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A Search for Strategies for Sustainable Dryland Cropping in Semi-arid Eastern Kenya

Proceedings of a symposium held in Nairobi, Kenya, 10–11 December 1990

Editor: M.E. Probert

Co-sponsors:

Kenya Agricultural Research Institute
Australian Centre for International Agricultural Research (ACIAR)
Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia

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Foreword

The population of Sub-Saharan Africa will have more than doubled between 1985 and 2010. More than half of this tropical region is semi-arid, and most rural people living in such areas must depend on small-scale dryland agriculture. However, in many areas the fertility of the farmed land has fallen as the pressure of human population has increased. Farm productivity has fallen and farmers have found themselves sliding into poverty.

In 1983 the Kenyan National Council for Science and Technology and ACIAR jointly hosted a symposium in Nairobi aimed at identifying how Australia, with its lengthy experience of agricultural research in its own tropical region, might contribute to solving the agricultural development problems of Eastern Africa. The difficulties of farmers in semi-arid cropping areas in eastern Kenya emerged as a high priority. Consequently, a joint project, sponsored by ACIAR and centred on the Katumani Research Station (now the National Dryland Farming Research Centre) and on farms in the Machakos and Kitui Districts, commenced in 1985. The project involved close collaboration between research staff from the Kenya Agricultural Research Institute (KARI) and the Tropical Crops and Pastures Division of CSIRO, Australia's national research organisation.

The results of nearly six years of research were presented to 64 Kenyan government administrators and researchers, and representatives of national and international development aid donor agencies, at another two-day symposium sponsored by KARI, ACIAR and CSIRO, and held in Nairobi during December 1990. These proceedings present the 15 papers delivered. Shortly, ACIAR will also be publishing a companion digest of the results.

A major difficulty that confronts researchers investigating agricultural problems in semi-arid tropical regions is the variability of the climate. This poses special problems when interpreting experimental results and formulating sound crop husbandry recommendations for farmers. The KARI/ACIAR dryland farming project has used a maize crop model to tackle these issues. Consequently, a tool now exists that can explore the interactions between water supply, nitrogen nutrition and such agronomic practices as adjusting the time of planting and planting density of crops, and simulate crop performance using historical weather data.

As well as describing the development and application of the model, the papers support the theme that a strategy of augmenting traditional soil fertility maintenance practices (such as applying manure) with modest amounts of commercial fertiliser provides the best prospects for food security and sustainable agricultural development in heavily populated semi-arid tropical lands. This view runs contrary to previous popular wisdom that prevailed when the land was less degraded. The level of interest among participants at the symposium was most gratifying. Equally gratifying is the fact that the approaches advocated are already being applied successfully by a few farmers in the Machakos and Kitui Districts.

ACIAR and the scientists involved in the project believe that the approaches and strategies developed could do much to improve the lot of poor farmers living in semi-arid areas of Kenya and other tropical African countries.

The project and the symposium could not have succeeded without the enthusiastic support of the Directors and staff at the Katumani Research Station, and the interest shown by Mr G.Muhoho, Minister of Research and Technology, and other Kenyan Government ministries is gratefully acknowledged. The contributions of the late Mr Peter Kusewa, who was Director of the Katumani Research Station during the formative stages of the project until his untimely death in 1990, and Mr Benson Wafula, who subsequently became acting Director, deserve special mention.

Mr Neil Huth of the CSIRO Division of Tropical Crops and Pastures did much of the hard work needed to bring the papers delivered at the symposium to the high standard of presentation in these proceedings.

G H L Rothschild
Director
ACIAR

Preface

Developing countries in Africa struggling to increase food production face a dilemma in the form of limited essential physical resources, such as land, water, nutrients and energy, and lack of proper technologies. This situation is exacerbated by high population growth rates, which make it even more challenging for governments to achieve the elusive goal of alleviating poverty and suffering.

Kenya is one of these countries that is short of arable land (20% only). Four-fifths of the country consists of arid and semi-arid lands (ASAL), which are characterised by a bimodal rainfall pattern that ranges from very low to 800 mm per annum. This rainfall is extremely variable and unpredictable, which leads to frequent crop failures. Physical features include large areas of flat land and gently rolling hilly areas as well as steep and ragged hills and valleys. Elevations range from 700 m to 1800 m above sea level, and slopes can be as high as 30% or more, making large areas prone to erosion.

The ASAL received prominence during the 1979–83 Fourth National Development Plan in response to the plan theme of poverty alleviation. They, in particular, have come under increasing pressure. The ASAL areas are inhabited by small-scale farmers, farming mostly at the subsistence level. They have the greatest population change, with a natural rate of increase of 3.5–4.0% per annum, and a higher actual growth rate due to migration from the crowded fertile areas of the highlands. Farm sizes range from 1.5 to 17 ha.

The area under crops in the ASAL is usually smaller than the area under grazing. However, due to the rapid increase in population, an increasing proportion of the grazing area is being put under cultivation. Migrant populations have brought with them farming technologies developed for the well endowed high-potential areas that are inappropriate to their new settlements. Inevitably, this has led to recurrent crop failures, hunger and suffering, which can be alleviated only by costly famine-relief operations. Even more serious is the problem of rapid resource degradation in this fragile environment, which is leading to declining productivity and possible eventual permanent barrenness.

The needs of the high-potential areas of Kenya have to a significant extent been met through research and the application of new technologies. The ASAL have, however, not received sufficient research attention, and therefore traditional production systems have benefited little or nothing from research-tested innovations. This gap became acutely apparent during the early and mid-1970s, when many parts of Kenya experienced a series of years with poor rainfall that coincided with population migrations from high-potential to marginal areas.

It was during this period that research scientists in the Ministry of Agriculture and the former East African Agricultural and Forestry Research Organisation (EAAFRO) began to give serious thought to strengthening research in rainfall-deficient areas. The initial thrust was to be in the Machakos and Kitui Districts of Eastern Province — populous parts of the country where crop failures and famine are virtually endemic.

The first positive action taken was the gradual strengthening of Katumani Research Station by the Ministry of Agriculture, culminating in its elevation in status to the National Dryland Farming Research Station (NDFRS) in 1980, with responsibility for planning and coordinating dryland research activities throughout Kenya. Financial constraints made initial program development slow. In 1979, however, technical assistance was secured from UNDP/FAO, and Project Document No. Ken/74/017, entitled 'Dryland Farming Research and Development', was endorsed by the Kenya Government and the donor agencies.

At an earlier date, UNDP/FAO and the Kenya Government had signed a Project Agreement (KEN/74/016), 'The Kenya Sorghum and Millet Development Project', a major objective of which was to develop sorghum and millet for the dry lands of Eastern Province. Though administratively separate, this project complemented KEN/74/017.

While the latter project was still in progress, bilateral negotiations in 1979 between USAID and the Kenya Government resulted in the formation of Project No. 615–0180, 'Dryland Cropping Systems Research Project', based administratively at KARI, Muguga, but with field studies carried out at the NDFRS, Katumani. Special care was taken at the project design level to ensure complementarity and collaboration between KEN/74/017 and Project No. 615–0180. The approach was multidisciplinary, and involved both expatriate and Kenyan scientists.

The two donor projects were due to end in early 1984. A symposium on Dryland Farming Research in Kenya which would bring together the results achieved during their rather short 4–5-year lifetime in a form easily available for reference was therefore convened in November 1983. Meanwhile, following the establishment of the Australian Centre for International Agricultural Research (ACIAR) by the Australian Government in June 1982, efforts were being made to identify major agricultural problems and priorities in eastern Africa where the Australian agricultural research community, with its experience of research in Australia's own tropical and subtropical regions, might effectively be applied in collaborative programs. A highly successful consultation between senior scientists and scientific administrators from Australia, seven eastern African countries, and international research and development organisations took place in Nairobi in July 1983, sponsored by ACIAR and the National Council for Science and Technology of Kenya.

A Memorandum of Understanding for scientific and technical cooperation between the Government of the Republic of Kenya and ACIAR was signed in June 1984, the year when most parts of Kenya were experiencing a drought of a severity not recorded for many decades. Arising from this agreement, the joint Australian–Kenyan Government project entitled, 'Improvement of Dryland Crop and Forage Production in Semi-Arid Regions of Kenya' (ACIAR Project No. 8326), and centred on the NDFRS, Katumani, commenced in 1985. The project involved collaboration between the Kenya Government, ACIAR and the Tropical Crops and Pastures Division of CSIRO, Australia's national research organisation.

The main emphasis in the first phase of the project was in support of some of the activities of the NDFRS, Katumani — namely socioeconomics, forage legume evaluation, climatic risk analysis and management, soil and water management and soil fertility management.

The project concluded on 30 June 1987. The Government of Kenya/Donor Appraisal Mission of the National Agriculture Research Project (NARP), in which Dr R.K. Jones the ACIAR co-project leader participated, took place in October–November 1986. It was timely as well as essential for consideration of the future of Project No. 8326, which was due for review in April 1987. All parties were anxious to ensure that the follow up project's objectives remained consistent with the priorities which emerged in the formulation of the NARP.

The follow up ACIAR project (No. 8735), entitled 'Improvement of Dryland Crop and Forage Production in the African Semi-Arid Tropics', commenced in January 1988 and was due to be concluded in June 1991. It was favourably reviewed in December 1990 with a recommendation that it continue for a further 2–3 years. The project involved close collaboration between research staff of the Kenya Agricultural Research Institute (KARI) and the CSIRO Division of Tropical Crops and Pastures. Immediately before the review, the two-day KARI/ACIAR/CSIRO symposium covered in these proceedings was convened at the International Centre of Insect Physiology and Ecology (ICIPE), Duduville.

Modern published scientific works are rarely the result of a single intellect. Often they involve a mixture of individuals with different attitudes and aptitudes. The proceedings of this symposium owe their success to dozens of dedicated scientists and policymakers. ACIAR deserves special mention for defraying the cost of sponsoring the symposium and the publication of these proceedings. Much of the coordinating responsibility was shouldered by Dr J.R. Simpson, ACIAR Joint Project Leader, and Dr B.W. Ngundo, KARI Assistant Director.

Special mention is also due to the late Mr P.K. Kusewa, who was the Director of the National Dryland Farming Research Centre, Katumani, during the formative stages of the project until his untimely death in 1990. The Australian High Commissioner, His Excellency D.C. Goss, and the Deputy Director of ACIAR, Dr J.G. Ryan both delivered special tribute speeches at the farewell dinner function in honour of the late Mr Kusewa for his contribution to the project. The Minister for Research, Science and Technology, the Hon. George Muhoho, who delivered the closing speech at this function also made a special tribute to the late Mr Kusewa.

The technical sessions were ably and voluntarily chaired by Dr B.W. Ngundo, Assistant Director, KARI; Dr F. J. Wang'ati, Secretary, National Council for Science and Technology; Dr B.M. Ikombo, Acting Director, NDFRC, Katumani; Dr A.M. Kilewe, Director, NARC, Muguga; Dr R.L. McCown, CSIRO Division of Tropical Crops and Pastures; Dr F.N. Muchena, Director, NARL, Kabete; and Dr J.G. Ryan, Deputy Director, ACIAR. Their contributions were much appreciated. The cost of this symposium was minimised through the generous offer of the excellent facilities of ICIPE by the Director, Professor Thomas R. Odhiambo.

C G Ndiritu
Director
KARI

Agriculture of Semi-arid Eastern Kenya: Problems and Possibilities

R.L. McCown* and R.K. Jones†

UKAMBANI is the traditional name for the homelands of the Akamba people and is today the Districts of Machakos and Kitui (Fig. 1). Unsustainable agriculture in this region has been a recurring national problem during most of this century, with drought, over-population, and unfortunate policies all contributing. 'The history of smallholder agriculture in Machakos has been one of population continually bumping up against a land-cum-technology constraint' (Lynam 1978, p.34).

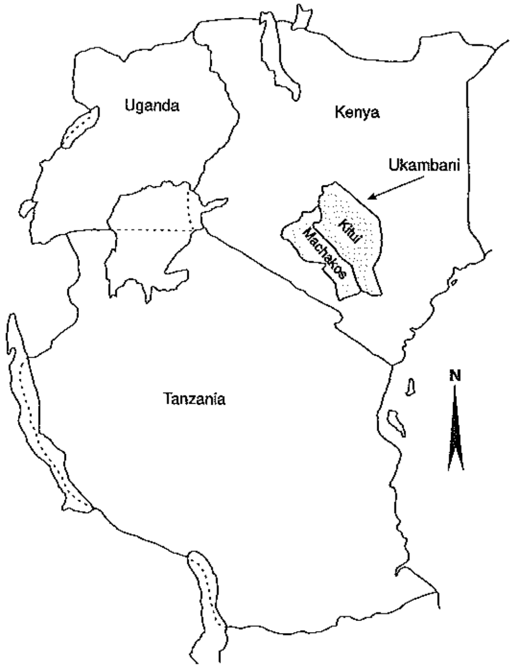

Fig. 1. Map of Kenya and some of its immediate neighbours, showing the location of Machakos and Kitui districts.

During the 19th century, the Akamba were settled on hill masses (Zone 3, Fig. 2), and largely confined to these restricted but relatively productive areas by the Maasai of the surrounding plains. They grew a red maize, beans, sorghum, millets, and cowpeas and herded cattle locally. Rainfall failed periodically, and serious famines are recorded (O'Leary 1984).

Farming practices used in hill farming were strongly conditioned by land shortage. There was increasing pressure to shorten fallows; limited grazing resources meant that manure was always in short supply, as were oxen for ploughing. There were serious problems of soil fertility decline, over-grazing, soil erosion, and poverty.

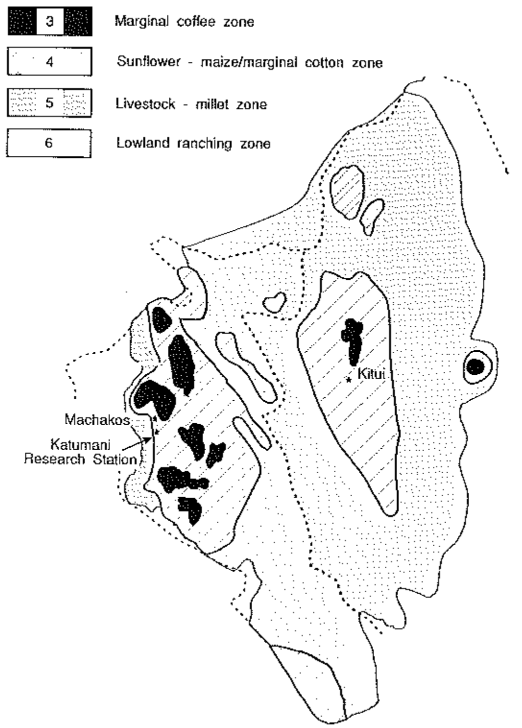

Fig. 2. Agro-ecological zones in Machakos and Kitui districts, Kenya (after Jaetzold and Schmidt 1983).

As conflict with the Maasai subsided in the early 20th century, it became common for Akamba families to have seasonal cattle camps on the plains (O'Leary 1984) (Zone 4, Fig. 2). It is likely that the introduction of the ox plough in 1910 (Moore 1979) contributed to a gradual migration of farmer settlers to the plains by enabling more extensive crop production.

The Quest for Improved Technology

The traditional response to population pressure on land has been out-migration, to other hill areas when possible but, as hill areas filled up, to the best-endowed plains areas. This involved a shift of enterprise balance and factor substitution but virtually no changes in technology. However, significant changes in technology brought about by colonial government intervention did occur around 1950. These changes had two foci, i.e. the plains and the hills.

In 1947 an official scheme began to resettle families from over-populated hill areas to plains using an imposed new farming system better designed to be adapted to more marginal conditions. Makueni was the first area. The approach was agro-ecological, with settler farms designed on the basis of the best current knowledge and a research station (Katumani) established to improve this knowledge base.

Lynam (1978, p.53) reports the characteristics of the Makueni farm plan.

- Twenty acres freehold, single family, restrictions on fragmentation
- Cropping integrated with livestock within individual farms (no communal grazing areas)
- Five to eight cows
- Ox power for cultivation
- At least 5 acres cleared and terraced (forced permanent cropping)
- Soil fertility to be maintained by manure, crop rotation, and grass leys
- Maize, millets, drought-resistant grain legumes, fruit trees
- Two acres cleared and planted to pasture grass.

The second intervention was in the hill areas and was an attempt to restore and sustain this more intensive production system. The first strategy was to gain control over soil erosion using terraces. The second was to increase incomes with new cash crops, high-yielding cultivars, and better agronomy (Lynam 1978, p.56).

Both these interventions alleviated the so-called 'Machakos problem' and, following independence, attention focused on the high-potential areas where problems and opportunities were seen to be greater. Good rainfall in the 1960s contributed to the impression that Ukambani was no longer a problem area (Lynam 1978, p.61).

However, by the 1970s, Ukambani had re-emerged as a problem area, but with the focus shifted from Zone 3 (hill areas) to Zones 4 and 5 of the plains (Fig. 2). The dynamics of the old problem of population outstripping production as the forage resources degraded and soil stocks were depleted had not changed (Fig. 3). While the pressure was relieved for a while, the same problem recurred, only this time in a climatic region where seasons with low potential yields occur more frequently.

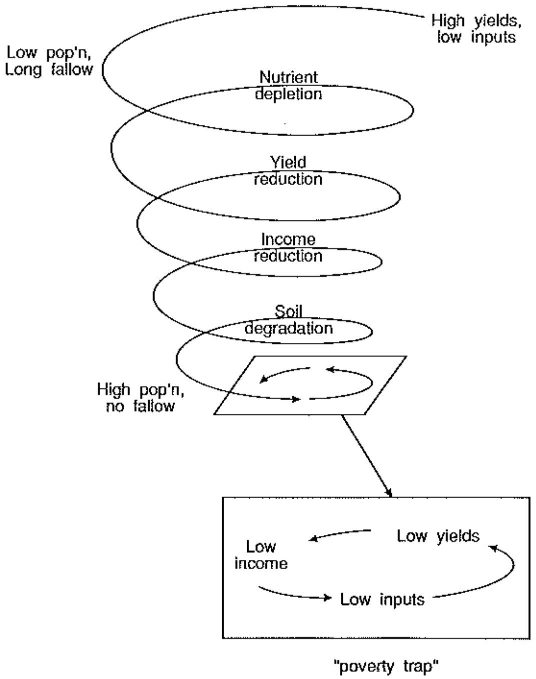

Fig. 3. Diagram showing how increasing populations and continuous cropping without inputs degrade farming systems in the semi-arid tropics to low levels of productivity (the 'poverty trap').

The technological strategy since the 1950s has been based on (a) sufficient land for integration of crops and livestock and fallowing of cropland, and (b) breeding of drought-resistant crops. By 1958 the first early-maturing cultivars of maize had been developed at Katumani and, although production is risky, maize production is viable in Zone 4 (Fig. 2). However, after only 40 years, population growth has again reduced farm size and fallow length to the point where soil impoverishment and

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accompanying erosion threaten viability of agriculture. The Makueni design for soil fertility maintenance (manure, rotations with legumes, and grass leys) can now be seen as inherently inadequate. While yields are low in the seasons of poor rainfall, over much of the region they are also low in the good seasons because of nitrogen and/or phosphorus deficiencies. With continued increase in exploitation pressures, the possibilities for use of chemical fertilisers, costly as these are, must be explored.

Fertiliser input can be considered most feasible when there is off-farm income, or savings from past off-farm endeavours. Off-farm employment became common during World War II, and 'by the fifties many households in Kitui regarded migrant work on a temporary or permanent basis as an essential source of income and as a means open to young men of poor families to establish their own households' (O'Leary 1984, p.44). This was true of the region in general, the degree differing mainly in relation to the surplus of agricultural labour and proximity to urban areas.

The availability of capital is a necessary but not sufficient condition for investment in increasing productivity. For the wage earner, there are many competing investment opportunities, both agricultural, e.g. terracing, and non-agricultural, e.g. education of children. The optimum proportion of off-farm earnings invested in intensification of production depends also on the future importance of agriculture in the family economy. O'Leary's (1984) warning about over-investment in agriculture in this region probably applies to the more resource-limited households. However, there are notable local examples of successful capital investment by farmers using savings, which inevitably involve a soil enrichment strategy of which commercial fertiliser is a component. It is clear that productive, profitable, and apparently sustainable crop production in this region is possible by augmenting traditional use of rotations and manure with commercial fertiliser. Such fertiliser-augmented soil enrichment hereafter will be referred to as a FASE strategy.

The Mineral Fertiliser Option: Precedents, Principles, and Possible Problems

The problem in Ukambani of declining yields due to soil fertility decline with continuous cropping is much the same as in smallholder systems with similar soils and climates in both sub-Saharan Africa and much of India. Knowledge of the outcomes of attempts to deal with the problem in these places should be helpful in devising a response in Kenya.

The following generalisations can be made.

- Manure supplies are inevitably inadequate to prevent yield decline to a 'low-level equilibrium' (Fig. 3) (Ruthenberg 1980; Nambiar and Abrol 1989).
- While nitrogen is generally the most deficient nutrient, responses to mineral N fertiliser are often low unless phosphorus is also applied (Nambiar and Abrol 1989; Bationo et al. 1985).
- Repeated application of mineral N and P fertiliser leads to yield decline and soil problems, specifically decline in organic matter (allowing increased acidity and exchangeable aluminium) and deficiencies of other nutrients (most commonly potassium, sulfur and zinc) (Pichot et al. 1981; Nambiar and Abrol 1989);
- The simplest means of avoiding these problems is to combine mineral N and P fertiliser and manure application (Pichot et al. 1981; Nambiar and Abrol 1989).
- Where the quantity of manure provides an insufficient supply of carbon for maintaining adequate soil organic matter, crop residues can substitute, but there is an increased risk of nutrient imbalance (Pichot et al. 1981).
- Fertiliser use is profitable without a subsidy for a sizeable proportion of farmers even in the dry semi-arid tropics (McIntyre 1986; Baanante 1986).
- Although it is well known that fertiliser use in Asia is high only in irrigated areas, old assumptions about the reasons why more is not used in dryland agriculture are being challenged. Indian states with extensive irrigation also have the highest proportion of rainfed areas fertilised (Anon. 1989). This may indicate the importance of limitations of supply of fertilisers and knowledge to smallholder use in dryland regions (Desai 1982, cited by McIntyre 1986; Mudahar 1986).
- The yield response expected by farmers seems to be more important than cost in the decision to buy or not to buy fertiliser (Desai 1982, cited by McIntyre 1986). In evaluating fertilisers, both farmers and professional agronomists face a situation where many things can go wrong, and too often do. Farmers often have inadequate knowledge to prevent mis-purchase, poor storage, or misapplication. The scientists understand the technology, but often are inexpert in growing the test crops in the given unfamiliar circumstances and/or suffer logistical problems. It may be that such factors have caused farmers and planners to underestimate the potential benefits of chemical fertiliser.

The overwhelming weight of evidence is that, while organic sources of nutrients are essential for good soil management, supplies are inadequate. Augmentation by commercial fertiliser is both generally profitable and essential for sustainable production at moderate to high levels.

Management Requirements for Efficient Yield Improvements from Fertiliser

Reports on response to fertiliser in smallholder systems tend to be highly variable, and this often masks the general importance of the soil fertility deficiencies. A more helpful interpretation is that, even when the applied nutrient is deficient, response may be poor due to a deficiency in any of several other factors, many of which can be controlled by the knowledgeable manager. Although the high cost is generally considered to be the main deterrent to fertiliser use, at least as important may be the management demands for getting other things right. The most important considerations are indicated in the following principles for efficient fertiliser use.

- Manage all deficient nutrients together. After sustained exploitative cropping without any fertiliser inputs, nitrogen will normally be most deficient, with phosphorus close behind. When this is the case, a response to supply of nitrogen alone will decline as phosphorus becomes increasingly limiting, and greatest economic returns at some point will be to phosphorus.
- Ensure that the maximum amount of applied nutrient gets to the crop. Fertiliser must be put at the right place at the right time and weed competition prevented.
- Grow a nutrient-responsive crop and cultivar. Maize is more responsive than millet and sorghum. Improved cultivars and hybrids are generally more responsive than local types, but fertilisation of local types is often profitable (McIntyre 1986).
- Minimise all other environmental constraints. Beyond planting at the optimum time, restraining runoff using structures, and mulching, water supply in dryland systems is largely out of farmer control. In this environment, risk of water deficits is considered the most important deterrent to fertiliser use. This is often expressed as the risk factor, but the more important effect of this climate may be simply the limit to expected (average) yields (McIntyre 1986). There is no doubt that the average returns to fertiliser are greater the more favourable the water environment, hence the high usage of fertiliser where there is irrigation. This does not negate the possibility that when soil fertility has declined to levels where yields are very low even in the best rainy seasons, a soil enrichment strategy that includes some chemical fertiliser is the best of the alternative options although response will be poor in the seasons with low rainfall. The small amount of information that exists indicates that in the latter situation much of the fertiliser nutrient applied is available to the crop in the subsequent season (Keating et al. 1991).

Management Requirements for Long-term Use of Fertiliser

In addition to management for efficient use of an expensive fertiliser material, other considerations are required to ensure that even efficient use is not detrimental to the soil. On poorly buffered sesquioxidic soils with depleted organic matter, such as those that prevail in Ukambani, sustained use of commercial fertiliser as a main source of nutrients could cause soil acidification and related problems (Dommen 1988; Nambiar and Abrol 1989). Compared to the agriculturally productive soils of the world, soils of this region are low in organic matter even at their best. After a long period of intensive cropping and erosion, organic matter has fallen to very low levels, and restoration of productivity will require 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.

Restoration of fertility requires increasing soil carbon as well as N and P. There is good scientific evidence that manure is the best amendment; it provides carbon, prevents acidification, and it generally provides the balance of all nutrients (Pichot et al. 1981; Nambiar and Abrol 1989). Unfortunately, boma manure is seldom available in sufficient quantities on farm, is bulky to transport, and there is no formal market for it.

While fresh crop residues are another possible source of carbon for soil organic matter, the retention of crop residues for soil improvement competes with other household needs, e.g. animal feed, fencing, and fuel. However, once a soil enrichment program is initiated with additions of the appropriate fertiliser, more residues are produced and, even with previous rates of removal, there is an increasing quantity that could be retained for the soil (McCown 1987). This opportunity to reverse the process of Figure 3 is enhanced by the improved water conservation that results from the beneficial physical effects of organic materials. Nevertheless, it is as yet unclear whether manure and/or crop residues in the amounts that are available can be sufficient to prevent carbon supply from strongly limiting organic matter recovery without periods of pasture.

A Research Project in Search of Strategies for Sustainable Agriculture for the Middle Potential Zone

Against this backdrop of problems and possibilities, a research program was designed and has evolved. The original on-farm studies (Fig. 4: socioeconomic components; Ockwell et al., in press) reflected an appreciation

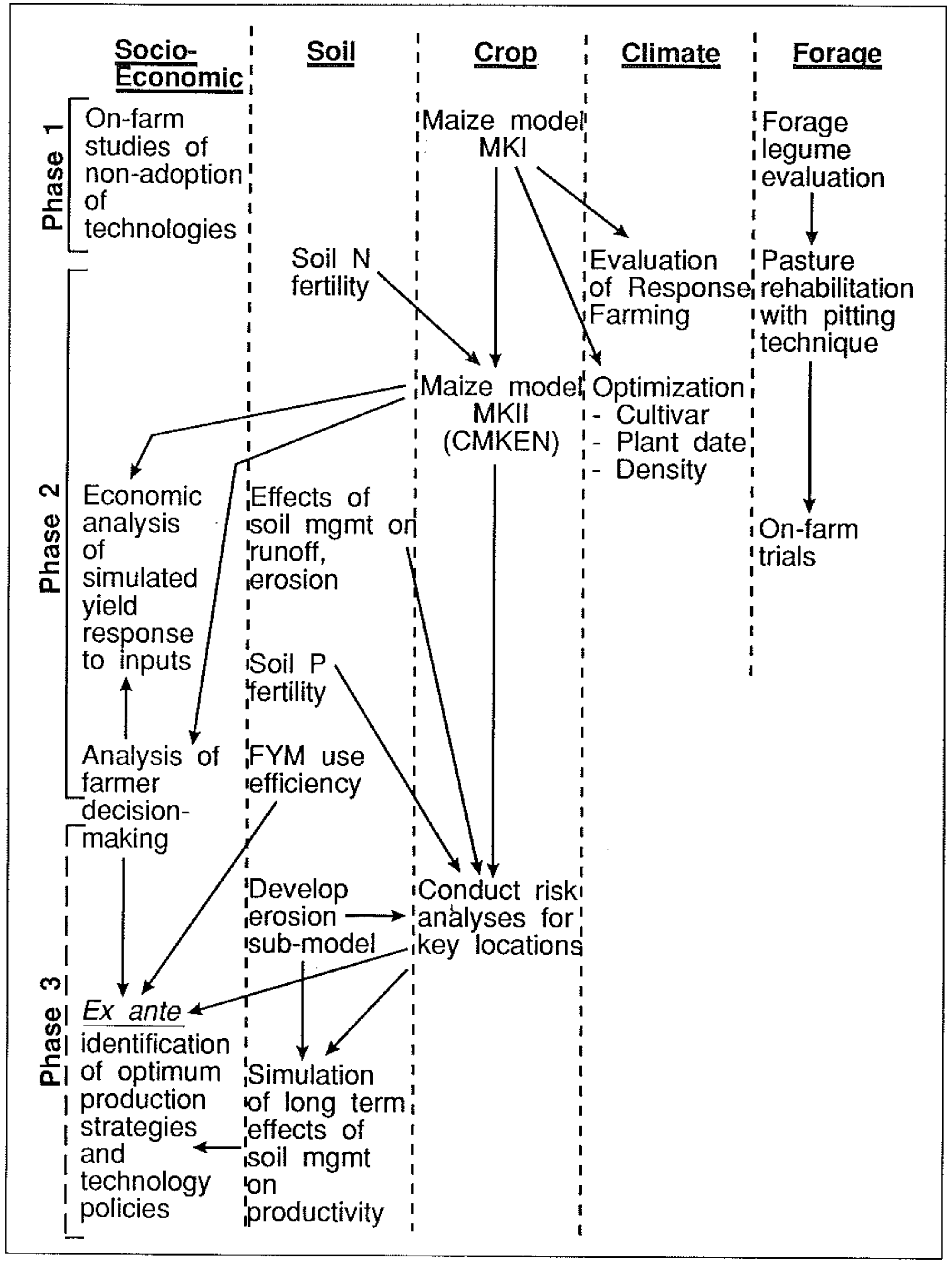

Fig. 4. Schema of research activities, disciplines and phases in the KARI/ACIAR collaborative research project on farming systems in the Machakos and Kitui districts of eastern Kenya.

of the value of diagnosis of problems in the farming system as a basis for design of technical research. However, as is often the case in assistance projects, the assured project duration did not permit completion of the diagnostic work before other research had to commence. The indications that agriculture under existing pressures and practices was unsustainable seemed sufficient to warrant an evaluation of a large number of pasture legumes in search of a well-adapted plant that might enhance the forage and soil nitrogen supplying capacity of fallow (Fig. 4: forage components; Menin et al. 1987). The obvious importance of climatic risk to allocation of scarce production resources suggested that there would be benefit from the early development of a tool for using historical rainfall records to quantify this risk and evaluate alternative farming strategies. A program of testing the CERES–Maize simulation model and adapting it for Kenyan conditions was initiated in Phase I (Fig. 4: crop components; Keating et al., Development of a modelling capability for maize in Kenya, these proceedings). This led to the critical evaluation of Response Farming, a promising scheme for reducing climatic risk to maize production (Stewart and Faught 1984) (Fig. 4: climate components; Wafula et al., these proceedings).

In time, the on-farm studies revealed that:

- even in good seasons, yields are low due to low soil fertility;
- because of the high intensity of land use, there seems little place for pasture legume-enhanced fallows as a main source of N;
- most farmers are aware of fertiliser but do not use it;
- a high risk of rainfall failure is very important in resource allocation decisions; and
- water erosion is a serious threat to productivity on both crop and pasture land.

These findings had several implications for the research program. The forage legume research emphasis shifted from fertility restoration of croplands to rehabilitation of grazing land (Fig. 4: forage component; Simiyu et al. these proceedings). The importance of improved soil surface management and inputs on both fertility maintenance and water and soil conservation formed the basis of a major field study instrumented to measure runoff and soil loss (Fig. 4: soil component; Okwach et al. these proceedings). The outcome should, in addition to providing a direct comparison of strategies, provide an erosion model that, when coupled with the crop model, enables comparison of strategies of soil management in terms which include long-term effects of erosion on productivity (Fig. 4: soil component).

The crop model, once adapted, has indeed provided a means of readily identifying risk-efficient management strategies (planting date, plant population density, cultivar phenological characteristics) (Fig. 4: climate component; Keating et al., Exploring strategies for increased productivity, these proceedings), and with a calibrated N submodel, provides credible surrogate production data for *ex ante* economic analysis of alternative input levels and strategies (Fig. 4: socioeconomic component; McCown et al. 1991; Wafula et al., these proceedings). Such analyses require, in addition to production data, information on farmers' attitudes towards risk and their perceptions of risk levels (Fig. 4: socioeconomic component; Muhammad and Parton, these proceedings).

The main thrust of research on soil fertility has been the efficient use of commercial fertiliser, recognising that boma manure is in very short supply and can only become more scarce as pressure on land continues to increase. Attention initially directed to nitrogen, the most conspicuous and uniformly deficient nutrient, later turned to quantifying phosphorus responses and the efficacy of various forms of phosphatic materials of differing costs (Fig. 4: soil component; Probert and Okalebo, these proceedings). A second thrust was to examine the way in which the boma and its manure content is managed, to see if there are untapped opportunities for more efficient nutrient capture and cycling back through the croplands (Fig. 4: soil component; Probert et al. these proceedings).

The remainder of this volume reports the progress in the various areas of research that have comprised this project in search of a sustainable farming strategy for Ukambani.

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