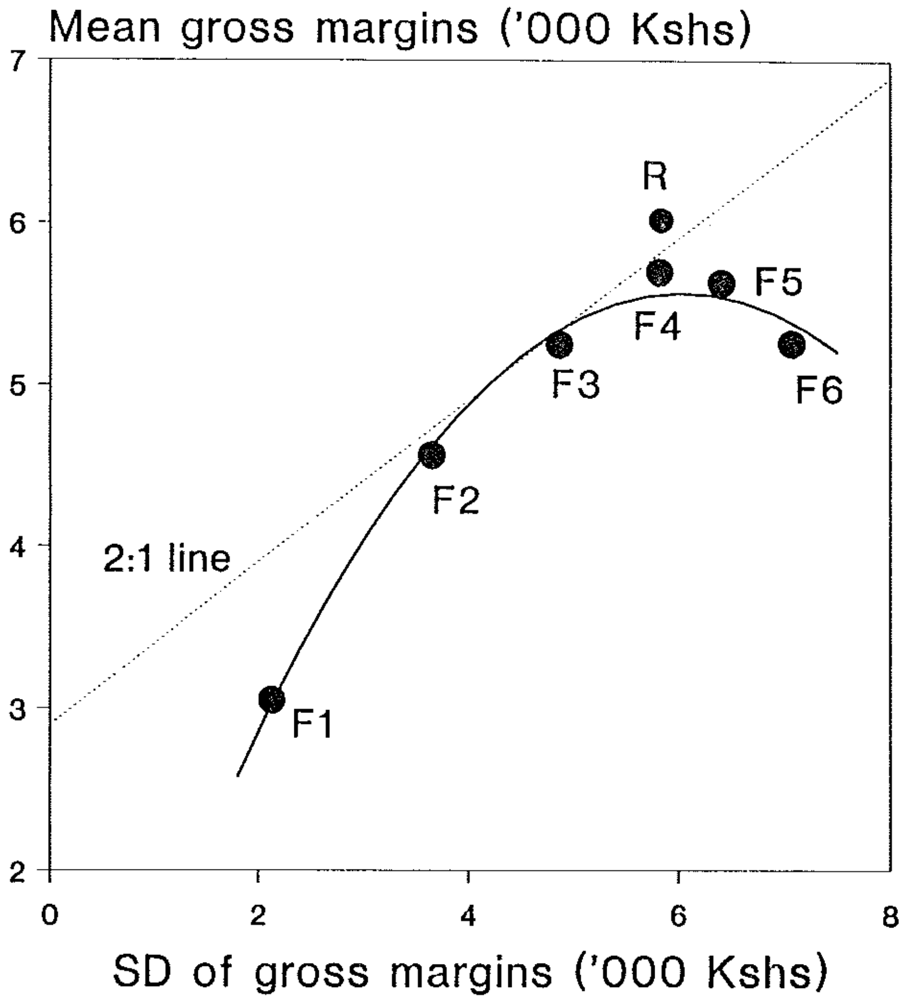


Figure 5 Gross margins in Kenyan shillings of maize production at Katumani depicted in mean-standard deviation space using simulated yields from Figure 2. F_1-F_6 represent nitrogen applications of 0, 15, 30, 45, 60 and 80 kg/ha and planting densities of 22, 27, 33, 37, 44 and 55 thousand plants/ha. R represents the Response Farming outcome. The 2:1 line is an approximate indifference curve used to indicate an optimum area on the returns-risk curve.

a line with a slope representing two units of SD to one of mean is drawn representing the limit of acceptable trade-off for a typical farmer (indifference line). This rule of thumb has been reported to represent attitudes to risk of small farmers in a number of places (Ryan, 1984) and is consistent with elicited attitudes of a sample of Ukambani farmers (L. Muhammad, reported in McCown *et al.*, 1991). F_1 (Nil nitrogen, 22k plants per hectare) represents the most common farmer practice. Of the strategies in which constant levels of fertilizer and plant density are used each year, i.e. no Response Farming strategy, the optimum lies close to F_3 (30 kg nitrogen, 33k plants per ha). The Response Farming strategy (R, Figure 5) produced a higher mean gross margin than any "fixed" strategy (the vertical distance to the 2:1 indifference line). However, the gain was modest and is achieved only with high inputs. Other measures of risk which place more emphasis on "safety first" criteria, such as the probability of gross margins dropping below some farmer-specific "survival" threshold, confer greater value to the response farming forecast (Keating *et al.*, in press). In either case, the most efficient way to increase average returns is to apply nitrogen fertilizer. Tactical adjustments in relation to seasonal forecasts, i.e. Response Farming, can be viewed as refinements to this basic need, rather than prerequisites for it.

What are the prospects of a FASE strategy for sustainable cropping?

Why don't more farmers use fertilizer?

In discussing the results of simulations of risks and returns for different levels of investment in fertilizer by a typical farmer near Machakos, McCown *et al.* (1991) considered four reasons for farmers being so far below the apparent optimum:

1. The estimated responses in mean gross margins to increases in fertilizer inputs and plant population are unrealistically high;
2. Local farmers are much more risk averse than indicated by the field research or represented in the model;
3. Farmers perceive the risks they face using fertilizers to be sufficiently greater than those depicted by the model output so that their present behaviour appears optimal;
4. Farmers have access to insufficient capital to adopt more optimal strategies that require higher input investment.

To some degree, 1. is valid because the production model is biased toward high yields by omission of yield-reducing factors e.g. pests and weeds, and the assumption that other management operations have been conducted satisfactorily. However, our experience is that responses like those simulated can be achieved by farmers skilled in this technology, and where this occurs, these farmers see the average responses as economically very attractive.

The available evidence indicates that farmers here have a degree of risk aversion similar to farmers elsewhere (McCown *et al.*, 1991) and too low to explain non-adoption (2. above). It is possible however, that the level of risk aversion measured in decisions in gambling games is different from that revealed in decisions on farms.

Most farmers may correctly perceive the risks associated with fertilizer use (3. above) as being much higher than we are simulating. They may underestimate the potential benefits, or they more realistically adjust for their own relatively poor knowledge and skills pertaining to the practice. Either way, it is conceivable that the problem can be reduced by education and experience. In addition, farmers may under-

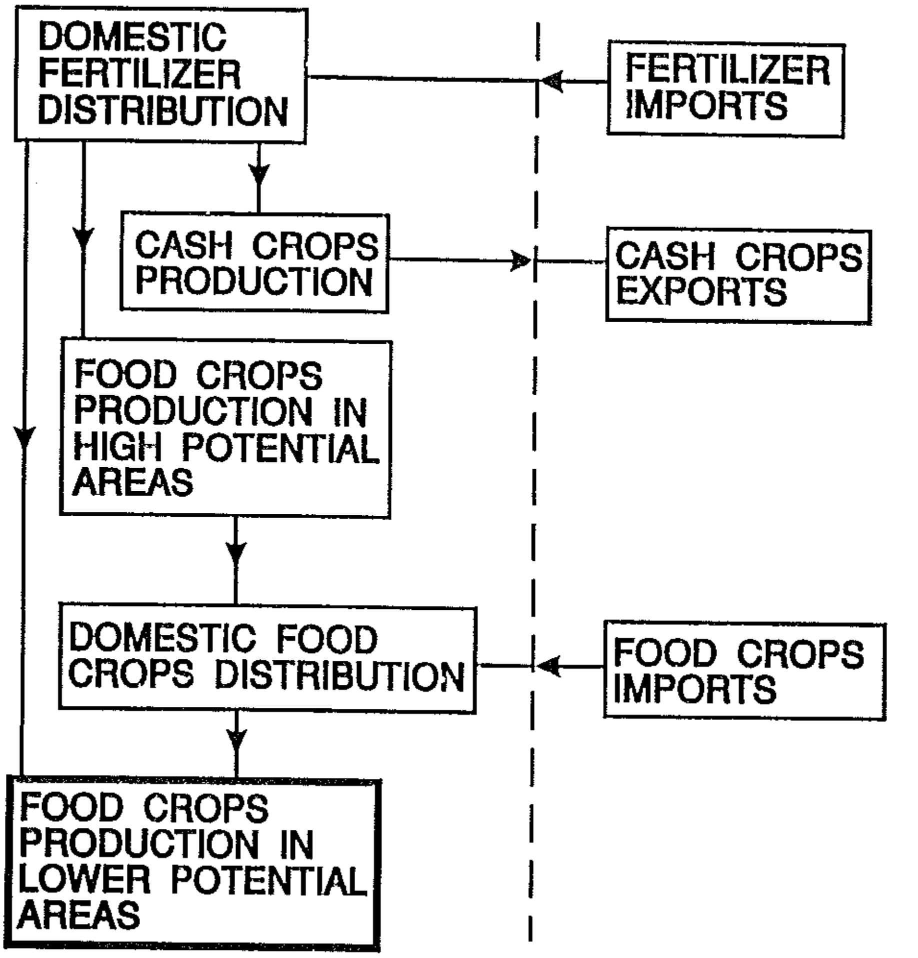


Figure 6 Schematic representation of national options of food and fertilizer supply to the semi-arid areas of predominantly highland Kenya (Parton, K. A., unpublished).

appreciate the residual fertilizer benefits after a season in which a crop failed due to drought. Use of fertilizer does require access to capital (4. above). A 50 kg bag of calcium ammonium nitrate (26% nitrogen) costs the equivalent of 15-20 days of farm labour wage or the returns from the sale of a goat. A substantial proportion of farms have a source of off-farm income, which is commonly used to purchase inputs (Rukandema *et al.*, 1981), although rarely fertilizer. Experience in India indicates that early growth in fertilizer use was more dependent on recognition of the physical productivity of fertilizer (point 3. above) than on price (Desai, 1982).

The above analysis is equally relevant to the question of why farmers do not store and transport manure to fields more efficiently. Possible investments might include increased labour, a wheelbarrow or cart, or more frequent removal and storage under cover.

Developing and testing a sound FASE strategy

It is important to remember that the aim of this research (Stage 4, Figure 1) is to identify what techniques or materials merit research with farmers (Stage 5, Figure 1). Since the outcome sought consists more of credible hypotheses than scientific conclusions, anecdotal information can be valuable. Simon is a clever, energetic, young man employed by the project as a driver *cum* general-purpose administrative assistant *cum* field assistant/translator. His contribution in the field was especially valuable because he was from the project area and was an active farmer (leaving the Monday-to-Friday management to his wife). In the course of his duties, he became familiar with fertilization techniques and shared experiences of fertilizer use in a wide range of circumstances. Before long he tried some fertilizer on a small area of his own maize. Within a few years he gradually developed an impressive FASE system involving manure, legumes, composted weeds and fertilizer.

It seems possible that FASE could become a strategy for sustainable crop production for many (but by no means all) farmers in this region. The logical next R&D step is methodical testing with a range of farmers - Stage 4 in Figure 1. This would involve working with farmers on procedures for developing the necessary new knowledge and skills, provision of fertilizer in smaller units and recording use and outcomes, testing ways of improving efficiency of nutrient capture and transfer from bomas and study of the economics of fertilizer use for farms covering a range of financial means.

Conflict with prevalent R&D views

The project's convergence on a strategy that requires fertilizer is not a generally popular outcome. One of the maxims of the R&D community in the Machakos-Kitui region is that research on fertilizer use is hard to justify because "local farmers don't use fertilizer". In an early survey of 100 local farmers, only 8 percent used any fertilizer; a resurvey of the same 100 farmers ten years later found that this had increased to 12 percent (Lutta Muhammad, personal communication). However, this rate of adoption was small compared with those of several other technologies. In such circumstances, it is not surprising that research on fertilizer use by a project which claims a farmer orientation is viewed with some perplexity. First and foremost, FSR is expected by many adherents to reflect realities that farmers face. In areas of widespread rural poverty, such as the project area, it is expected that a FSR project might identify improved conservation/biological strategies requiring little or no purchased inputs.

However, we place more emphasis on FSR as a framework for testing, against the backdrop of identified farming system needs, possibilities which may be outside the experience of many farmers and policy makers. A substantial proportion of the land in this region which has been cropped for more than 20-30 years produces low maize yields even in the good seasons. There is often dramatic evidence that this is due to soil fertility depletion. Restricting possible options for improvement to those which all farmers can afford may eliminate the options that offer the best prospects for regional food self-sufficiency and for improving and sustaining soil productivity. Although the high relative cost of fertilizer inputs undoubtedly puts this option out of reach of many, the problems of soil depletion and degradation are so serious, and the prospects for alleviation using a nutrient conservation/biological strategy so limited, that research on efficient use of small amounts of fertilizer by those who can afford it deserves high priority. As Ruttan (1983) points out, research systems are weak instruments for changing income distribution, and preoccupation with equitable growth risks loss of capacity to contribute to any growth at all.

Conflict with current government policy

The suggestion of a strategy that includes fertilizer may be no more popular with Kenyan government authorities than with the R&D community. National R&D objectives for the semi-arid areas (Kenya Government, National Development Plan, 1989) include (a) improved food self-sufficiency, (b) improved sustainability of existing croplands and (c) improved technology for expanding cropping into the most climatically-favourable remaining rangelands. Although the policy on fertilizer states that "the Government will aim at increasing the use of fertilizer by all farmers . . ." in the policy for Arid and Semi-arid Lands (ASAL), development of dryland farming systems "will hinge on the continued development of low-cost outlays of technical packages". . . (Kenya Government National Development Plan, 1989). This section of the Development Plan promotes development of crop cultivars with greater drought resistance, and improved conservation of soil and water. Neither soil fertility decline in the semi-arid lands nor fertilizer is mentioned.

The probability of a policy constraint to a FASE strategy in the semi-arid regions became clear to us only late in the project. While fertilizer is readily available in the project area in retail outlets, this visibility probably belies a supply problem if demand increased. All fertilizer is imported, and consumption, therefore, has a foreign currency cost. The Kenya Government National Development Plan (1989) states that "heavy foreign exchange costs and transport requirements" are the "major constraining influence" on fertilizer use. This creates a national dilemma if a FASE strategy for the Machakos-Kitui region was confirmed to be economic at current local fertilizer prices. The flow diagram in Figure 6 shows that prospects of FASE as a basis for sustained crop production in the semi-arid zone (embedded in the bottom box) depends heavily on factors external to the FSR framework (Figure 1).

Where to from here?

Although a prominent feature of the FSR schema in Figure 1 is continuity between stages, continuity is rarely notable in the real world of international agricultural R&D assistance. This project will not now be proceeding to the on-farm testing of FASE (Stage 4, Figure 1) and to investigation of the policy aspects of fertilizer supply for this region (Figure 6). While those in the funding body who originally approved the project agreed in principle that a ten year duration was more appropriate for a farming systems project than the normal 3 year term, all parties accepted the reality that assured funding for this period was not possible. In the six years between the project initiation and the recent decision to wind it up, the funding body has moved toward a policy of limiting projects to six years (one renewal), and funding for projects in Africa has halved in response to a shift in regional priorities in Australian development assistance. (A concession has been made for a modest extension to this project to facilitate consolidation and training in risk analyses using models).

While there are Kenyan scientists who have been associated with the present project who could continue this research, this will occur only if the Kenyan Agricultural Research Institute and another donor agency see it as a high priority. A policy component in a new project would be both stimulating and complicating. The potential conflict with existing policy direction of such a new project is not likely to be overlooked by government bureaucracy; the possibility that this research might provide a more secure basis for future policy for increasing production in this region might well be. The crop simulation tool now available could greatly aid objective comparison of the two options of bringing more rangelands under cultivation with increasing the productivity of current cropping areas using higher inputs.

Conclusions

As opportunities for expansion of cropping area diminish, growth in food production must depend on increasing land productivity. However, arguments about the economics of fertilizer for particular places and circumstances will continue. The problem of discerning the path forward would be less if market forces could be trusted to reflect economic appropriateness of a FASE strategy. Our findings indicate that the economics are favourable in densely populated Ukambani, but farmers are insufficiently aware of this. Even if national policy makers are aware, they may have reason to be content with low level of farmer awareness. If fertilizer inputs are as important to improved and sustainable productivity in this region as our results, and the general conclusions of others (Okigbo, 1991; Ruthenberg, 1980), indicate, this situation is as serious as it is intractable.

It is hard to see a solution without major involvement of the international aid donor community. But present aid policy appears to be clouded by (a) debate concerning the social bias implicit in unequal access among farmers to capital for increased inputs and (b) a technology bias caused by a backlash against the overuse of chemical inputs in the agriculture of major donor countries.

When asked "How can poor farmers afford to buy fertilizer?", Simon replied without hesitation, "Almost all farmers in this place have to buy food. Buying fertilizer is cheaper than buying food."

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