Constraints in the Smallholder Farming Systems of Zimbabwe

E.M. Shumba*

Abstract

This paper reviews constraints to crop production, the status of technology development and future research needs of the smallholder farms in the semi-arid areas of Zimbabwe.

ZIMBABWE'S agricultural industry consists of two major sectors; the large-scale commercial and the smallholder (communal) sectors. Prior to 1980 production from the communal sector was largely for subsistence requirements. However, its contribution to marketed maize output has increased from 8% in 1976 to 48% in 1986-88 while its proportion of cotton production rose from 22% to 50% over the same period (Table 1). Such advances clearly demonstrate that, given the appropriate technical and institutional support, communal farmers have the capacity and willingness to invest in expanding the country's agricultural production.

Un fortunately, this analysis becomes misleading when one considers that about 80% of the maize delivered by the smallholder sector to the Grain Marketing Board in 1985 came from only 20% of the one million communal area households i.e. those located in the higher rainfall environments (Natural Regions I and II). The majority of farmers contribute very little because they live in the low rainfall areas (NRs III to V). Many of these farmers experience food shortages (both in terms of quality and quantity), particularly during drought years (Fig. 1).

Table 1. Proportion (%) of total crop delivered to official marketing outlets by sector, 1976-88.

<table>
<thead>
<tr>
<th>Crop %</th>
<th>Year</th>
<th>Large-scale commercial farms</th>
<th>Communal areas*</th>
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<tr>
<td></td>
<td>1976-80</td>
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<tr>
<td></td>
<td>1986-88</td>
<td>44</td>
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*Includes deliveries from small-scale commercial farms and resettlement areas.
Source: Agricultural Marketing Authority and Central Statistical Office.

Table 1.

Constraints to crop production in communal areas

Communal areas of Zimbabwe are characterised by low levels of agricultural production and productivity. This is largely due to biophysical and socioeconomic problems in this sector.

About 74% of the communal farmland is located in NRs IV and V which are characterised by low and erratic rainfall and a short growing season, and therefore are generally considered marginal for crop production (Vincent and Thomas 1960). The predominantly light textured soils are also less fertile than those found in the large-scale commercial sector. These soils have been extensively cropped with little or no addition of fertilisers, and thus are severely depleted of nutrients, especially nitrogen and phosphorus (Mashiringwani 1983). Grant (1981) demonstrated that it was difficult to obtain good crop yields on these soils without regular applications of inorganic fertiliser, manure or lime. However, moisture shortages during the crop growth cycle limit the extent to which crops can respond to inorganic fertilisers on these soils (Mackenzie 1987).
The major socioeconomic constraint is the poor resource base which limits the extent to which smallholder farmers can invest in agricultural activities. Table 2 shows the resource endowments of farmers in two communal areas located in high (Mangwende) and low (Chivi) rainfall areas. The relatively high cropping intensity in Chivi, a semi-arid site, illustrates the farmers' desire to spread risk by cropping larger areas. While the large areas of 0.69 and 0.59 ha cultivated per active family member in Mangwende and Chivi, respectively, resulted in labour bottlenecks during the cropping season; such labour shortages contributed to delayed weeding and late basal fertiliser application. Both these practices have been shown to reduce crop yields (Shumba 1989; Mabasa, pers. comm.). Furthermore, weed competition has been found to be more severe if it coincides with early dry spells and in the absence of inorganic fertilisers.

Approximately half the farmers in Chivi and Mangwende communal areas do not own cattle and therefore have poor access to draught power. The
situation is exacerbated by droughts and lack of dry season feed that result in a weak and reduced draught power pool available to service an increasing number of cultivators at the beginning of each cropping season. This leads to late crop establishment and a further reduction in the length of the growing season, hence low crop yields, particularly for the non owners of cattle (Shumba 1989).

Smallholder farmers in the semi-arid areas realise lower incomes than those of their counterparts in the higher rainfall areas. In fact the former get more than half of their annual cash incomes from non-farming activities. Such low incomes limit the extent to which they can invest in agricultural production, e.g. Chivi farmers invest only 14% of their annual income of $Z173 in agricultural inputs compared to 28% by their counterparts in Mangwende, a high rainfall site (Table 2).

| Table 2. Resource base of smallholder farmers in Mangwende and Chivi communal areas.* |
|---------------------------------|----------------|----------------|
| Farm size, ha                  | Mangwende*a   | Chivi*a        |
| (n=80)                         | 2.87          | 2.82           |
| Average cropping intensity (%) | 75            | 82             |
| Family size (no.)              | 7.4           | 8.5            |
| Family members active on the farm (no.) | 3.1 | 3.9 |
| Area cultivated per family member (ha) | 0.69 | 0.59 |
| Farmers hiring casual labour (%) | 30            | 39             |
| Farmers owning draught animals (%) | 45            | 41             |
| Annual cash income ($Z)         | 601           | 173            |
| Income from off-farm sources (%) | 27            | 57             |
| Income spent on agricultural inputs (%) | 28        | 14             |


The foregoing biophysical and socioeconomic constraints account largely for the low crop yields achieved by smallholders in the semi-arid areas of Zimbabwe (Table 3).

| Table 3. Average crop yields (t/ha) achieved in Mangwende and Chivi communal areas.* |
|---------------------------------|----------------|----------------|
|                                  | Mangwende*a   | Chivi*a        |
| National average for communal areas | 2.6          | 1.0            |
| Maize                           | 2.6           | 1.0            |
| Groundnuts                      | 0.7           | 0.3            |
| Finger millet                   | 0.9           | 0.4            |
| Sunflower                       | 0.6           | 0              |
| Sorghum                         | 0             | 0.4            |
| Pearl millet                    | 0             | 0.5            |

a. Mangwende and Chivi are in Natural Regions II and IV respectively.


Status of technology development

Previous and current research has concentrated on developing technologies to increase and stabilise crop yields under conditions of low and erratic rainfall on depleted sandy soils. They include the following:

Crop improvement. Over 95% of the smallholder farmers buy and plant hybrid maize seed each year (Rohrbach 1988, Shumba 1990). The local breeding effort has, over the years, concentrated on drought-tolerant maize with emphasis on early maturing and high-yielding three-way hybrids. When compared to the commercially available open pollinated varieties, such hybrids are superior in both yield and yield stability under marginal conditions (Shumba 1990). Furthermore, hybrid maize seed is also widely available throughout the country. However, the adoption of the recently released early maturing and high-yielding varieties of sorghum and pearl millet has been poor due largely to the shortage and limited distribution of the improved seed and unattractive crop producer prices.

Inorganic fertiliser use. Research carried out on depleted sandy soils showed considerable variation in crop yield response to N-P-K fertiliser depending on site and season (Agronomy Institute 1985). Although the regular application of cattle manure in combination with nitrogen fertiliser has increased available soil N and P over time, crops have not benefited from the nutrient buildup during below average rainfall years. The apparent unreliability of the benefits from chemical fertiliser used under semi-arid conditions partly explains why the technology has not been widely adopted by smallholder farmers (CIMMYT 1982; Rohrbach 1988).
Moisture conservation. Although a number of moisture conservation practices such as ridge and farrow planting have been designed, tested and widely promoted (Johnson 1987), most of the smallholder farmers still plant crops in conventional seedbeds prepared by ox-drawn mouldboard ploughs. This is despite the potential of such practices to improve crop response to fertilisers under low rainfall. Among other things, Waddington (1991) has attributed the low adoption to the uncertain short-term crop yield benefits from the technologies on light textured soils.

Plant population. Work conducted by the Agronomy Institute has shown considerable site and year variation in crop yield responses to plant population in semi-arid areas. While a maize stand of 36000 plants/ha was considered optimal during a good rainfall season, it significantly reduced grain yield in a dry year.

Intercropping. Although most research conducted in the humid and subhumid areas indicated that intercropping reduces risk of crop failure from factors such as drought (Fisher 1977), some local research has established that the practice may not have a big effect on yield stability in the marginal rainfall areas. Under these conditions intercropping drastically reduced the yield of the main crop without much improvement in overall land productivity in a dry year (Shumba et al. 1990).

This overview demonstrates a strong dependence of some of the technologies on soil and rainfall-related factors. To account for this, researchers have traditionally collected the relevant soils and rainfall data and used it qualitatively to interpret their results. However, the Agronomy Institute has started recently to build quantitative models of the systems under study in order to help researchers interpret results.

Future research needs

Future research could focus on the following broad areas.

- Improving upon the existing cropping systems so that they become more productive and stable through crop improvement and crop management research. Crop improvement could focus on screening germplasm for drought tolerance and nitrogen-use efficiency at sites with low rainfall and infertile sandy soil. However, because of its complexity and long-term nature, this type of work lends itself to joint research projects with international agricultural research centres such as CIMMYT, in the case of maize.

Crop management research could concentrate on improving the researchers’ understanding of the responses of key crop husbandry practices to variations in soil fertility and rainfall through modelling. The success of this approach depends on good site characterisation and maintenance of detailed records on the experiments. Given the site-specificity of crop management research and the limited funding available for such efforts, there is need to select carefully a few representative sites for this type of work.

- The development of new farming systems. The fact that more than 50% of the annual cash incomes realised by smallholder farmers in semi-arid areas comes from off-farm sources suggests that the existing cropping systems have failed to meet their needs adequately. There is therefore need to develop new, profitable and sustainable farming systems that improve the standards of living of these farmers. These could include agroforestry-based cropping systems, introduction of irrigated agriculture, and concentrating on livestock at the expense of dryland cropping.

References


Mashiringwani, N.A. 1983. The present nutrient status of the soil in communal areas of Zimbabwe. Zimbabwe Agricultural Journal, 80, 73–75.


An Integrated Approach to Soil Fertility Improvement in Malawi, Including Agroforestry

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Abstract

Approximately 80% of land under cultivation in Malawi is planted to maize. Most maize is grown by smallholders, whose farm sizes average less than 1 ha per farm family. Because of the high population density (>75 people/km²), most land is continuously cropped. The introduction in 1991 of flinty hybrid maize varieties, which have processing and storage characteristics similar to local varieties, has led to a sharp increase in hybrid maize adoption in Malawi. Hybrid varieties currently account for 20% of the total land area planted to maize.

The fertilisers available to smallholder farmers in Malawi contain only N and P and, in some cases, S. Hybrid maize varieties currently available in Malawi have yield potentials in excess of 10,000 kg/ha, but on farmers' fields average less than one-third of this amount. 'Minus one' nutrient trials conducted from 1989 to 1992 revealed potential deficiencies of K, S, Zn and B at some sites.

Soils from over 400 demonstration sites were analysed, and a nutrient supplement of S, Zn and B (and in some cases K) was added to the existing N and P fertiliser recommendation. The nutrient supplement resulted in substantial and economical yield improvement at several of the sites tested. The demonstration trials also revealed that hybrid maize performed better than local maize under zero and suboptimal rates of fertilisation. Farmers have been under the mistaken impression that hybrid maize requires substantial amounts of fertiliser to outperform local maize. The results may encourage farmers who cannot afford large amounts of fertilisers to adopt hybrid maize.

Other research indicates that the amount of P supplied in the fertiliser recommendation, 40 kg P₂O₅/ha, may be excessive, and in some cases may be detrimental to maize yields. Band application of P fertilisers has been shown to be more efficient than the current dollop method. Surface application of urea has proved as effective as dollop application at topdressing. Late application of both basal and topdressing fertilisers is suspected to cause lowering of yields. An early season dry spell characteristic of rainfall patterns in Malawi is suspected to reduce greatly the effectiveness of late-applied basal dressing fertiliser.

Agroforestry could play a substantial role in soil fertility improvement. Data from alley cropping trials indicate that trees cycle substantial quantities of calcium (Ca), magnesium (Mg), phosphorus (K) and sulfur (S) to the upper 15 cm of the soil profile. However, little P is cycled, and even N-supply by the leaves is fairly limited. Adding N and P at low rates to an alley cropping system substantially improves yields, and permits maize to take advantage of other nutrients cycled by the trees. The particularly favourable S and K status is soils under alley cropping was encouraging in light of the deficiencies of these elements found in Malawi soils.
Statistics on maize production accumulated by CIMMYT (1992) show the effects of population pressure on soil fertility. The population of Malawi is growing at 3.5% annually. However, land available for maize production is limited, and increased only 1.7% annually from 1981–1990. Maize yield on a per hectare basis actually decreased 1.2% annually over this same period, resulting in an annual decrease in per capita consumption of 2.3%. The decrease in per-hectare yields was in spite of an average annual increase in fertiliser consumption of 7.8% from 1970 to 1989. Clearly, increased land pressures have resulted in declining soil fertility and lower yields. With the population continuing to grow and little uncultivated land available for future production, the current agricultural system in Malawi is unsustainable and in decline.

Because of the limited land area available for crop production, the trend of declining maize yields must be reversed if food self-sufficiency is to be maintained in the face of an increasing population. Maize yields in Malawi average 1.1 tons/ha. Available hybrid varieties in Malawi have yield potential in excess of 10 tons/ha. However, hybrid seed use is low, and the yield potential of hybrid varieties can be achieved only under improved soil fertility. Because rainfall is normally adequate in the major maize-producing areas of Malawi, the key to increased maize production is improving soil fertility and increasing hybrid seed use.

One of the major obstacles to hybrid seed adoption, the lack of varieties acceptable to farmers, has been addressed with the release of the varieties MH17 and MH18 in 1990–91. Local maize has traditionally been preferred by farmers because of its harder (flinty) endosperm. The flintiness imparts considerable resistance to weevils, a major pest that usually decimates the softer endosperm (denty) hybrids in storage. Furthermore, a higher percentage of endosperm is recovered from local maize in the traditional maize processing. The new maize varieties have a large proportion of hard endosperm, giving them a flinty texture more like the local maize. Farmers perceive the new varieties as possessing similar storage and processing characteristics to local maize (Snale et al. 1993).

The area planted to hybrid maize has been increasing steadily since 1986: maize area planted to hybrids approaching 20% in 1992-93. Hybrid adoption has been hindered by a perception that hybrid varieties must be fertilised at high rates in order to yield economically. Most farmers purchase hybrid seed and fertiliser through government credit packages. Because of the high rates of fertiliser (92 kg N and 40 kg P₂O₅/ha) that must be purchased with the seed, the packages are expensive. Farmers are reluctant to accept this large credit risk.

Maize Fertilisation Practices in Malawi.

Currently, a single fertilisation recommendation exists for hybrid maize throughout Malawi. That recommendation is 92 kg N and 40 kg P₂O₅/ha. Basal fertiliser is supplied by either diammonium phosphate (DAP; 18% N and 48% P₂O₅) or 23:21:0+4S. Topdressing N is supplied as either urea or calcium ammonium nitrate (CAN; 28% N). Both basal and top dressing fertilisers are applied in two concentrated dollops, applied 10 cm on either side of each maize planting station, at a depth of 10 cm. The maize itself is planted on 90 cm rows in planting stations of three plants spaced every 90 cm. There are approximately 12,350 planting stations per ha. Thus 24,700 dollops should be applied at basal dressing and another 24,700 at topdressing. This is a very labour-intensive process.

Several shortcomings on current recommended fertilisation practices exist. These are summarised below.

(i) The rate of fertiliser in the recommendation for hybrid maize is beyond the means of many smallholder farmers.

(ii) Fertilisers available to smallholders supply only N and P, and in some cases S. Potential deficiencies of Ca, Mg, K, Zn, Cu and B are not accounted for in the recommended fertilisers.

(iii) The blanket N/P recommendation does not take into account regional soil fertility differences.

(iv) The practice of applying fertilisers in dollops is extremely labour-intensive. Farm costs for a single fertiliser application are the same as required for ridging. Because of the labour required, fertilisers are often applied too late for maximum effectiveness.

(v) Apart from being labour-intensive, dolloping can be an inefficient method of fertiliser application. Urea, when concentrated in a dollop, may convert slowly to available-N forms, and could reduce N-availability during critical growing stages. P is often more efficiently applied in a band than in a dollop because of improved root contact with the fertiliser.

The Malawi Maize Commodity Team (MCT) has been addressing these constraints in an integrated approach to increasing maize yields by improving soil fertility. This paper highlights research...
methodology and results. In addition, results relating to maximising returns from alley cropping are presented.

Hybrid Variety Yields Under Low Soil Fertility

The Malawi Ministry of Agriculture (MoA), the United Nations Development Program (UNDP) and the Food and Agriculture Organization (FAO) have been conducting a joint maize demonstration program on farmers' fields since 1989-90. The demonstration consists of four treatments: hybrid and local maize unfertilised, and hybrid and local maize fertilised at recommended rates (92 kg N and 40 kg P₂O₅ for hybrid and 40 kg N and 10 kg P₂O₅ for local). Details of trial results are presented in Jones (1993). Figure 1 summarises trial results from 1989-90 to 1991-92. As expected, fertilised hybrid maize yielded the highest, averaging 3300 kg/ha, including the severe drought year of 1991-92.

On average, hybrid maize without fertiliser yielded 165% of unfertilised local maize, and 85% of fertilised local maize. Because hybrid maize yields better than local maize under low fertility, it offers a way for smallholder farmers who cannot afford the full fertiliser package a way to improve their yields. The complete substitution of hybrid maize varieties for local maize would immediately increase national maize production by over 30%, without additional fertiliser use. These three years data suggest that policy should be modified to recommend hybrid maize at any rate of fertilisation, and to supply fertiliser credit packages with lower rates of fertiliser.

Supplying the Right Nutrients for Maximising Yields

Four fertilisers are available to smallholder farmers in Malawi—diammonium phosphate (DAP; 18% N, 46% P₂O₅), 23:21:0+4S (N:P₂O₅:K₂O), urea (46% N) and calcium ammonium nitrate (28% N). These fertilisers supply only N and P, and in the case of 23:21:0+4S, sulfur. Several essential nutrients are not supplied at all, including K, Ca, Mg, Zn, B, and Cu. Past soil and plant analysis indicated that Fe and Mn were almost always adequate.

'Minus one' type fertiliser trials conducted by the MCT indicated maize response to K, S, Zn, and/or B in some areas. Results from the average of five sites in the Dedza Hills from the 1990–91 growing season are presented in Figure 2. However, because of the limited number of sites on which the trials were conducted, it was impossible to make assessments with regards to regional nutrient deficiencies.

Figure 1. Effects of fertilisers on yields of local and hybrid maize varieties over three seasons.
In an effort to deduce the degree to which nutrients other than N and P were limiting yields, the MCT collaborated with MoA, UNDP and FAO in their maize demonstration trials in 1992–93. Soil samples were taken from each of the 400 demonstration sites (all on farmers’ fields) from Lilongwe, Kasungu, Mzuzu, and Blantyre Agricultural Development Divisions (ADDs). These ADDs account for 75% of Malawi’s maize production. Four treatments were added to the previous 4-plot demonstrations in Lilongwe and Kasungu ADDs. These treatments were hybrid maize at the local maize fertilisation rate (40 kg N and 10 kg P₂O₅/ha), hybrid maize with 92 kg N/ha (no P), local maize with 40 kg N/ha (no P), and hybrid maize with 92 kg N, 40 kg P₂O₅, and a supplement of 15 kg S, 5 kg Zn, and 0.5 kg B/ha. Potassium was added to plots where soil tests indicated low K levels.

The final results for all these trials are not yet available. However, preliminary results indicate that the nutrient supplement increased yields at those sites where nutrient deficiencies were indicated by soil tests by an average of 20–30%. Hybrid maize outperformed local maize at the reduced fertiliser rate of 40 kg N and 10 kg P₂O₅/ha. Both local maize and hybrid maize suffered when P was not applied. These preliminary results indicate that soil tests can identify nutrient deficiencies of nutrients other than N and P, and that these deficiencies can be amended by fertiliser applications. Soil test results are described in detail in Wendt (1993).

Fertiliser application methods

Fertiliser recommendations in Malawi stipulate that both basal and topdressing fertilisers be applied in dollops. Dolloping fertilisers is very labour-intensive and often results in delayed application.

Basal dressing fertilisers are dolloped after emergence. However, an early season dry spell commonly follows planting rains. Because no water is available, applied fertilisers are not able to diffuse into the rooting zone. The young plant is therefore stressed for nutrients, which can affect its viability during the dry period and its future yield potential.

In addition, dolloping is an inefficient way to apply fertilisers. Figure 3 shows average maize yields from five sites with dollop and band application methods. While responses varied from site to site, for band applications average yields were as high with 20 kg P₂O₅/ha as with 40 kg P₂O₅/ha.

The negative consequences of applying urea in a dollop are reviewed by Jones (1993). After concentrating urea in a dollop, pH changes inhibit enzymes and microbes that permit conversion of urea into plant-available nitrate and ammonium. Concentration of urea at a point may also increase leaching losses because the adsorptive capacity of the soils in the application zone is exceeded. The maize team has conducted research (data not shown) that shows that
topdressing urea on the surface rather than in dollops does not reduce, and in some cases increases, maize yields. Under these conditions ammonia losses from surface applied urea must have been insignificant.

In 1993–94, the MCT will test on a wide scale, in cooperation with Malawi agricultural extension, band application basal dressing and surface application top dressing methods, versus the conventional dollop method.

Optimising Yields Under Alley Cropping

Alley cropping is the growing of crops between hedgerows of woody leguminous species. Prunings from the trees serve to fertilise the crop. Hedgerow leaves have high concentrations of N, Ca, Mg, K, and S relative to maize leaves (Kang et al. 1981). These nutrients, cycled from the soil, can contribute to maize fertility. Some nutrients may be cycled in greater or lesser quantities than others in relation to maize demand. By strategically supplementing leaf additions with appropriate fertilisers, yields from alley cropping systems can be maximised.

In 1986, an alley cropping trial using *Leucaena leucocephala* was begun at Chitedze Agricultural Research Station near Lilongwe, Malawi. Three leaf management strategies were employed: (i) leaves applied; (ii) leaves removed; and (iii) leaves removed + 100 kg N/ha applied as calcium ammonium nitrate. These treatments continued until the 1989–90 season, and are described in Bunderson et al. (1991).

In 1990–91, the MCT superimposed a trial on the site. A confounded 34 factorial design using 81 plots was employed. A full trial description is given in Jones et al. (1993) and Wendt et al. (1993). The treatments were as follows:

(i) leaf application history, as described previously;
(ii) N rate: 0, 30, and 60 kg N/ha;
(iii) P rate: 0, 18, and 36 kg P/ha;
(iv) plant population: 14 800, 29 600, and 44 400 plants/ha.

Soil analyses had indicated a low P status in all plots, regardless of leaf application history. Figure 4 shows the effect of the leaf application history × P rate interaction on maize yield. The clear response to P additions shows that P was deficient. Plots with a history of leaf application responded most to P additions. This indicates that nutrients cycled by the leaves could not be utilised by the maize crop until the most limiting nutrient, P, was supplied. Plots with a history of leaf application had higher levels of Ca, Mg, K, and S than plots where leaves have not been added. These results show that leaf application had little effect on soil P status, and that P application was necessary to get the full benefit from leaf application.
Figure 5 shows the effect of the N rate \( \times P \) rate interaction on maize yield. Very little yield response to \( P \) additions was realised until \( N \) was added, and little response to \( N \) additions could be found until \( P \) was added. This shows that both \( N \) and \( P \) were limiting. Substantial yields could be achieved with the application of small rates of \( N \) and \( P \).

![Figure 5. Effect of \( N \) and \( P \) application on maize yield.](image)

### Future Research

In the 1993–94 season, the MCT will run, in cooperation with Malawi Agricultural Extension, a series of demonstration trials that compare new fertiliser types, placement methods, and timing of fertiliser application with the current recommended methods. Trials will take place on farmers' fields. In addition, approximately 3000 topsoil samples will be taken from farmers' fields throughout the country. These samples will receive a full analysis, and analytical data will be used to locate regional nutrient deficiencies. These deficiencies will be addressed with the new fertiliser sources to be tested in cooperation with extension.

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### References


Economic and Climatic Risks in Cropping Systems in Chivi Communal Area, Zimbabwe

B.G. Mombeshora and M. Mudhara*

Abstract

This paper describes the components of the farming systems in Chivi communal area where the climate and soils are unsuitable for intensive crop production. Studies of the socioeconomic circumstances of farmers reveal that there are serious constraints to investments in soil fertility management. Draught power and cash are in short supply. The land tenure system prevents the adoption of certain technologies. Marketing is generally inefficient.

The farmers' cropping systems are dominated by cereal crops which are combined with some leguminous crops and oil seeds. Landholdings are small.

Resources for soil fertility management are not readily available due to lack of cash for purchasing inorganic fertiliser, cattle for provision of manure; and labour for collection of anthropoid soil. The situation is made worse by the high variability in rainfall leading to high risks of applying these resources.

Crop modelling is postulated as a possible means of resolving the interactions brought in by the complex system in which crop production is conducted in the area.

The information presented in this paper covers approximately 10 years of farming systems research in Chivi by the Farming Systems Research Unit (FSRU) of the Department of Research and Specialist Services (DR&SS) as well as information from other government and non-government organisations working in the area.

A summary description of the farming system component is presented, followed by observations and ideas on how these relate to soil fertility management in the area are given.

Climate

Chivi communal area is located in agroecological regions IV and V (Vincent and Thomas 1960, see also Fig. 1 Waddington, these Proceedings) between 20.0° to 20.55° south and 30.05° to 30.53° east. Regions IV and V are extensive farming areas, mainly livestock production in the commercial sector and mixed crop–livestock production in the communal areas. Chivi lies at a general altitude of 1000 metres above sea level (range 600–1300 m). The mean annual rainfall is 643 mm (range 230–1191 mm) falling between early November and May. Both the total rainfall per season and its distribution are highly unpredictable and variable with delays in the start of the rainfall season, heavy downpours over short periods of time, and severe mid-season droughts being experienced across the whole area. During the wet season, temperatures range from 18° C minimum to 30° maximum, while in the dry season (May to October) temperatures range 5–25° with occasional ground frost in some areas.

Soils and vegetation

The cropland soils in Chivi are diverse, ranging from heavy clays to sands. Spatial variability occurs at a variety of scales from landscape differences in soil type (catena) characteristics to field level variations in micro-environments due to topography and associated soil and water relations. Generally the soils are of poor to medium fertility, are shallow and of low water-holding capacity, with low levels of organic matter, associated deficiencies in micronutrients, and

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low pH less than 4.8. About 40% of the soils in the area are sands derived from granite and most of soils are kaolinitic and fersiallitic group. Nitrogen as well as P, S, and Zn deficiencies are typical in these soils. Other soils are derived from sandstones, shale conglomerates, metavolcanics, gneisses and metasediments.

The general vegetation in Chivi consists of mixed veld with light to medium woodlands with scrub understorey. The veld consists mainly of perennials (Heteropogon and Eragrostis spp.) and a high proportion of annuals. The woodlands are mainly of Brachystegia spp., with mopane (Colophospermum mopane) and acacia (Acacia spp.) dominant with some baobab (Adansonia digitata) in the central area.

Socioeconomic circumstances

Land is held under customary law. The household has the right to till the land which is allocated by the chief through his headman. (This role of allocating land has now been transferred from the traditional leaders to locally elected councillors.) In most cases the bulk of arable land is located some distance from the homesteads. Smaller patches can be cultivated around the homestead. The average arable land area per household was 4.84 ha in 1990–91. The fact that the land is not owned by the farmers has meant that they are not willing to make long-term investments on their farms for fear of losing the investment. Many farmers will be moved when the proposed Totwe-Mukosi dam is constructed. Farmers feel that the compensation they are receiving from the government is very low.

It is the responsibility of the headman (councillor) to ensure that some land is set aside for livestock grazing with all households having communal rights to the land, especially in summer. In winter, farmers are free to graze their livestock anywhere, since field crops have been harvested. Only securely fenced fields cannot be grazed. Due to resource constraints most crop fields are not fenced. This makes it difficult for farmers to adopt certain technologies that require protection from livestock, e.g. agroforestry or permanent soil structures.

Average cattle holdings are very low. In January 1991 the average cattle number per household was approximately four. After the devastating 1991–92 drought cattle numbers had fallen to approximately 1.7 per household (Table 1).

Cattle are the main source of draught power although donkeys are also used. A survey conducted before the 1991–92 drought revealed an average of one donkey per household. Draught power ownership is a critical element in the communal area farming systems. Surveys conducted 1991–92 revealed that farmers with access to draught power till more land, apply inputs on larger proportions of their fields to improve soil fertility and in general are better endowed with implements essential for farming. As a result they are able to obtain better harvests than those without draught power. Cattle are used also for payment of dowries and act as a bank account as they can be sold readily for cash.

Table 1. Numbers of cattle owned per household (before and after the 1991–92 drought)

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</tbody>
</table>

Households tend to be large. The average household size recorded during a survey in January 1991 was seven (minimum one, maximum 23). The members of the household also supply the bulk of the labour used for crop production. The same survey revealed that, in some years, the number of household members was directly correlated with the area planted for particular crops, e.g. groundnuts, sorghum, pearl millet and maize. However, labour becomes a constraint during land preparation and weeding.

Due to the low agricultural output in Chivi remittances from family members play an important role. Information from the survey showed that the number of family members per household was highly correlated ($p < 0.01$) with the amount remitted to the household over a 12-month period. The survey also showed that on average $243$ had been remitted per household (minimum 0, maximum $1200$).

As there is so much risk associated with crop production, insurance measures such as remittance are necessary to cushion farmers. Some remittances are provided in the form of goods (e.g. clothes, groceries, agricultural inputs). Incomes generated by members of the household who are resident in the area are an important source of income. On average $154$ (minimum 0, maximum $1670$) was generated through various activities by family members resident at the homestead. In general the financial resources are limited.

The communal area has a growth point (development centre) which lies about 50 km and 40 km from its southern and northern borders respectively. Most agricultural inputs can be obtained from the growth
point. However, due to the exorbitant prices charged by local traders, farmers prefer to procure most of their inputs from Masvingo, the provincial capital even though it means travelling further. In some instances farmers are not given an adequate range of inputs from which to choose. In such cases they end up buying whatever is available on the market. This is especially the case with seeds, to the extent that inappropriate varieties are being used. Also due to the input supply bottleneck, farmers use seed obtained from the previous season's crop.

Due to low crop productivity, there are no Grain Marketing Boards (GMB) depots in the area. In some instances mobile depots have been put in place. In most cases crops are sold through private buyers who are authorised by the GMB. However, under this system farmers realise lower prices than they would if they had sold directly to GMB. An all-weather road runs through the communal area but feeder roads tend to be bad. Local transport is generally inadequate and expensive and this, combined with the low prices realised by farmers from approved buyers, drastically reduces the revenue per unit output.

Cropping systems

Farmers in Chivi rely on a mixture of rainfed farming, a few irrigation schemes, livestock rearing and off-farm income to support themselves. The cropping system is dominated by grain crops, e.g. maize, sorghum, millet, which are combined with sunflower, cotton, finger millet, groundnuts and a range of other minor crops such as cowpeas, pumpkins and bambara nuts. Field sizes are generally small (average 4.8 ha/household) due to high population density (around 30 people/km²) and 63% of the arable land is planted with the grain crops, which are staple starches. Farmers also grow a variety of vegetables (cabbage, tomatoes, onions, beans, etc.) in the dry season, on small gardens usually situated in the wet vleis and near wells or boreholes, for domestic consumption and cash.

Although some cowpeas, pumpkins and, sweet sorghum are mixed with the grain crops, monocropping is the main practice recommended by extension. Crop-to-crop rotations are practised to a limited extent and crop-to-fallow rotation is practised where shortages of labour or draught power exist. These are insufficient for effective fertility management. Cereal monocropping dominates because of the preference for grains and the small field sizes available. Farmers who have draught power practise winter ploughing to conserve soil moisture while those without power plough: only during the wet season. Planting of grain crops, especially maize, is staggered to early mid and late season to minimise the risk of mid-season droughts. The full potential of the rainy season is thus not captured, resulting in low maize yields (<1.0 t/ha) by the late planted crops.

Soil fertility management

There is a range of fertility management options in Chivi. These include inorganic fertilisers, livestock manure, ash/household compost, antheap soil and leaf litter (FSRU 1993). These may be combined with a variety of other management options including fallowing, crop rotation, use of leguminous crops and intercropping. In spite of these options, during the period 1988–89 to 1992–93, between 75% and 90% of the total area planted did not receive any form of fertilisation. This reflects a number of factors:

(i) the lack of cash for inputs like inorganic fertilisers, as well as low availability (marketing and transport constraints);

(ii) low or uncertain returns to fertiliser inputs;

(iii) lack of manure due to low livestock numbers in relation to arable area; and

(iv) labour constraints on leaf litter collection, antheap soil collection and composting, etc.

Only 9% of the farmers use inorganic fertilisers (both compound D and top dressing). This is not only due to cash shortages but because of the realisation that recommended fertilisers and rates of application are uneconomical. Responses to fertilisers are related to the crop–soil moisture relations, which often are not favourable, resulting in poor results from soluble fertiliser applications (FSRU 1993). Other forms of fertility management, used by 70% of farmers (manure, litter etc.), are constrained by labour requirements and the limited quantities available in the area. The overall situation is that only a small percentage of the arable areas receives either inorganic fertilisers or other forms of nutrients, the remaining area being depleted of soil nutrients without replacement and recycling. Table 2 shows the rankings by Chivi farmers of the advantages and disadvantages of various fertility improvement inputs.

The current situation of crop production and soil fertility in Chivi is complex and results from the interaction of factors already outlined, including the political situation. Soil fertility and crop yields are declining; erosion is on the increase. Several factors contribute to this situation.
Table 2. Preference for alternative fertility inputs.

<table>
<thead>
<tr>
<th>Input</th>
<th>Ranking</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antheap soil</td>
<td>B 2</td>
<td>Reduces water logging. 2-3 years residual effect</td>
<td>First year application not effective, excess kills crop, much labour needed.</td>
</tr>
</tbody>
</table>

Note: A = rank of actual current use; B = preference under good rainfall; C= preference under poor rainfall.
Source: FSRU 1993.

(i) Over-cultivation and soil nutrient depletion associated with increased population, high cropping intensity, reduced fallow periods (less than three years, up to continuous cropping), and limited crop rotations;

(ii) poor vegetation cover and heavy downpours, favouring high rates of runoff and soil erosion;

(iii) limited use of fertility inputs associated with high costs of inorganic fertilisers, inadequate supplies of alternative inputs and low crop responses to conventional inputs due to soil types and low rainfall; and

(iv) the communal land tenure system, which prohibits use of fertility-improving agroforestry practices such as growing trees for green manure.

Replanted crops often fail, placing farmers in a critical position as they do not have the necessary resources for further replanting.

The variability in seasons has often meant that on-farm trials are conducted without enabling conclusive agronomic recommendations to be achieved. At each stage in the experimentation process, some issues have remained unresolved. Crop modelling can be used for deriving better decisions on how to cope with soil and climatic variability. It is likely to be the best way of handling the time series data which, in most cases, are not fully utilised by other methods, due to variability. The main cost of using the modelling approach is the requirement for detailed experimental and meteorological data.

References


Recent Developments in Systems Modelling

Peter S. Carberry*

Abstract

In July 1990, an International Symposium was held in Australia to review the application of simulation models in managing climatic risk in crop production in the semi-arid tropics and subtropics. In looking back on this symposium as a reference point for modelling activities up to the end of the 1980s, one is impressed by the general endorsement given to modelling as a means of problem-solving in agricultural production systems. Nevertheless, the progress in development of systems modelling since 1990, both in the enhancement in software capability and in the application and interpretation of simulation results, has been extensive.

Recent efforts in Australia have been directed towards creating a modelling capability that (i) simulates agricultural production systems, (ii) includes a portfolio of simulation models for a range of crops and pastures, and (iii) encapsulates rigour in software development, programming and maintenance, and provides a user-friendly operating environment. The Agricultural Production Systems Simulator (APSIM) has been designed and developed to meet these criteria and now represents a core technology of systems research in northern Australia.

A second area of advancement in system simulation is the extension of model output beyond the simple presentation of simulated yields or gross margins. Combining the tools of system simulation with those of economic decision analysis provides a powerful means of evaluating economic returns, their associated risks and farmer preferences for the trade-off between return and risk.

This paper reports on these recent developments in systems simulation and provides an example of a relevant application study in northern Australia.

MODELLING is not new to research on agricultural systems. In fact, it goes back to at least the 1940s. Since then, investment in simulation modelling has grown in line with the rapid advances in computers and, over the years, one can identify a number of significant milestones in the development of crop and soil models (Angus 1991; Ritchie 1991). The question that this paper addresses is whether dynamic simulation of agricultural systems has made significant progress over more recent years and, if so, in what ways?

In answering this question, the status of modelling at July 1990 is taken as a benchmark against which developments since then can be evaluated. At this time an International Symposium was held in Australia, the purpose of which was to review the management of climatic risk in crop production in the semi-arid tropics and subtropics, with particular emphasis on the application of simulation models (Muchow and Bellamy 1991). Contributions were drawn from a cross-section of the modelling fraternity and collectively represented the achievements at that point in time in both model capability and application. The status of modelling in both semi-arid Kenya and Australia was presented.

This paper takes the somewhat narrow view of models in adopting the definition that a model is 'a combination of mathematical equations and logic used to conceptually represent a simplified crop production system' (Ritchie 1991). Such models are used to predict the changed state of the system being simulated, given input of initial system conditions, management interventions to the system and the daily weather variables that drive the system. Crop yields are a primary output of such predictions, although changes in other state variables, such as soil loss from erosion, are also often of interest. Ritchie

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(1991) provided an excellent review of crop simulation models and their make-up at this level of relevance.

Progress in systems modelling is addressed under two broad headings: improvements in the development of simulation models, and greater relevance in modelling applications. Models improve by either (i) increased accuracy in predictions, (ii) broadened simulation capability, or (iii) better software. More relevant applications encompass the need for models to make significant impacts on agricultural decision-making. This paper reviews the state of system modelling at July 1990 and identifies the scope for advancement in each of these areas. In particular, the progress being made in Australia by the Agricultural Production Systems Research Unit (APSRU) in addressing these areas is highlighted.

The Status of Modelling in 1990

1990 Climatic risk symposium

Three papers at the Symposium were of particular interest in helping to define criteria against which the status of modelling in 1990 could be judged. Firstly, Ritchie (1991) dealt with the specification of the ideal crop model, then Penning de Vries and Spitters (1991) addressed prospects for improvements in prediction accuracy in the future. Ritchie (1991) gave seven criteria against which models can be judged (Table 1(a)). Although open to argument, simulation models being used in 1990 were judged to have achieved significant advancement in only three criteria. Take either CERES-Maize (Jones and Kiniry 1986) or the less-detailed soybean model of Sinclair (1986) as examples. On the whole, the level at which processes are simulated in these models has been endorsed by the similarities between them and other models (cf. Rosenthal et al. 1989; Carberry and Abrecht 1991; Monteith and Virmani 1991; Chapman et al. 1993). Both approaches have been widely adopted (Hodges et al. 1987; Carberry et al. 1989; Liu et al. 1989; Keating et al. 1991; Hammer and Muchow 1991; Meinke et al. 1993) suggesting that the data requirements for running the models were attainable and that predictions were generally applicable, although on this last point, the need for local adaptation was identified by almost all such groups. On the contrary, by 1990, there were few if any examples of models that were well programmed or user-friendly. The more likely situation was that model code was written by researchers and reflected a lack of input from professional programmers. Likewise, the person that built the model often was the only person that could drive the model. Few models by 1990 had been linked to pest models nor indeed dealt with weeds or diseases.

Table 1. Criteria suggested for (a): the ideal model for predicting crop yields (Ritchie 1991) and (b) improvement in simulation (Penning de Vries and Spitters 1991).

(a) Ideal model
• balance between all components of a model
• general applicability in space and time
• realistic data requirements
• ability to be linked with pest models
• structured programming
• user-friendliness

(b) Improved simulations
• matching of problems to simulation ability
• computers and software
• skilled modelers
• models of relevant systems
• model parameters
• data — physical
  — biological
  — climate

In general, the crop models represented at the 1990 Symposium demonstrated improved prediction accuracy over the first crop models developed prior to the 1980s. Coefficients of determination ($R^2$) for predicted versus observed grain yields ranged from 0.88 to 0.63 (Keating et al. 1991; Hammer and Muchow 1991). In contrast, the validation of the widely-used SORGF sorghum model (Arkin et al. 1976) initially did not display good prediction accuracy for grain yield ($R^2 < 0.40$) (Vanderlip and Arkin 1977), although accuracy improved with further developments over time ($R^2 = 0.74$) (Huda 1987). Of the criteria (Table 1(b)) of Penning de Vries and Spitters (1991) to improve simulation ability, all were met to varying degrees by the models around in 1990, the point being that simulations have improved by advances in each of these areas. For example, the advances in computers and software have greatly improved the ease of computer modelling. Access to reliable long-term climatic data has often been one of the greatest hindrances, yet the recent development of weather data generators is seen as a solution (Hutchinson 1991). The availability of experienced modelers and of models of relevant agricultural systems has been more limiting, but interest in modelling is on the increase. However, the usual sampling errors contained in experimental data will continue to impact on reliable estimation of model parameters and on the accuracy of validation data, meaning that models will probably not achieve accuracy much greater than that achieved by the 1990 vintage models ($R^2 = 0.90$).
Anderson (1991) provided a framework of a farming system against which the usefulness of models could be judged (Table 2). The framework suggested that the utility for farming consists of the economic performance of the farming system plus the personal preference of the farmer. The economic component of this socioeconomic model is a function of farmer decisions, of the probability distributions of yields attained and prices received, and of the effects of any policy interventions to the system, such as by governments or financial institutions. Anderson's (1991) assessment was that, judging by the papers presented at the Symposium, the great majority of interest by modellers concentrated on yield prediction alone. In fact, only two papers (Keating et al. 1991; McCown et al. 1991) effectively considered the economics of farming practices, by addressing the trade-off between simulated gross margin (GM) return and the associated risk, although most papers presented simulated yields and several presented simple GMs.

| Utility | = U (economics, personal preference) |
| Economics | = f (management, P(Y), P(p), policy) |
| P(Y) | = f (management, climate) |
| P(p) | = f (demand, policy, supply) |

The terms P(Y) and P(p) refer to probability distributions for yield and price respectively.

The other notable deficiency of modelling with regard to Anderson's (1991) framework was a concentration on the management of single crop enterprises as opposed to enterprise combinations, and following on from this, simulating single-season effects, not long-term consequences. Only three papers fell into this latter category. Carberry and Abrecht (1991) simulated components of a ley-farming system, Freebairn et al. (1991) presented long-term simulated yield decline due to erosion from a wheat-fallow cropping system and Clewett et al. (1991) simulated components of a farm dam system for irrigating sorghum. A major reason for this deficiency was the limited availability of models that could simulate system phenomena. Of the system models around in 1990, EPIC (Williams et al. 1983) traded-off prediction accuracy (Steiner et al. 1987; Williams et al. 1989) for scope in simulating a broad range of systems using a generic crop model, whereas DSSAT (Ueihara and Tsuji 1991) consisted of a set of full crop models (e.g. CERES-Maize, SOYGRO) but was limited by not dealing with crop sequences. PERFECT (Littleboy et al. 1989) was positioned somewhere between the two ends of the capability/accuracy tradeoff, being limited to wheat, sorghum and sunflower but dealing with long-term consequences of crop sequences.

Where was modelling 'at' in 1990? Judging from this review, models were mostly of single crops, predicting yields with reasonable accuracy, but consisting of poor software coding and reliability, operated from limited computing environments and containing the single ability to produce probability distributions of yield. To progress it was clear that what was needed were models of agricultural systems, embodying professional software development and reliable operation, a user-friendly computing environment and the ability to produce applicable economic analyses. Finally, to justify such developments, modelling had to become relevant to the research needs of the farming system.

**Improvements in Model Development**

**APSIM—Agricultural Production Systems Simulator**

In January 1990, the Agricultural Production Systems Research Unit (APSRU) was formed in Australia to undertake research on the farming systems of northern Australia. The core technology of APSRU is operational research (McCown 1989-1991). In forming APSRU, two distinct efforts in developing system simulation capacities in Australia, PERFECT (Littleboy et al. 1989) on the one hand and AUSIM (McCown and Williams 1989; Carberry et al. 1992) on the other, were amalgamated. This amalgamation of effort has resulted in the development of the Agricultural Production Systems Simulator (APSIM), consisting of a user interface (APSIM shell) and model code (APSIM model). How APSIM addresses the criteria of model capability, model accuracy, software programming and user environment is briefly outlined in the following sections. More detailed descriptions of APSIM are provided elsewhere by Hammer et al. (1993) and McCown et al. (1994).

**Model capability**

APSIM is a flexible software system for simulating agricultural production systems, which it asks the user to specify rather than a model of a particular cropping system. That is, the APSIM model is a collection of modules, each describing specific physical and biological processes, that are combined in meaningful ways to represent agricultural systems.
Figure 1 graphically represents this concept. Here, there are a number of modules, grouped as either biological, environmental, managerial or economic, that are linked only via an ‘engine’. The ‘engine’ is a communication system that passes information between modules according to a standard protocol. The fact that two modules are not directly linked allows modules to be plugged in or pulled out of the ‘engine’ depending on the specifications for the simulation task. For example, if one wished to simulate a rotation involving crops A and B, modules for crop A and crop B would be plugged into APSIM along with modules for a soil-water and nitrogen balance. While modules for alternative crops or water balances exist within APSIM’s libraries, there would be no need to link them into APSIM for this task. In this way, the simulation capacity of APSIM is limited only by the availability of modules to simulate the processes peculiar to the system of interest.

The initial emphasis of APSIM is to deal with the dryland cropping systems of semi-arid and subtropical Australia. However, such an emphasis does not preclude APSIM being configured for other agricultural systems, e.g. sugar production in the Australian humid tropics (B.A. Keating 1993 pers. comm.) or intercropping systems in sub-Saharan Africa (Adiku et al. 1993).

Model accuracy

By using an approach that allows almost any existing model of a crop or soil process to be easily interfaced with the APSIM ‘engine’, there has been no need to compromise simulation accuracy for modelling capability. Therefore APSIM has adopted many of the existing models that simulate crop, pasture, soil or animal processes in Australia and elsewhere (Table 3). The accuracy of APSIM therefore derives from the validation accuracy of each original module plus the degree to which such validations are affected by the module combination linked into APSIM for a particular application. While the use of existing validated modules provides for confidence in APSIM, the effect of module combinations on prediction accuracy is the focus of APSIM’s on-going development and testing processes.

Software programming

A major aspect of the development of APSIM has been the emphasis placed on high standards in software development and rigour in coding correctness. The software development of APSIM has represented approximately 10 person-years of professional programming. The programming objectives of APSIM are grouped into three broad requirements. Firstly, there was the need to implement APSIM’s protocol which permits the modular plug in/pull out interface with the APSIM ‘engine’. Secondly, programming standards were developed to ensure program reliability and maintainability by implementing a disciplined approach to subroutine design, to readability of code, to program testing and to version control of source code. Thirdly, a modelling environment was created to facilitate the use of APSIM for both program development and maintenance and for operational research purposes.

User environment

The APSIM shell uses a Microsoft Windows™ operating environment. The APSIM window is made up of a number of buttons, each representing a module that can be accessed from the APSIM library. Source code of a module, if available, can be accessed in an
Table 3. List of current and planned modules within APSIM and references to their origin.

<table>
<thead>
<tr>
<th>Group</th>
<th>Module</th>
<th>Original Model</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crop</td>
<td>cotton</td>
<td>OZCOT</td>
<td>Hearm and Da Rosa (1985)</td>
</tr>
<tr>
<td></td>
<td>cowpea</td>
<td>APSIM-Cowpea</td>
<td>Adiku et al. (1993)</td>
</tr>
<tr>
<td></td>
<td>maize</td>
<td>AUSIM-Maize</td>
<td>Carberry and Abrecht (1991)</td>
</tr>
<tr>
<td></td>
<td>peanut</td>
<td>QNUT</td>
<td>Hammer et al. (1992)</td>
</tr>
<tr>
<td></td>
<td>sorghum</td>
<td>QSORG</td>
<td>Hammer and Muchow (1991)</td>
</tr>
<tr>
<td></td>
<td>sunflower</td>
<td>AUSIM-Sorghum</td>
<td>Carberry and Abrecht (1991)</td>
</tr>
<tr>
<td></td>
<td>wheat</td>
<td>QStJN</td>
<td>Chapman et al. (1993)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CERES-Wheat</td>
<td>Ritchie et al. (1988)</td>
</tr>
<tr>
<td>Pasture</td>
<td>grass</td>
<td>GRASP</td>
<td>MeKeon et al. (1990)</td>
</tr>
<tr>
<td></td>
<td>legume</td>
<td>GRAZPLAN</td>
<td>Moore et al. (1991)</td>
</tr>
<tr>
<td>Soil</td>
<td>water</td>
<td>CERES</td>
<td>Ritchie (1985)</td>
</tr>
<tr>
<td></td>
<td>N erosin</td>
<td>PERFECT</td>
<td>Littleboy et al. (1989)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SWIM</td>
<td>Ross (1990)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CERES</td>
<td>Godwin and Jones (1991)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PERFECT</td>
<td>Littleboy et al. (1989)</td>
</tr>
</tbody>
</table>

editor by selecting the appropriate button. As part of the APSIM installation process, users specify their own software development tools such as compilers, linkers, file viewers and editors. These tools can be accessed via pull-down menus from the menu bar of the APSIM window.

Within the APSIM shell, a module is incorporated into (or omitted from) APSIM model executable code by marking (unmarking) the checkbox of the module button, then compiling and linking the combined modules into executable code. This APSIM version can be run by selecting a control file, which defines a simulation run, and, where appropriate, climate, soil and experimental databases. These activities can be undertaken by using pull-down command menus, although the APSIM model can also be simply run under DOS or other operating systems. After running the model, output can be interrogated by viewing output reports and graphing output variables using the custom-developed graphics package.

The basis of APSIM’s operating environment is to provide easy access to all the activities that users would normally undertake in modelling.

Relevance in model applications

Over past years, the continued development and/or refinement of models often has taken precedence over their application. For example, in a search of the literature since 1986, 283 publications were found on the topic relating to maize (corn) models. Of these, roughly 83% could be classified as papers where model development was the major research activity. Model development in this case included activities to define functional relationships, calibrate or validate models or functions within models. Only 17% of papers were classified as papers which used models in some way and only a fraction of these papers addressed outcomes in terms other than crop yields. This survey is obviously an oversimplification, as many applications may not be published in scientific papers. Nevertheless, in the current research environment in Australia, and probably elsewhere in the world, a disproportionate effort in developing new models cannot be justified. It is of little benefit to clients of agricultural research continually to explore new ways of prediction if the predictive tools are not used to help them make decisions. This is especially so if the scope for improved accuracy in predictions is not great. Therefore, a culture of using models in operational research is clearly needed in the future development of system modelling.

Arguments for models to be used in operational research have been well put by several others in these Proceedings. Clearly, in many cases, models are the most appropriate means of generating yield distributions for alternative strategies. But much of the past work in applying models has stopped at simulating yield production, where the relevance of such applications would have increased significantly if predicted yields were transformed into economic
returns. The following sections firstly describe several of the economic analysis tools that are easily applied to simulation output, secondly, outline an example of where these economic tools have been recently applied in Australia, and finally, briefly introduce the use of model output in computerised decision support systems (DSS).

**Economic analyses**

When making decisions in climatically variable environments, no strategy or practice is best in all years. Typically there is a trade-off between the economic return of a strategy and its riskiness. Strategies that have the potential to produce large economic returns in the good years also represent the risk of greatest losses in the poor years. Alternatively, strategies that are tailored to minimising losses in the poor years forgo profit when the seasons are good. In these situations, techniques commonly employed in economic analyses can assist in comparing strategies which differ in their trade-off between returns and risk. Two useful tools are stochastic dominance and mean variance \((E,V)\) analysis (Anderson et al. 1977).

Stochastic dominance is a means of comparing plots of cumulative distribution functions (CDF), which specify the cumulative probability (y-axis) of obtaining less than a specified outcome (x-axis) (Fig. 2a). First-degree stochastic dominance (FSD) assumes that a decision-maker will always prefer more to less economic return, and occurs when a dominant CDF (e.g. curve G) is never less than another CDF (e.g. curve F) at any probability level. Second-degree stochastic dominance (SSD) further assumes that the decision-maker is risk-averse. When two CDFs cross over (e.g. curves G and H), SSD occurs when the area between two CDFs at the low probability levels is greater than the area between the CDFs at the high probability levels (Fig. 2a). A third approach is stochastic dominance with respect to a function (Meyer 1977), which has much greater discriminating ability than FSD or SSD but requires knowledge of the degree of risk-aversion of decision-makers. When comparing a number of strategies, stochastic dominance does not necessarily select one dominant strategy, but more probably identifies a set of risk-efficient strategies. Risk-inefficient strategies can be discarded as being inferior options due to the existence of alternative strategies with higher probabilities of return.

In \((E,V)\) analysis, the assumption is that risk can be equated with variance. Risk-efficient strategies within an \((E,V)\) analysis dominate others by having either higher mean economic return or lower variance (or standard deviation in \((E,s)\) analysis) of return. A subset of risk-efficient strategies can be delineated by plotting mean against standard deviation of return for a number of strategies to create a mean-standard deviation \((E,s)\) space (Fig. 2b). A convex 'efficiency frontier' is defined by fitting a curve through points with the highest mean at each given standard deviation. Strategies which fall below this efficiency frontier are regarded as inefficient, i.e. alternative practices exist which produce greater returns at lower or equivalent levels of variability. Resource combinations falling on the frontier are equally risk-efficient and choice between them depends on attitude to risk. A decision-maker can trade-off a high return/high risk strategy for a strategy with lower returns and lower risk. A derivative of \((E,V)\) analysis is a mean-negative deviation space (Parton 1992), where mean return is plotted against a probability weighted sum of deviations below a target return; the target is set to a value

![Figure 2.](image-url)
below which a farm business will not survive. Mean-
negative deviation space better accounts for a safety-
first approach to the return/risk trade-off that
decision-makers face.

An example application

Is cropping profitable in semi-arid northern
Australia?

In the semi-arid tropics of northern Australia, there
has been limited commercial dryland crop produc-
tion. Despite past experiences being generally
unprofitable and short-lived, there continues to be
sporadic investment into cropping, encouraged by the
favourable reports of the soil and climate resources
The question of how representative were these com-
mercial experiences is difficult to answer in a highly
variable climate. In addressing this question, Car-
berry et al. (1991, 1993) used simulation models to
predict crop yields for the long-term historical
climate data of representative sites in order to esti-
mate the economic prospects of rainfed cropping
systems in this climatic zone.

From Carberry et al. (1991), dryland crop produc-
tion for two potential cropping regions in this
climatic zone can be compared. By simulating maize
yields for the historical climate record and by calcu-
lating GM returns and plotting the mean against their
standard deviation of return, \((E,s)\) space was used to
examine the tradeoff between expected returns and
the riskiness of different levels of resource manage-
ment for two representative sites (Fig. 3). At the site
in north Queensland (NQ), few risk-efficient strate-
gies produced returns higher than the break-even
return (taken as an estimate of fixed costs) and their
selection involved a high level of risk. In contrast, at
the site in the Northern Territory (NT), only the
lowest input strategies were risk-efficient and no
strategy, on average, produced profitable returns.

On-going research over a decade in the NT has
suggested that the prospects for dryland cropping can
be improved by implementing a legume ley farming
system (McCown et al. 1985, 1993). In such a
system, several years of a legume ley pasture provide
valuable forage for cattle grazing as well as reducing
the costs of production through the supply of mineral
nitrogen to a subsequent cereal crop. During the
cropping phase, the legume pasture is allowed to
form an understorey intercrop with the cereal in
order to set seed from which the pasture ley can be
re-established. The question here is whether the
enhanced soil nitrogen status after the legume ley
increases the profitability of cereal cropping, given
the likely reductions in cereal yield due to competi-
tion from the legume intercrop. By developing a
model of this proposed system (Carberry et al. 1992,
1993), simulation analyses were able to demonstrate
that the probability of achieving high maize yields
from cropping after a ley pasture increased over con-
ventional cropping but so did the probability of
achieving low yield due to competition in the water-
limiting seasons (Fig. 4). At the world export price
for maize, neither system resulted in profitable
returns for the maize crop in any season (Fig. 5).
However, when the value of the intercropped legume
pasture as hay was considered, maize/pasture pro-
duction during the wet season was stochastically
dominant (FSD) over conventional maize production
and resulted in returns greater than the break-even
cutoff in 40% of seasons. Profitability increased
markedly at the NT import parity price for maize
although failures still occurred in about one in
10 seasons (Fig. 6).

\[\text{Figure 3. } (E,s) \text{ spaces for maize at (a) Mt Garnet, Qld;}
\text{and (b) Katherine, NT. Symbols refer to rates of nitrogen}
\text{fertiliser applied - O } 0 \text{ kg/ha, } 40(\text{O}) \text{ kg/ha, } 80(\text{I}) \text{ kg/ha,}
\text{and the estimated level of fixed costs (---) is shown.}\]
Figure 4. CDFs for predicted grain yields for maize grown at Katherine, NT, as a conventional crop (●) or in an intercrop following a legume ley (○).

The analyses of Carberry et al. (1991, 1993) confirmed that profitability is marginal and cropping is very risky for dryland maize production at these sites in northern Australia. Similar conclusions were reached for other sites and when alternative crops to maize (sorghum, peanuts) were used in the simulation analyses (Carberry et al. 1991). Adoption of an integrated crop/pasture system in the NT did improve GM returns but, at world grain prices, not to a sufficient level to encourage cropping investment. However, returns from the current cropping of small areas to supply the local NT grain market have been sufficient to support a viable industry.

As a result of the operational research undertaken in northern Australia, decisions on new investment in cropping, on the farming system currently practised and on the resources placed in agricultural research in the region have been significantly influenced. In fact, clear demonstration of the poor profitability over the longer term of cropping in semi-arid northern Australia was a major contributor to the decision to transfer research capability from the region into the sub-tropics as part of the formation of APSRU.

Decision support systems

The argument for models to be put to use is well justified, but exactly how is another matter. Hamilton et al. (1991) put the case for information generated by models to be incorporated into computerised Decision Support Systems (DSS) to assist clients in their decision-making. Although relatively few Australian farmers use computers to assist their farm management, Hamilton et al. (1991) argued that DSS have not been oversold, but just underdeveloped. They suggested that, for new DSS products to become more widely accepted, they must be better designed. While Cox (1993) agrees that much of the blame for the non-adoption of DSS lies with the absence of any accepted design criteria, he goes further in his criticism and points to the lack of analysis of the value of alternative approaches to decision support, particularly a comparison against much simpler practical measures. The suggestion is that computerised DSS may not be an appropriate medium for information transfer at the farm level. If this is, in fact, the case, one of the principle conduits...
in making models more relevant to agriculture disappears. Certainly, computerised DSS continue to be refined and developed in Australia (Woodruff 1992), and their acceptance by farmers will be assessed with great interest.

Conclusions
The recent development of APSIM has extended the capabilities for simulating agricultural systems far past what was available in 1990. Now, APSIM provides the ability to simulate a range of cropping systems in a user-oriented environment using well-developed software. Efforts elsewhere in the world have likewise been moving in similar directions (Jones 1993). The challenge now is to use our modelling capability in meaningful ways.

In these Proceedings, McCown and Cox explore ways in which the recent developments in system modelling, as discussed in this paper, can be applied in research on farming systems both in Australia and Africa.

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References


Linkages between Australia and Africa in Agricultural Research for the Semi-arid Tropics

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Abstract

African countries with semi-arid lands in the tropics and sub-tropics have much in common with Australia. The common problems are climatic variability, infertile soils, extensive soil erosion, poor quality forage, poorly educated farmers, transport and communication difficulties, and marginal profitability. These problems are set against a background of broadly similar climates and soils.

The various phases of two research programs—one in northern Australia based mainly in Katherine in the Northern Territory, and the other in Kenya in the Machakos and Kitui Districts—are described. Both moved progressively over a 10-15 year period from a more empirical exploration of options and technology development phase, through an understanding and model-building phase, to a phase of integration and extrapolation in space and time using the modelling tools developed in phase 2.

The common problems can be aggregated into three larger issues: those concerned with climatic variability, with complexity, and with extrapolation and efficient use of scarce R&D resources. Crop and farming system modelling in a farming systems research context are seen as the way of dealing with these issues.

Most of the Australian scientists involved in this workshop have had a strong interest in the semi-arid tropics of sub-Saharan Africa for the last 10 to 20 years. While the principal countries with which they have had in-country involvement are closer to the equator than SADC countries, namely Kenya, Ethiopia, and Nigeria, they have also been very interested in the progress of R&D in the SADC countries and are anxious to learn more about it.

The involvement and interest results from recognition of the similarity of the problems and of the scientific principles behind these problems in the two regions. Research in the African semi-arid tropics (e.g. in West Africa, Jones and Wild 1975) is relevant to tropical and subtropical Australia, and the researchers firmly believe that the reverse is also true, despite the contrasting socioeconomic environments. Figure 1 shows Australia, superimposed at the appropriate scale and latitude, on a map of Africa.

The broad latitudinal similarities between Australia and parts of tropical and sub-tropical Africa are obvious, both to the north and the south of the Equator.

As a broad generalisation, many of the following problems are shared (Fig. 2).

- Climates are highly variable. Rainfall and, at times, temperatures are unfavourable for vigorous and continuous plant growth even during the short growing seasons.
- Soils are often infertile and suffer from widespread deficiencies of nitrogen and phosphorus and sometimes other major and trace nutrients.
- Soil erosion is widespread because rainfall intensity is high, and soils are often poorly-structured and hence highly erodible.
- Forage for grazing animals is generally of low quality, particularly during the long dry seasons.
- Farmers are often poorly educated and, in some regards, relatively unsophisticated.
- The areas are relatively remote from population centres, so transport and communication services are often poor.

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Figure 1. Maps of Australia, superimposed, at appropriate scale, orientation, and latitude, on a map of Africa.

Figure 2. Biophysical, human, and economic problems common to the semi-arid tropics of Africa and northern Australia.

Australia has been actively involved in concurrent research programs in the semi-arid tropics of Eastern Kenya and Northern Australia over the 10-year period 1984–1993. The purpose of this paper is to describe the environments of the two regions in broad terms and to give an overview of the main thrusts of the two research programs. Three other papers in these Proceedings (Keating et al., McCown and Cox, Probert et al.) elaborate on the climatic and soil fertility aspects of the research. The final paper takes a broader perspective and looks at recent developments in Operations Research or Farming Systems Research in Australia and elsewhere.

The Australian Semi-arid Tropics

Australia has extensive areas of agricultural land in the semi-arid tropics and sub-tropics (Fig. 3). Parts of it are already used for broad-scale cropping and other areas have the potential for cropping (Fig. 4). There is an enormous range of soils in an area as large as this, but Vertisols and Alfisols are probably the most widespread. Climatically, there are strong similarities between parts of Africa and Australia. To take a Zimbabwean example, analyses of climatic similarities between four locations in Zimbabwe and climatic surfaces for Australia have been conducted by Booth (1989), an Australian forester, and are shown in Figure 5.

A considerable body of R&D for farming systems involving the integration of cropping and grazing in the Australian semi-arid tropics has been conducted at Katherine in the Northern Territory of Australia (Fig. 4); some has also been done in North Queensland and will be reported in the paper by Carrberry (these Proceedings). A climate diagram for Katherine is presented in Figure 6a and shows the uni-modal rainfall concentrated over a 4-month period, high levels of radiation, and high maximum and minimum temperatures except during a short (3-month) winter. This region of Australia is sparsely settled and is used predominantly for grazing cattle on large properties or cattle stations varying in size from 10 000 to 500 000 hectares. Agriculture here suffers many of the problems mentioned earlier of climatic variability, infertile soils, extensive soil erosion, poor quality forage, poorly educated farmers, transport and communication difficulties, and marginal profitability.

Research to develop a new type of integrated farming system based on legume leys was initiated in 1978 and has been described by McCown et al.

• Profitability of farming is marginal because of high production and price risks.
The main features of the Hypothetical Farming System researched were:

(i) self-regenerating legume ley pastures of 1–3 years duration are grown in rotation with maize or sorghum;
(ii) cattle graze native-grass pastures during the green season and leguminous pastures and crop residues in the dry season;
(iii) crops are planted directly into the pasture which is chemically killed at or shortly before planting; and
(iv) the legume sward which volunteers from hard seed after the pasture is killed is allowed to form an understorey (intercrop or live mulch) in the main crop.

The progress of this research since 1978 is shown in Figure 7. The first phase took a 'best-best' approach using various adapted legume species, but particularly *Stylosanthes hamata* cv Verano, and demonstrated that up to 60 kg of N could be provided to subsequent crops by a vigorous legume ley.

The beneficial effects of a mulch of chemically-killed pasture material on soil temperatures, rates of drying, infiltration, and trafficability, and hence on establishment and yield of maize and sorghum were striking. This realisation necessitated a great deal of very successful R&D (particularly D) to optimise the weed control chemicals and application technology, and the zero-till planting machinery necessary for such a system to operate in a mechanised agricultural context. Towards the end of this phase, a pilot trial of the hypothetical Legume-Ley Farming System involving 2-year leys of pure legumes, one year of maize, and dry season grazing of pasture and crop residues was commenced in order to look for deficiencies in or problems of the system not apparent from the component research.

The second phase of the R&D program concentrated on understanding and quantifying the effects of ley legumes and mulch on the soil physical and chemical conditions which, in turn, influenced crop establishment and growth. It was realised that some sort of systems modelling framework was required in order to be able to address the problem of climatic
Figure 5. Areas within Australia most climatically similar to four sites in Zimbabwe. (From Booth 1989).

Figure 6. 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; annual rainfall 890 mm).
variability and to extrapolate the results to other soil types, locations, climatic conditions, and management combinations. Existing maize and sorghum crop models of the CERES family were therefore modified for use in the semi-arid tropics and further developed in order to store and make accessible the understanding acquired from the research both here and elsewhere in the world. This modelling activity was synchronous with that in the Kenyan semi-arid tropics research program and is described more fully by Keating and Carberry and their collaborators (these Proceedings).

During this phase, the pilot trial of the hypothetical system was concluded (McCown et al. 1986). It demonstrated that the system worked well. Excellent maize crops could be produced on biologically-fixed N alone, and animals on this system, at a high stocking rate of 0.3 ha/head during the 120-day dry season, then on native pasture at a low stocking rate of 15 ha/head during the remainder of the year, gained about 35 kg more live weight per annum than those on native pasture continuously. At turnoff, the 100 kg per head live-weight advantage represented a very significant improvement in animal productivity and financial return. The trial did, however, achieve its objective of acting as an 'early warning system' of problems in the hypothetical system as a whole. It encountered some management problems in relation to grass weeds and decision-making about when to remove the cattle from the ley pastures at the end of the dry season. However, the system is now used commercially on several thousand ha in the Northern Territory, with great success.
The third phase of the R&D program provided the opportunity to draw together all the threads of the earlier research and to use the by-now validated sorghum and maize models to examine various climatic and management scenarios from a probabilistic point of view. Thus Carberry and Abrecht (1991) simulated the effects of date of pasture kill (hence amount of surface mulch), sowing date, crop duration, and plant population of sorghum and maize at Katherine over the 100 years for which rainfall data was available. This enabled them to identify optimum production strategies for that environment. Similar work at a range of sites in north-east Queensland (Carberry, et al. 1991) incorporated economic data on variable and fixed costs and evaluated strategies on the probabilities of the gross margins rather than simply the grain yields.

Overall, it can be seen from Figure 7 that the Australian research in the semi-arid tropics moved steadily from a more empirical and technology development phase, through a phase of detailed understanding and modelling of the processes involved, to a final phase where the ‘tools’ developed (models) were used to extrapolate the production and economic risk analyses in space and time. The R&D at Katherine has now terminated but the more applied R&D by the Northern Territory authorities continues as commercial development, fuelled by a rapid expansion in the live cattle export trade.

The Kenyan Semi-arid Tropics

Like northern Australia, Kenya also has extensive areas of agricultural land in the semi-arid tropics, particularly in the Machakos and Kitui districts of the Eastern Province, where our collaborative project with the Kenya Agricultural Research Institute was conducted. Populations are expanding rapidly in these districts, as a result of a natural increase which is high on a world scale, together with migration from the overpopulated (higher potential) lands in the Highlands and the lands nearer Lake Victoria on Kenya’s western border. This is putting excessive pressure on the productivity of these semi-arid lands under current management and inputs. Many farmers are in a downward spiral involving nutrient depletion, and soil erosion leading to reduced yields and ending in a ‘poverty trap’ from which it is difficult to escape.

Climatically, the area has no direct counterparts in Australia, because of the unusual bimodal rainfall regime (Fig. 6b). From a radiation and temperature point of view, however, there are strong similarities to locations on the Atherton Tableland of north Queensland. Despite differing rainfall regimes, all the problems mentioned earlier for northern Australia are evident in the Machakos and Kitui districts.

The joint ACIAR–CSIRO–KARI research project also had three recognisable phases (Fig. 8). In phase one, we studied the farming systems practised on a range of farms, evaluated about 150 pasture legume species for use as ley plants, and researched a number of agronomic issues on maize, namely planting time, water supply, nitrogen fertiliser, plant populations, and their interactions. A start was also made on testing and modifying the temperate maize model (CERES-Maize) as a framework for the results of the agronomic research.

The on-farm studies helped us understand the biophysical and economic problems faced by farmers in the region and set the scene for research in phase two. It became clear that farm yields were extremely low, even in favourable seasons (when they seem to be limited by nutrient deficiencies). Many farmers used farmyard (or boma) manure but the supply was inadequate for the areas of crop land involved. Very few used fertiliser of any sort. The pressure on land was so great that our earlier idea of using legumes in leys to restore nitrogen fertility in rotation systems now seemed inappropriate in many situations. Finally, it was clear that soil erosion was an important problem on the usually-terraced crop lands, but a massive problem on the grazing lands which were usually part of the average farm.

In phase two of the R&D program, the crop research concentrated on the validation and development of the maize model and its application to important agronomic and management problems faced by farmers. The results were able to be expressed as gross margins and, by running the model using climatic data from past seasons, estimates of the long-term probabilities of various management strategies were produced. This work is reported by Keating and co-workers (these Proceedings) and linked with the large body of research which had been conducted in this region in the previous 25 years. Soil fertility also received considerable emphasis during this phase and large responses to farmyard manure and to N and P fertiliser were documented and the problems and possibilities of each understood. This work is reported by Probert and colleagues (these Proceedings). In relation to the situation on the grazing lands, the adapted forage legume species found in phase one were an important component in a novel pitting system developed to rehabilitate and protect eroded these lands. Long-term research on runoff and soil loss on crop lands and its impact and interaction with plant population,
surface mulch, and N fertiliser was also commenced at the National Dryland Farming Research Centre, Katumani, and is continuing in order to sample a wide range of rainfall/runoff situations. Finally, farmers’ perceptions of, and attitudes towards, risk were studied to provide the understanding required for devising ways of getting the technologies required to raise productivity adopted by the farmers.

The third phase, as in the Australian work, allowed us to integrate the results of the research in both space and time. Thus risk analyses were done on the effects of various crop management options using climatic data from a large number of stations in the two districts. The understanding of the problems and the ‘tools’ developed during the project to address these problems allowed us to examine the long-term effects of a Fertiliser-augmented Soil Enrichment Strategy (FASE) devised to help farmers escape from the poverty trap.

**Problems of R&D in Semi-arid Environments**

The problems faced by farmers, agricultural R&D workers, and indeed National Agricultural Research Services (NARS) in semi-arid environments can be aggregated into a smaller number of classes of major problem. Two of these, climatic variability, and complexity — are particularly important in the semi-arid tropics, while the third, efficiency of use of the R&D resources, is a universal problem, regardless of climate.
Climatic variability

Agricultural R&D in semi-arid environments is faced with far greater problems than that in more equable climates of Europe or North America because of the much greater climatic variability. Thus, it is not possible in the semi-arid tropics to make advances in understanding the factors driving production or to develop sensible recommendations for farmers simply by repeating an experiment in a number of seasons and averaging the results. To illustrate this, Figure 9 shows the results of experiments conducted by Nadar (1984) in Kenya on the response of maize to N fertiliser in different seasons. The shape of the response curves varied enormously, from linear depressions in yield with increasing N rates to strong sigmoidal responses up to the highest rates. Virtually any shape of response curve seemed possible, and simply averaging the results would produce meaningless results.

We found that the shape of the response curve was very dependent on the seasonal rainfall experienced, so it is interesting to look at how the seven seasons sampled in the experiment compared with the larger sample of seasons available in the historic rainfall record for this location (Fig. 10). It appears from this larger sample that the years sampled by Nadar were towards the more favourable end of the spectrum of possible seasons. If he had conducted his experiments in a different set of seasons the results should have been quite different.

This example makes the point that agricultural R&D workers in semi-arid environments need a way of setting the results of their experimentation, done in a particular season and under particular management conditions, in a wider context so that the probabilities of occurrence of a particular outcome can be estimated.

Complexity

The second class of problem common in the semi-arid tropics is that of the complexity of the interactions between factors affecting agricultural productivity and profitability. The response curves of Nadar, for example, were obtained from experiments planted on a particular date and grown at a particular plant density. As Keating demonstrates (these Proceedings), they would have been of different shapes if these factors had also varied because of the fact that, in these semi-arid environments with their ubiquitous N deficiency, there is a complex water supply (rainfall less runoff) \times plant population \times time of planting \times N supply interaction operating, and variation in any one of these factors can affect the outcome.

This complexity problem which plagues agricultural R&D in the semi-arid lands of both continents is too great for the human mind to comprehend and too great to be handled by the traditional experimentation approach. The human mind can handle two-factor interactions fairly easily. Three-factor interactions are much more difficult, but four-factor and above interactions are virtually impossible for it to comprehend. It is not possible to experiment with all
the possible permutations and combinations of the factors known to be affecting production. Clearly, we have to find new ways of getting better value from the information we have from the combinations we are able to sample experimentally, and from our understanding of the biological processes involved.

![Seasonal rainfall at Katumani](image)

**Figure 10.** Seasonal rainfall at Katumani (near Machakos, Kenya) 1957–1988. Hatched bars refer to the period during which the N fertiliser experiments shown in Figure 9 were conducted.

**Efficiency of use of R&D resources**

The third class of problem requiring a common approach in our two continents is that of efficiency of use of the R&D dollar. The priority accorded to agricultural R&D versus other science and technology investments is steadily declining in Australia as it is in many parts of the developed world. While the priority for agricultural R&D might still be high in SADC countries, it would seem that the total resources available are often severely limited. We therefore have the responsibility of finding ways to make the R&D more effective and more efficient.

One aspect of this is to conduct fewer experiments but get more value from them by collecting more comprehensive information and ensuring that it is in a form which enables it to contribute to the further development and application of crop and cropping system models. Another aspect concerns the extrapolation of results of experiments conducted at one location on one soil type in one series of seasons to other locations, soil types, seasons, and economic circumstances. This is particularly relevant for expensive long-term experiments investigating the effects of rotations and management practices. Even in a relatively affluent country like Australia it is out of the question to have more than a few such experiments.

Other papers in these Proceedings (Carberry, Keating et al., McCown and Cox, Probert et al.) attempt to relate our experiences in wrestling with these three classes of problem in both Australia and Kenya, including some new approaches to the modelling of agricultural systems and its use to address real-world problems of farmers.

**References**


