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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

Model Development in Northern Australia and Relevance to Kenya

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J.N.G. Hargreaves† and S. Nguluu§

IN 1978, a project was initiated by CSIRO to assess the feasibility of a new dryland cropping system in the semi-arid tropics (SAT) of northern Australia. The system centred on the use of no-tillage technology and the inclusion of legume leys into the cropping system (McCown et al. 1985; McCown 1989). This research in the Australian SAT led to the development of the KARI/ACIAR/CSIRO Dryland Project in the Kenyan SAT, the origins of which, its objectives and an overview of research undertaken are provided by McCown and Jones elsewhere in these proceedings.

Of consequence to the Australian research was the early recognition in the Kenyan project, firstly, of the overriding influence of climatic risk to dryland crop production and, consequently, that only through simulation techniques could this variability be readily quantified and options for reduction explored. This corresponded with a recognition in the Australian project of the need for models to assess the climatic and soil constraints to dryland cropping in northern Australia and to develop and evaluate cropping practices that reduce risks and costs. Research in both countries focused on developing this modelling capacity to simulate yield of maize crops in response to the important environmental constraints.

One benefit of developing models that can simulate soil and crop response to environment is their portability across regions. Innovations in model development in either northern Australia or Kenya that are relevant to the other location can be readily transferred. One of the goals of the Kenyan KARI/ACIAR/CSIRO Dryland Project was to conduct research in Australia to support and complement the research in Kenya and this goal has been well fulfilled. The objectives of this paper are to briefly describe research in model development as part of the Australian project and to specify the relevant links to research in the Kenyan project.

Environmental Constraints of Northern Australia and Relation to Kenya

The climate of the SAT of northern Australia is distinguished by a single annual cycle of wet and dry seasons, with potential for dryland cropping only within the monsoonal months of November to April. The rainfall distribution of Katherine (14°28'S, 132°18'E, 108 m) is unimodal with most rain falling between December and March (Fig. 1a). The cropping season in this region is dominated by high radiation load, extreme temperatures and consequent high evaporative demand which greatly reduces effective rainfall for dryland crop production (Williams et al. 1985). The high evaporative rates frequently result in periods of soil water deficit developing soon after rain during the crop's life. High air temperatures during crop development can reduce yields. Poor crop establishment, from rapid drying of the soil surface and either high soil temperatures or seedbed slaking, frequently results in crop failure in the low altitude SAT (Carberry and Abrecht 1991). The dominant cropping soils of northern Australia are the red earths, which nevertheless are generally of low fertility, low water- holding capacity and of poor structural stability (McCown et al. 1984; Williams et al. 1985). Under conventional tillage systems soil loss rates can be very high and this represents the major challenge to sustainable crop production.

Although the climate and soils of the northern Australian SAT have been shown to be very similar to regions of West Africa (McCown et al. 1984; Williams et al. 1985), environmental constraints of this region are similar to many of those in East Africa. As in Australia, soil constraints of low fertility, high runoff and erosion are characteristic of the Kenyan SAT (McCown et al. 1984). Cropping in the high altitude Kenyan SAT does not have to contend with injurious effects of high temperatures. Classification of regions of both Australia and Kenya as semi-arid is indicative of similar constraints due to their variable water environments. The bimodal distribution of rainfall at Machakos, Kenya (1°35'S, 37°14'E, 1601 m) (Fig. 1b) produces two cropping seasons each of approximately 110 to 120 days duration (Keating et al., Impact of climatic variability, these proceedings). Due to constraints on crop establishment at Katherine which delay sowing until mid-December (Carberry and Abrecht 1991), the cropping season is also very short, ranging from 90 to 110 days. Maize genotypes of similar short duration are therefore required in both regions.

A significant difference between the Australian and Kenyan SAT is the degree of cropping currently undertaken in each region. In Australia, there is minimal cropping in the SAT and research has concentrated on evaluating the potential for cropping given prevailing environmental constraints. In the Kenyan SAT, large populations rely on crop production for basic food requirements and hence lifting the current low yield potential of the region has been a basic goal of research.

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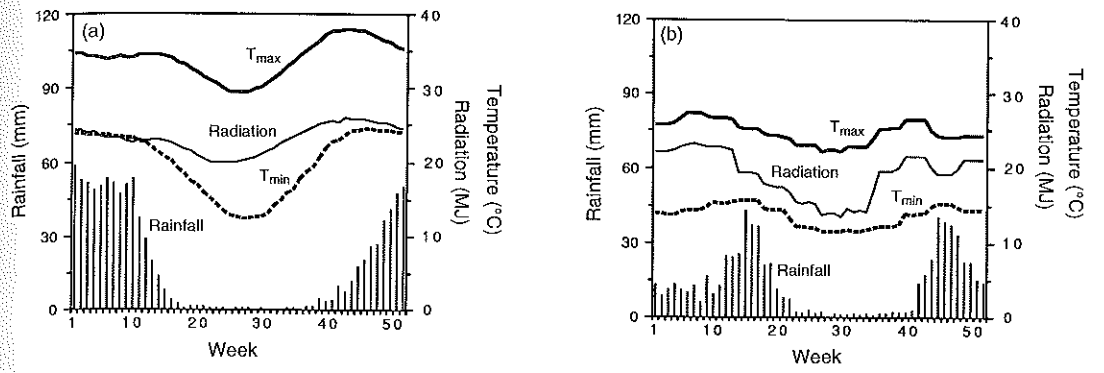

Fig. 1. Mean weekly rainfall, solar radiation, and maximum and minimum temperatures at (a) Katherine, Northern Territory, Australia (lat. 14°S; elev. 120 m; annual rainfall 871 mm); and (b) Machakos, Kenya (lat. 1°N; elev. 1600 m; annual rainfall 890 mm).

Model Development

At the start of the project, existing maize models had been developed from research conducted under high input conditions in temperate agricultural systems. The environmental constraints of the SAT are often outside the domain in which these crop models have been developed. For this reason, this project has invested heavily in the modification and then validation of simulation tools which can be applied to the important constraints to cropping in both northern Australia and Kenya.

Model development in both Kenya and Australia commenced with the selection of the CERES–Maize simulation model, developed in North America to simulate the growth, development and yield of maize crops in response to climate, soil and management information (Jones and Kiniry 1986). Our approach in applying CERES–Maize to northern Australia has been to validate each component of the model, the three main processes being the simulation of maize physiology, the soil water balance, and the soil nitrogen dynamics. In this regard, the Australian project can be readily divided into research activities analogous with these model components.

Research in Australia also included enhancements to the original model, dealing with other crops and other processes. The effects on seedling establishment by altering the seedbed environment, the consideration of rotations or intercrops, the supply of phosphorus to crops, the inclusion of soil degradation by erosion and organic matter rundown, and the ability to interpret simulations by economic decision analysis were important additional requirements sought through research undertaken as part of the Australian project. This work has gone well beyond the simulation model of a maize crop and as such has been encapsulated into the cropping systems model AUSIM (McCown and Williams 1989). Consequently, recent focus of model development in Australia has been the AUSIM model and its application in operational research objectives (McCown 1989).

Crop Models

The initial testing and calibration of CERES–Maize to the Australian (Carberry et al. 1989) and Kenyan (Keating et al., Development of a modelling capability, these proceedings) SAT regions were undertaken through parallel yet independent research in both countries. Close collaboration between the two groups facilitated error detection and correction, and enabled development of innovations within the model to improve predictive capacity at both sites. The two groups collaborated on the development of an innovative procedure to better simulate leaf area development of crops based on the appearance, expansion and senescence of individual leaves of plants (Fig. 2) (Muchow and Carberry 1989,1990; Carberry

1991; Keating and Wafula 1992). Subsequently, however, emphasis in model development diverged, with work in Australia concentrating on crops other than maize and on the issue of poor crop establishment, whereas Kenyan work has concentrated on validating the nitrogen version of CERES–Maize.

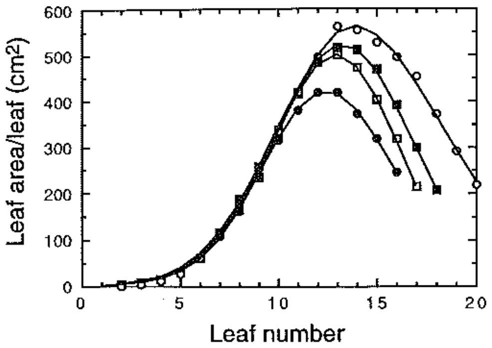

Fig. 2. Fully expanded area of individual leaves for sorghum plants with final leaf numbers of 16, 17, 18 and 20 leaves. The fitted relationship is of the form

$$Y = Y_0.\exp[a.(X - X_0)^2 + b.(X - X_0)^3]$$

where X_0, Y_0, a and b can be expressed as linear functions of final leaf number per plant (Muchow and Carberry 1990).

To date, simulation models of maize (Carberry et al. 1989; Carberry and Abrecht 1991), sorghum (Birch et al. 1990; Carberry and Abrecht 1991) and kenaf (Carberry and Muchow, unpublished data) have been developed and validated for use in northern Australia (Fig. 3). These models include enhancements to simulate the effect of soil water deficit on phenology, leaf development, and seedling mortality (Abrecht and Carberry 1992; Carberry and Abrecht 1991). The models predict maximum soil surface temperatures, and high soil temperature effects on crop establishment are simulated (Carberry and Abrecht 1991). Current research involves validation of the maize and sorghum models in subtropical Australia. The development of similar models for peanut, soybean and mungbean crops is also planned in recently initiated research.

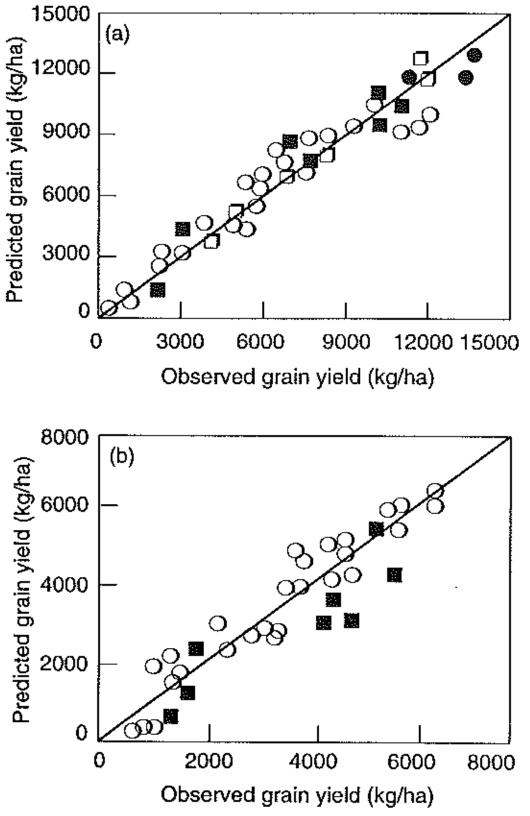

Fig. 3. Grain yields predicted by maize and sorghum simulation models versus observed oven-dry grain yields for a number of experiments: (a) maize; (b) sorghum. Key: ○ = Katherine; ▲ = N.T.; ❑ = W.A.; ● = S.E. Qld; ■ = N. Qld; —— = 1:1 line.

The maize simulation model can be run for at least seven contrasting maize genotypes. The genotypes were parameterised from data collected at sites in northern Australia ranging in latitude from 13.8°S (Douglas Daly, N.T.) to 27.6°S (Gatton, Qld). Data on the Kenyan genotype, KCB, were collected at four of the sites (Table 1). Crop duration of KCB ranged from 85 to 115 days between sowing and maturity. Mean leaf numbers per plant of KCB ranged from 15.7 to 19.1, which indicated a significant photoperiodic response. The current Kenyan version of the maize model, CM-KEN, does not incorporate a photoperiodic response and so the Australian data will be used to this end. Also apparent was an effect of high air temperatures on grain numbers which is also unaccounted for by CM-KEN.

Soil Water Balance

The infiltration, drainage and runoff functions of the CERES–Maize WATBAL water balance have been evaluated against data collected in both Australia and Kenya (B.H. Wall, unpublished data). Several problem areas were identified in the simulation of soil water balance. For two soil profiles characterised by Jones and Kiniry (1986), CERES–Maize greatly underestimated drainage under saturated conditions as calculated using known values of saturated conductivity. When compared to data for bromide leaching for soils at Katherine (J.P. Dimes, unpublished data), the model adequately simulated drainage on a clay loam soil, but underestimated drainage on the sandy loam soil. In Kenya, simulations by CERES–Maize overestimated the amount of runoff measured for selected rainfall events at Katumani Research Station (Ulsaker and Kilewe 1984). Finally, CERES–Maize proved inadequate in simulating soil water balance of a thin surface layer (D.G. Abrecht, unpublished data), an important requirement for predicting surface soil temperatures and surface residue decomposition.

Table 1. Information on maize grown at four locations in northern Australia, giving latitude (°S), date of sowing, daylength (h) at 20 days after sowing, mean leaf number per plant and mean days from sowing to 50% silking for both the Kenyan KCB and Australian Dekalb XL82 genotypes.

Location	Latitude (°S)	Sowing date	Daylength (h)	Leaf number KCB	Leaf number XL82	Silking KCB	Silking XL82
Katherine	–14.5	23.12.88	13.7	17.9	18.9	46	48
Kununurra	–15.7	9.06.89	12.0	15.7	18.8	61	73
Walkamin	–17.1	19.12.88	13.9	16.1	17.0	56	60
Gatton	–27.6	8.11.88	14.5	19.1	20.7	60	62

CERES–Maize employs separate empirical equations for each process in the soil water balance and, as such, a number of inadequacies have been identified. The USDA curve number system (USDA Soil Conservation Service 1972) is used to simulate runoff, and although it can be calibrated for overall estimation of seasonal runoff, it is less appropriate for runoff prediction of particular storms. CERES–Maize does not account for problems such as surface sealing and the influence of rainfall intensity of soil properties. Alternatively, the SWIM (Soil Water Infiltration and Movement) model, which numerically solves Richard's equation (Ross 1990), provides an improved, more physically based method for simulating the soil water balance.

The SWIM model has been implemented in AUSIM for use with both Australian and Kenyan crop models. SWIM has made redundant the routines by which CERES–Maize calculated soil evaporation, surface water runoff, drainage and nitrate leaching. In contrast to CERES–Maize, SWIM also permits the simulation of soil water in thin layers at the soil surface. The implementation of SWIM has been done such that minimal additional input information is required by AUSIM. This extra data can be readily derived from data collected in the same experiments as detailed for users of CERES–Maize. Consequently, users are no worse off by using SWIM but with the prospect of achieving better results by allowing for simulation of relevant management scenarios. For this reason, SWIM is currently being evaluated in comparison with CERES–Maize. Event-based data on rainfall, runoff and soil loss are being collected as part of the Kenyan project in order to test SWIM and to develop routines to simulate the processes of soil erosion (Okwach et al. 1991)

Another departure from CERES–Maize is the method of determining transpiration and root water uptake. In transferring CERES–Maize to a different environment or converting it to a different crop, the requirements for detailed root data have proved prohibitive. Alternatively, transpiration in Australian versions of the maize, sorghum and kenaf models is now calculated as a function of biomass accumulation, a transpiration efficiency coefficient, daily vapour pressure deficit and a 0–1 soil water deficit factor. The root-defined fraction of available soil water on a given day is determined from the ratio of available soil water in a simulated rooting zone to a maximum soil water deficit value, which increases as a function of time after sowing.

Soil Nitrogen and Phosphorus

To date, research on nitrogen supply to crops in Kenya has concentrated on validation of crop yield predictions of CERES–Maize under conditions of low soil fertility supplemented by different application regimes of nitrogen fertiliser (Keating et al. 1991c; Wafula et al., these proceedings). Research in Australia has complemented the Kenya work by concentrating on validation of the routines which simulate the soil-N dynamics, primarily the processes of N mineralisation, immobilisation and leaching. Such research is easier undertaken in Australia where access to ^{15}N labelled nitrogen and chemical analyses are routine. The initial testing of the nitrogen modules of CERES–Maize in Australia was undertaken under the no-till ley farming system proposed by McCown et al. (1985).

At Katherine, mineral-N supply under a bare fallow (Wetselaar 1962) or mineralisation following a grass pasture were generally well predicted by CERES–Maize, but prediction of mineral N after a legume pasture was underestimated (J.P. Dimes, unpublished data) (Table 2). Several other problems with the prediction of soil N by CERES–Maize were also identified. Mineral-N released deep in the soil profile was overestimated, there was insufficient sensitivity of mineralisation to variation in the soil water regime, and periods of low mineral-N supply due to high immobilisation were not well sim-

Table 2. Predicted and measured levels (kg/ha) of soil nitrate under three different residue systems.

System	Soil nitrate	
	Predicted	Measured
Bare fallow	111	124
	169	179
	222	236
Grass	61	62
Legume	102	149

ulated. Levels of nitrate leaching were generally underestimated, a problem that can be traced to the soil water balance of CERES–Maize. Inaccuracies in simulating water flux through the profile to deep drainage or in soil evaporation impact especially on the N balance. Finally, CERES–Maize simulates mineralisation of fresh organic matter incorporated into the soil but has no function for decomposition of residues situated on the soil surface — an obvious deficiency for simulating the no-till farming system at Katherine.

To address the problems identified in the N subroutines, several modifications have been made to CERES–Maize. The substitution of the SWIM water balance model in place of the CERES WATBAL subroutine has potential to improve simulation of nitrate leaching and decomposition of organic matter which is essentially water-driven in the biologically active and important surface layer. CERES–Maize simulates mineralisation from two main N pools, a humic pool and a pool of fresh organic matter. A third pool of potentially mineralisable N has been quantified for the system at Katherine (Table 3), and this labile pool is being added to the CERES mineralisation subroutines. Its importance was identified from Katherine data where, in the grass system, the supply of mineral N from the labile pool was immobilised by the demand for N associated with the decomposition of a large, N-poor root system. In contrast, for the legume system, demand for N associated with decomposition of a smaller and higher N content root system resulted in a substantially larger net mineral N supply (Table 2).

Table 3. Determinants of mineral N supply following grass and legume pasture leys on two red earth soils at Katherine.

	Clay loam		Sandy loam	
	Grass	Legume	Grass	Legume
C:N ratio	59	22	80	32
Total N (0–20 cm)	2014	2014	681	690
Labile N pool	132	110	41	38
Root dry weight	10530	5690	4611	3914

Using experimental results from ^{15}N labelled surface residues (J.P. Dimes, unpublished data), the mineralisation routines of CERES–Maize have been modified to account for decomposition of residues on the soil surface. Given residue amount and its C:N ratio, potential mineralisation calculated from the rate coefficients in CERES–Maize is modified by a water index and a contact factor to accurately simulate measured dry matter decomposition of surface residues (Fig. 4a). Whereas rates for organic N mineralisation mirror those for carbon decomposition in CERES–Maize, 37% of legume N and 18% of grass N was leached from surface residues in soluble form. When this leaching of soluble N was taken into account, the function for decomposition of surface residues successfully predicted N mineralisation from surface residues (Fig. 4b).

Phosphorus deficiency limits the productivity of legumes grown at Katherine in terms of total dry matter produced and biologically fixed N (S. Nguluu, unpublished data). This research project aims at quantifying the legume response to applied P, its influence on N-fixation and the resulting N supply from legume residues to following crops. Results will be employed in the development of a P submodel to be added to the crop models for application in both Australia and Kenya (cf. Probert and Okalebo, these proceedings).

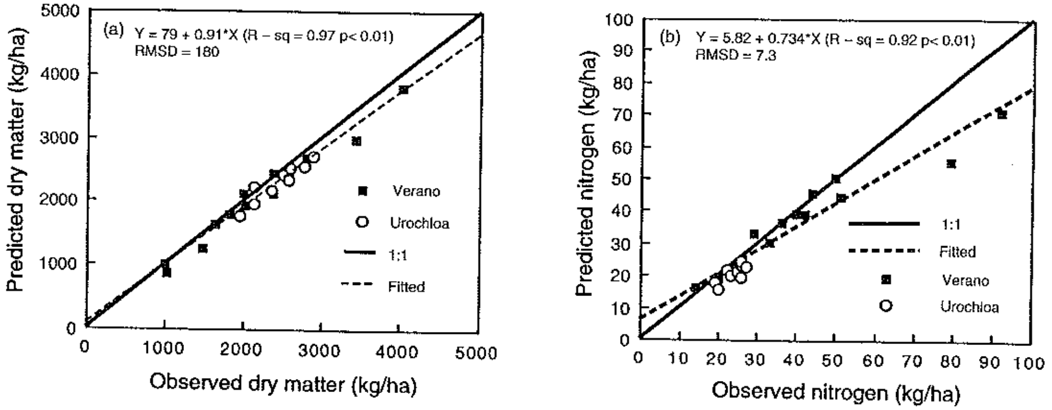

Fig. 4. Predicted versus observed recovery (kg/ha) of (a) dry matter, and (b) nitrogen from residues applied to the soil surface.

The AUSIM Cropping Systems Model

To deal with crop production systems, including different cropping strategies, soil management alternatives and problems such as soil erosion, we needed a cropping systems model for use in operational research in both Australia and Kenya. The AUSIM cropping systems model (McCown and Williams 1989) has been developed to utilise our existing crop, soil water and nutrient models, thus retaining their level of process treatment. AUSIM is well structured and modular, with modules for different crops, environmental variables and management rules readily replaceable and communicating via a 'tallyboard' of state variables (Fig. 5). While, in most cases, the operational objective in using models is simulation of crop yield, the significance of AUSIM is its emphasis on the dynamics of the soil environment. In simulations, crops can come and go, but the soil accrues their effects.

Developments in programming the AUSIM cropping systems model (J.N.G. Hargreaves, unpublished data) include a running prototype of the modules to simulate intercropping, which allows growth of concurrent crops to be simulated. A generic crop module has also been developed which supplies a common format for the development of crop models. This commonality between crop modules will greatly increase efficiency in the development and maintenance of models for new crops. Finally, a comprehensive management module has been detailed for implementation in AUSIM. This management module has been based on the Response Farming module developed for Kenya (Wafula et al. 1991) and will allow for complex simulation of systems phenomena such as rotations and sowing and fertiliser decisions dependent on incident climatic conditions.

Model Applications

Rainfed crop production in the SAT of both northern Australia and Kenya is risky. Figure 6 shows predicted maize yields at Katherine for the period 1889–1988. In these situations, yield simulation provides a means of

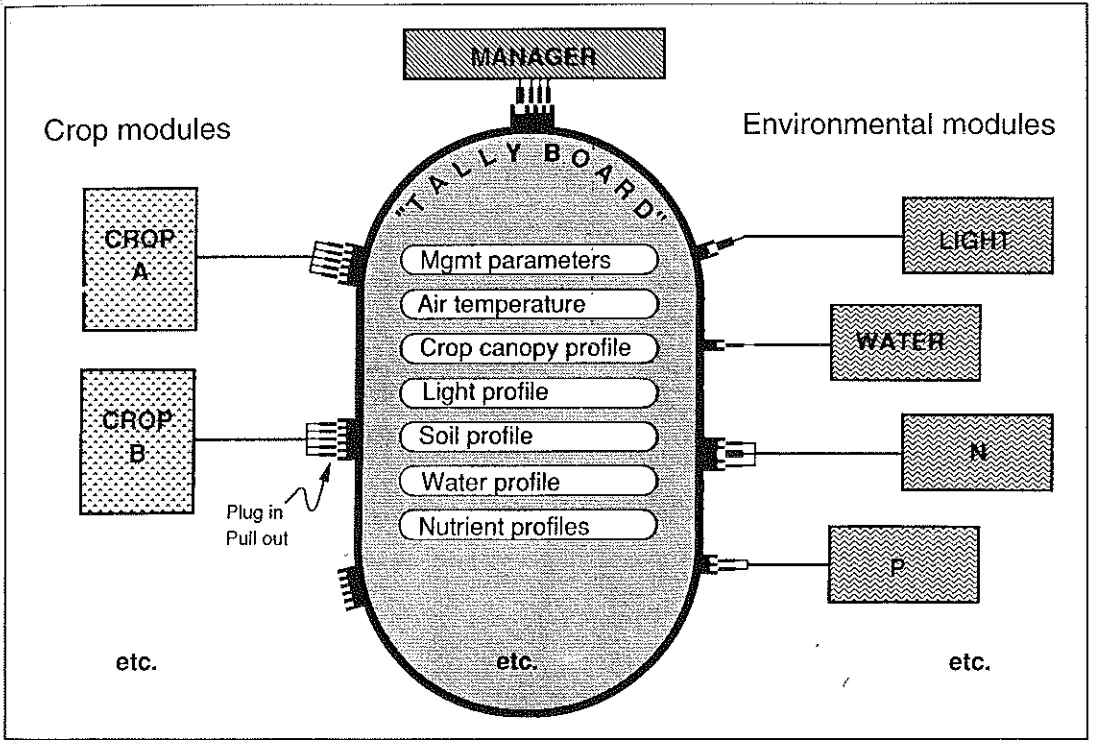

Fig. 5. Program structure of the AUSIM cropping systems model.

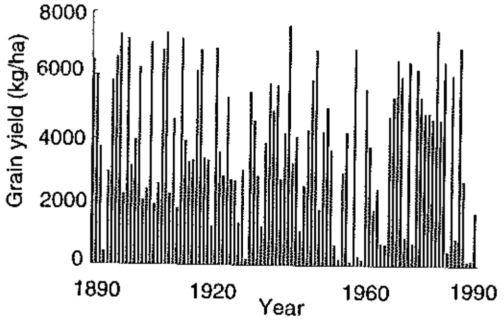

Fig. 6. Simulated maize grain yields from 1889 to 1988 at Katherine (Carberry and Muchow 1991).

quantifying production risk by utilising the whole climatic record, whereas field experimentation is hampered by a relatively small number of sample years. The potential of maize at Katherine differed markedly between short runs of years: simulated mean yields for the periods 1958–1965 and 1973–1980 were 1636 and 5638 kg/ha, respectively, compared with 3770 kg/ha for the complete 100-year period (Fig. 6).

Using the crop models, the prospects for cropping in northern Australia have already been assessed in a number of studies. For maize and sorghum, these studies include the simulation of yields and assessment of risks to cropping at different locations, for different genotypes, for a range of planting times, and for different tillage strategies (McCown 1990; Cogle et al. 1990; Carberry and Abrecht 1991; Muchow and Carberry 1991; Carberry et al. 1991; Muchow et al. 1991).

The significance of model improvements made by the project can be highlighted in the results of the example application study shown in Figure 7. In the Australian SAT, both the opportunities and yield advantage from early sowings that were simulated when seedling mortality was ignored were negated once seedling mortality from soil water deficit and high soil surface temperatures was simulated. Therefore, only models which realistically deal with key constraints in SAT enable the design and evaluation of crop and management strategies for this zone.

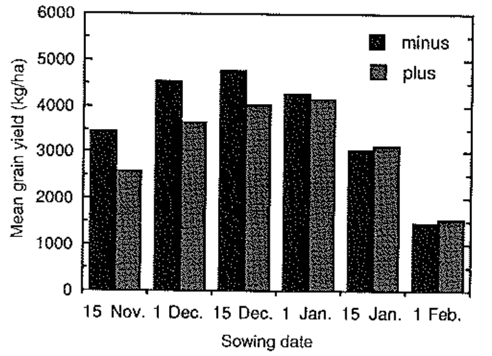

Fig. 7. The influence of different sowing dates over 100 seasons at Katherine on the mean grain yield of maize simulated with either plus or minus enhancements for simulating problems during crop establishment (Carberry and Abrecht 1991).

Relevance of Research to Kenya

Research undertaken in Australia has unquestionably benefited research in Kenya, and the converse is equally true. The recognition in the Kenyan project of the need for an operational research approach introduced the opportunity to undertake component research in Australia to support model development in both places. The resulting transfer of information between the two locations has been achieved through models which can account for temporal and spatial variation in the soil and climatic influences on crop production.

After the early, concurrent work on testing CERES–Maize in both countries, the ensuing divergence in activities nonetheless complemented both groups. The Kenyan project validated predictions of maize yield response to fertiliser N and this work has given added confidence in the nitrogen subroutines for use in Australia. The template for a management module in AUSIM was developed for the purpose of analysing Response Farming in Kenya, and research leading to the development of phosphorus and erosion modules is being primarily undertaken in Kenya. The Australian research has provided, in turn, improved routines to simulate soil N, model enhancements which account for seedling retardation and mortality, access to data for the Kenyan genotype KCB grown over diverse locations, a model for sorghum and an improved method for simulation of the soil water balance.

An attractive aspect of this ACIAR/CSIRO/KARI-sponsored project has been the efficient allocation of tasks between research groups that utilised the comparative advantages of each group's environment. An important outcome of this research is the development of the AUSIM cropping systems model which allows operational research questions to be answered in the SAT cropping regions of both Kenya and Australia.

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