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# Eastern Africa-ACIAR Consultation on Agricultural Research

## Major Agricultural Problems and Research Priorities in the Eastern-Africa Region

Nairobi, Kenya
19-22 July 1983

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

## Contents

# Foreword

Australia has been called a 'lucky country'. In many respects this is true, but in one sense it is not. It is no ready-made 'Garden of Eden'. On the contrary, it shares with much of Africa extensive areas with harsh arid and semi-arid conditions used both for agricultural and pastoral activities. In these areas it has made considerable technological advances – assisted greatly by research activities in the Universities, in the Commonwealth Scientific and Industrial Research Organization (CSIRO), and in the State Departments of Agriculture. It is these research techniques and results that Australia is offering to share with developing countries.

The instrument for this activity is the Australian Centre for International Agricultural Research (ACIAR). ACIAR is charged with making available its experience by establishing collaborative arrangements with developing country research organizations – where that seems to promise a fruitful outcome and is requested by the country concerned.

One of the methods of establishing contacts and of determining the relevance or otherwise of Australian experience is the 'Workshop'. This not only establishes personal contacts between scientists but does determine whether or not Australian experience is relevant to the specific developing country problems under review. The Consultation held in Nairobi in collaboration with the National Council for Science and Technology was one such case. The clear lead given by the Hon. K.N.K. Biwott, Minister for Regional Development, Science, and Technology, in Kenya set the tone for discussions now likely to lead to a more fruitful relationship between agricultural scientists in Eastern Africa and Australia. These Proceedings will serve as a basic document in the development of that relationship.

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# Agriculture in Australia's Seasonally-Dry Tropics and Subtropics: Climatic and Soil Constraints

**R.L. McCown, R.K. Jones, and G.L. Hammer**[*]

In this workshop we want to examine agriculture in Eastern Africa and agriculture in Australia to see what benefits there might be to a closer linkage of our agricultural research and technology development activities. The broad aim of this paper is to describe the physical environment of agriculture in Australia and to draw some comparisons with that of agriculture in Eastern Africa to 'set the stage' for subsequent papers and discussions. The scope of coverage in this paper is set by the workshop's focus on those regions of Eastern Africa where crops are grown, but where productivity is constrained by insufficient rainfall; the paper reviews those aspects of climate and soils that most strongly determine the character and productivity of Australian agriculture in the climatic zones which are most comparable to those in Eastern Africa.

Figure 1 shows the area and latitudinal distribution of land in Australia relative to Africa. Southern Australia has a Mediterranean climate. Most of Australia between latitudes 30° and 20° S is desert, not unlike the Sahara. Northern Australia has a tropical climate that is similar to Africa's Guinea and Sudanian zones but also to the coastal and subcoastal areas of Eastern Africa (Papadakas 1975) (Figs. 2, 3). Australia's subtropics are similar to areas of Mozambique and Botswana (Papadakas 1975; Russell and Moore 1976) (Figs. 2, 3). Climates in Australia that most closely resemble those of the midlands of Africa (1 000-1 500 m elev.) occur only in two very small areas, but neither exceed 1 000 m (Papadakas 1975) (Figs. 2, 3). Although they are not homologous, comparisons between the crop climates of the African tropical midlands and the Australian subtropics may be useful.

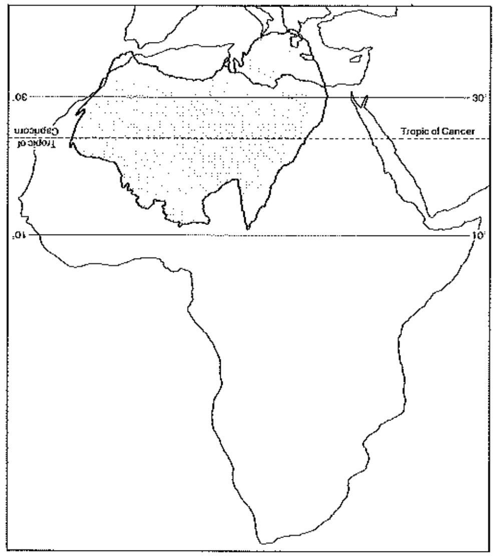

Figure 1. *Australia, showing comparative area and latitudinal position with northern Africa.*

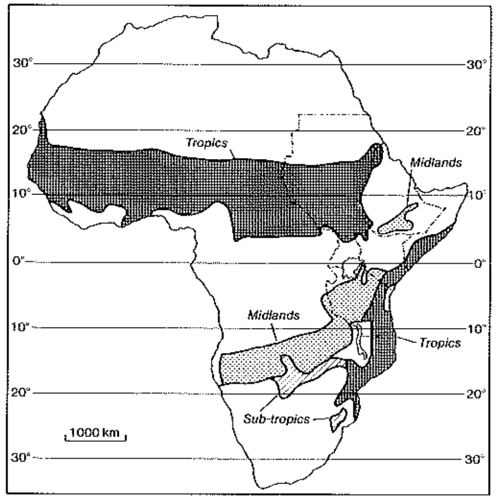

Figure 2. *General distribution of seasonally dry tropical and subtropical climates in Africa suitable for agriculture.*

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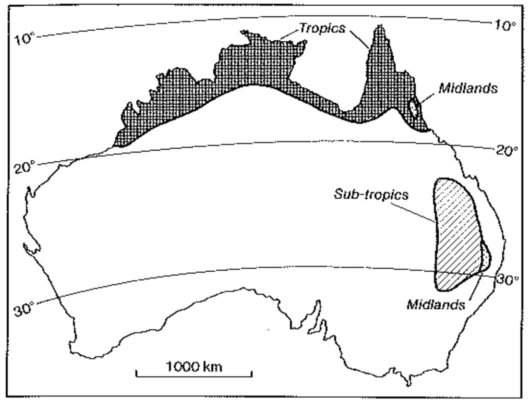

Figure 3. *General distribution of seasonally-dry tropical and subtropical climates in Australia suitable for agriculture.*

Figure 4 shows the distribution of existing and potential cropland in the semi-arid zone which rings the great Australian desert. Agricultural development began in the temperate south-east and spread north into the subtropics where it is still expanding. Sustained development has yet to begin in the far northern tropics, although agricultural resource assessment and research has been conducted here for nearly forty years.

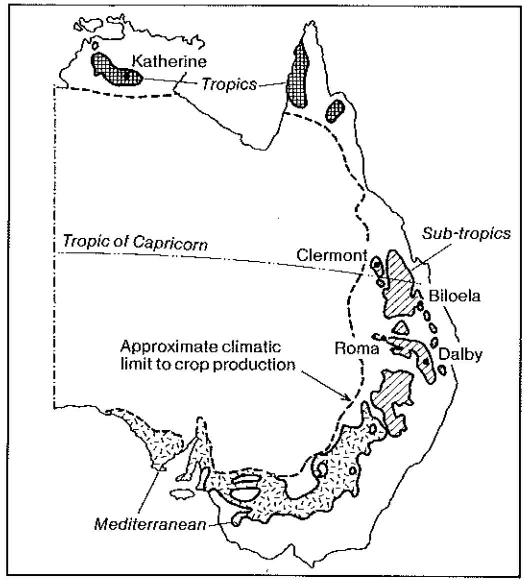

Figure 4. *Land under crops or, in the case of the tropics, with the potential for dryland cropping.*

Of the land in the far north that has a suitable climate for cropping, a large proportion has unsuitable terrain or soils (Nix 1979; Williams et al. 1983). Thus most land in this zone is destined to continue to be used for beef cattle grazing, although possibly with important linkages to new crop areas.

## The Subtropical Environment in Australia

### Climate

All along the east coast, the wettest zone is on the coast, with rainfall decreasing and potential evaporation increasing with distance inland. The subtropical dryland cropping belt lies between the 750 and 500 mm isohyets of effective rainfall (total rainfall minus runoff) (Fig. 5). Mean annual Class A pan evaporation varies between 1 400 mm in the east to 2 100 mm in the west. Rainfall has a summer maximum throughout the region with a slight second mode in winter in the south (Figs. 6, 7).

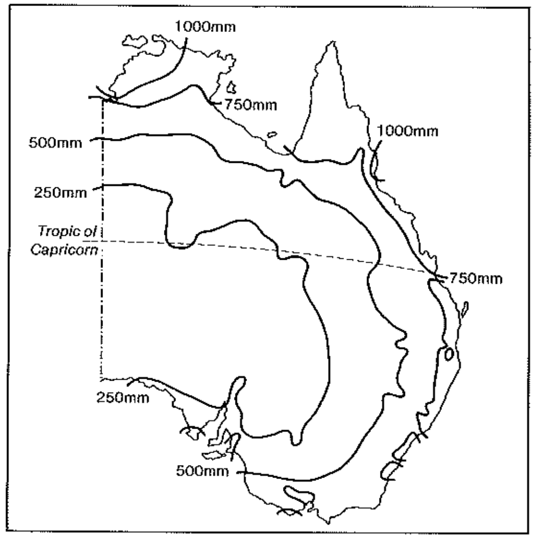

Figure 5. *Map of isohyets for 'mean effective rainfall' (rain minus runoff). (From Warner 1978).*

There is a marked seasonal variation in temperature with a difference of about 12°C between summer and winter monthly maxima and about 15°C between summer and winter minima (Figs.

6, 7). (This contrasts with the weak thermal seasonality of the highland areas of Eastern Africa, with only about 5°C fluctuations). Frosts occur throughout the region, but with risks much lower in the north (Figs. 6, 7).

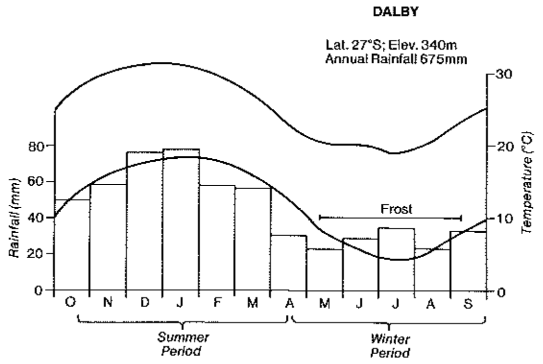

*Figure 6. Median monthly rainfall, average monthly maximum and minimum temperatures, and 80% frost duration for Dalby.*

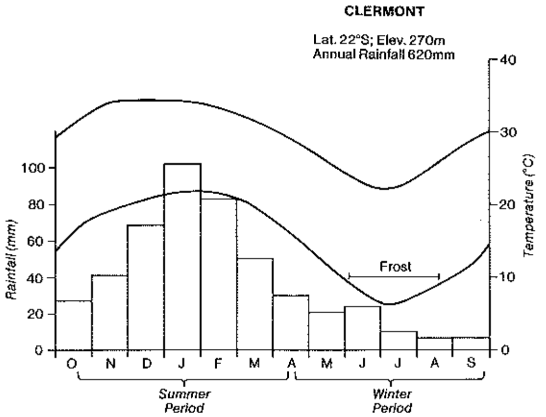

*Figure 7. Median monthly rainfall, average monthly maximum and minimum temperatures, and 80% frost duration for Clermont.*

Although both winter and summer crops are grown, they are rarely grown consecutively on a given field. Rather, the other season preceding cropping serves to accumulate water under a bare fallow. Wheat, grown in winter, follows summer fallow; a summer crop, e.g. sorghum, maize or sunflower follows a winter fallow.

Judging from the rainfall histogram for Dalby, it appears that the summer season has the better water supply (Fig. 6). When seasonal variation in potential evaporation is superimposed (Fig. 8), the resulting pattern of soil water availability is strikingly different from that of rainfall, and the winter season emerges as the more mesic (Fig. 8).

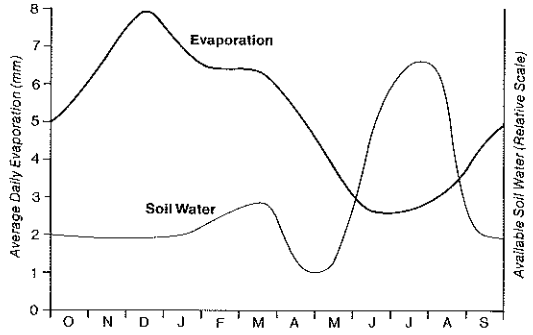

*Figure 8. Seasonal trends in daily Class A pan evaporation and in available soil water at Dalby. (From Weston et al. 1975).*

An appreciation of the seasonal patterns of water supply and temperature in relation to a wheat crop can be obtained from Fig. 9 (Adapted from Nix 1975). Soil water is recharged under bare fallow from January until sowing, shown in Fig. 9 as occurring on June 1st. Recharge continues up to floral initiation when both temperature and leaf area rise rapidly causing an exponential rise in potential evapotranspiration. Water supply from this time on is increasingly provided from the water store. On average, water deficiencies (Et > Ea) develop around anthesis and intensify with time thereafter.

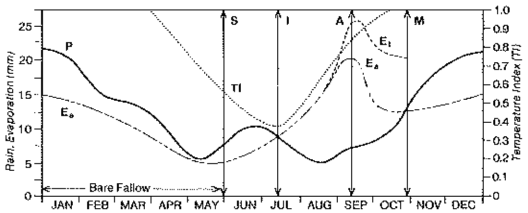

*Figure 9. The seasonal pattern of environment and development of a wheat crop at Dalby. (rainfall (P), potential evaporation ($E_t$), actual evaporation ($E_a$), temperature index (TI), sowing (S), floral initiation (I), anthesis (A) and maturity (M)). From Nix 1975).*

The starting point in management is the optimization of date of anthesis with respect to frost risk on the one hand and soil water depletion on the other (Nix 1975). If anthesis occurs before the last frost, yields suffer. However, even more serious losses may result if anthesis occurs too far into the terminal drying period. Woodruff and Tonks (1983) found that, in the absence of frost, highest yields resulted when anthesis occured in mid-winter, with a steep yield decline with later anthesis. They concluded that, except where frost risks are high, it may be preferable to risk the frost than the water stress.

In the case of summer crops, avoidance of frost, both in early stages of growth, and during reproduction are considerations in species and cultivar selection for a given planting opportunity, i.e. suitable moisture conditions. Frost incidence and severity varies greatly within the region, both latitudinally and locally. Indication of the duration of the frost prone periods in the south (Dalby) and in the north (Emerald) is given in Figs. 6, 7. Hammer and Rosenthal (1978) provide detailed probabilities for these plus three other representative stations in this region.

Even after selection of the most appropriate cultivar and planting date, there remains a substantial risk in any given year that the weather needs and tolerances of the crop will not be adequately met. By far the most important uncertainties are (a) the timing of planting rains and (b) adequate water supply to finish the crop. In very broad terms, about 15-25 mm of rain is needed to plant a winter crop and 50-100 mm for a summer crop (Berndt and White 1976; Hammer et al. 1983). Not only is there a risk that planting rains will be late (or will not occur), but that rain will be excessive, resulting in delayed planting due to un-trafficability of the poorly drained heavy clay soils. Late planting increases the risk of high temperatures and/or severe water deficits following anthesis (Fig. 9).

Rainfall amount varies greatly from year to year. The coefficient of variability (CV) of winter crop period rainfall varies from 40% in the south-east to 60% in the north of the region (Nix 1975). Monthly rainfall for the past three years for Dalby illustrates the degree of departure from the average pattern (Fig. 10). Addition of the soil water carried over from the bare fallow damps the variability in water supply to a CV of 30% in the south-east and 40% in the north.

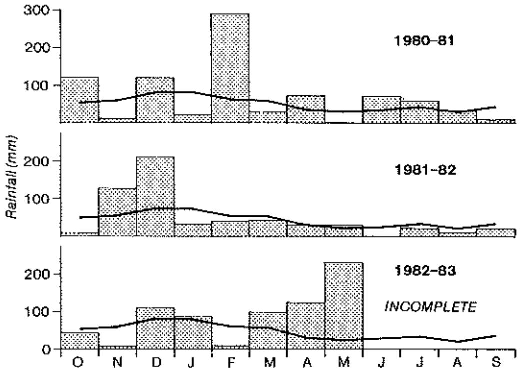

*Figure 10. Monthly rainfall over three years compared with the long-term median at Dalby.*

In order to quantify year-to-year variation in wheat yields, Hammer et al. (1983) simulated the yields for a number of stations using 92 years of weather records. Cumulative frequency distributions of simulated yields for Dalby and the drier, more inland, station of Roma are shown in Fig. 11. Increased marginality resulted in lesser yields and greater frequency of very low yields, but no apparent change in variablility. The curves are very flat over a wide yield range, indicating more or less equal propabilities of different yields within this large range.

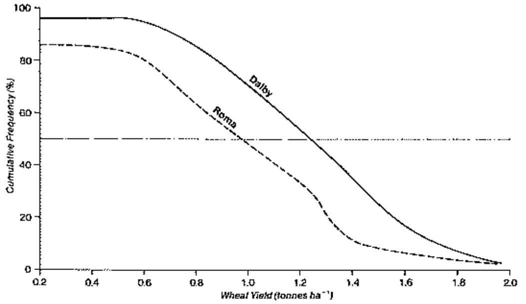

*Figure 11. Cumulative frequency distribution of simulated wheat yields at Dalby and Roma for 92 years (from Hammer et al. 1983).*

Berndt and White (1976) carried the simulation further to include economic returns. While the chances of losing money on a wheat crop at Dalby are 1 in 8, the chances at Roma are about 1 in 3. The summer crop is at a higher risk at both locations, such that negative income is predicted 1 in 3 years at Dalby, and 2 in 3 years at Roma.

## Soils

Throughout the region, crops are grown almost exclusively on cracking clay soils. These occur typically on rolling plains, are neutral to strongly alkaline, calcareous, and moderately saline at depth. These soils appear on the World Soil Map as Vertisols, and in the Handbook of Australian Soils as black earths and grey, brown and red clays (Stace et al. 1968).

The most important feature of these soils as regards agriculture to date is their high natural fertility. It is this resource that has been, and for the most part continues to be, the back bone of agriculture in this region. In general, all of these soils are naturally high in nitrogen and some are also high in phosphorus. Rates of fertilization are gradually increasing in this region due both to expansion onto inherently less fertile soils and to the decline in fertility in the older cropping areas.

As indicated earlier, physical properties of these soils exert an important influence on farmer practices and on crop yields. Because of their high clay content and well developed structure, the plant available water range tends to be high (Williams 1983). Except where soils are shallow, this makes possible the storage of large quantities of water. During re-wetting, water enters initially via large cracks, but once these close, permeability is very low. This results in large volumes of runoff during heavy rain, slow recharge of the water store, and prolonged wet conditions following rain. The high runoff contributes to large soil erosion losses (see below); slow drainage following rain delays operations, e.g. tillage, planting etc.

By far the most important soil problem is the rate at which soil is being eroded by water under this agricultural system, which keeps soil cultivated and without cover during the main rainy period. In the southern part of the region, gullying losses of 75-200 t ha$^{-1}$ from bare-fallow during heavy rain events have been reported (Anon. 1978). Losses on similar, but generally shallower, soils in the northern part of the region were estimated at 400 t ha$^{-1}$ (Anon. 1978). The severity of the problem comes into sharper focus when these losses are compared with the 12.5 t ha$^{-1}$ yr$^{-1}$ considered to be the 'tolerable' soil loss rate in the wheat belt of south-eastern Australia (Anon. 1980).

The prospect of continued losses at these rates raises the question of how long agriculture can remain viable. Estimates made by Cummins et al. (1973), using loss rates considerably more conservative than those cited above, indicate a lifetime of only 10-50 years on shallow soils under existing land use practices (Table 1).

**Table 1. Estimated erosion losses and production life expectancies for some Darling Downs soils under a range of slope conditions. (Data from Cummins et al. 1973.)**

| Soil | Slope % | From bare fallow t/ha/yr | From crop[a] t/ha/yr | Est. life expectancy of agriculture under existing land use (yr) |
|---|---|---|---|---|
| Shallow black | 1-3 | 63 | 32 | 50 |
| earth | 3-5 | 98 | 49 | 30 |
| (10-30 cm) | 5-8 | 126 | 63 | 10 |
| Medium black | 1-3 | 62 | 30 | 130 |
| earth | 3-5 | 96 | 40 | 100 |
| (40-90 cm) | 5-8 | 126 | 52 | 40 |
| Deep black | 1-3 | 76 | 31 | 320 |
| earth | 3-5 | 118 | 48 | 210 |
| (120-200 cm) | 5-8 | 269 | 110 | 90 |

a. Average management, stubble incorporated.

# The Tropical Environment in Australia

## Climate

In the north, rainfall declines and potential evaporation increases with distance from the coast (Fig. 5). Katherine, although in the drier end of the region, serves to illustrate the main climatic features of the region (Fig. 12). Rainfall is strongly summer dominant; in many years no rainfall occurs between May and October. Because rain spoils dry legume herbage, the high probability of rainless dry seasons is important to the nutrition of cattle grazing legume pastures (McCown et al. 1981). However, crop production depends entirely on summer rainfall. Because rainfall in October and November is extremely unreliable it is prudent to delay planting until mid-December, and then to plant only with the additional safeguard of 50 mm of stored soil moisture. Crop water supply is generally reliable until late March, although there is a substantial risk of water stress sometime in this period. Crops of maize or sorghum generally mature after rain ceases, using stored soil water.

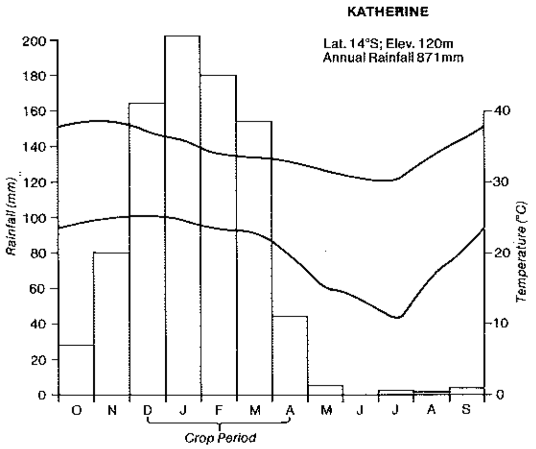

*Figure 12. Mean monthly rainfalls, maximum temperatures, and minimum temperatures at Katherine, N.T.*

There are two critical periods in the life of a crop in this environment. The first is between planting and seedling establishment. In this environment, final yield is more closely dependent on achieving a good stand than in a temperate environment, which allows more compensations in inflorescence densities via tillering. Good emergence is jeopardized by a dry soil surface in this period, resulting in impairment of emergence by either high soil temperatures or strong surface seals. Although soil physical properties are important variables, no problem occurs as long as the soil surface is moist during this period.

The second critical period is during anthesis and grain filling. This period, in which the crop is particularly sensitive to water stress, occurs in March and April as the reliability of rainfall is rapidly declining (Fig. 12). Premature terminal soil water depletion is a major cause of low yield in the southern part of the region.

The annual variability of rainfall for the region (Katherine = 21%) is low by Australian standards, but higher than most tropical regions receiving similar rainfall amounts (Williams et al. 1983).

Risks of drought-caused crop failure or low yields are not as yet well defined. Williams et al. (1983) estimated a low yield 1 year in 3, but the results of McCown (1982) suggest that 1 in 5 is more realistic. More work is needed to better define this risk.

## Soils

Those that have been found to be most suitable for cultivation are the red earths (Stace et al. 1968) which correlate with the Ferric Luvisols and Ferric Acrisols on the FAO World Soil Map. These soils are free draining, have generally sandy or loamy surface textures, are generally deep, and often contain ironstone nodules in the lower B horizons. They generally have low contents of soluble salts, organic carbon, nitrogen, phosphorus, sulfur, and exchangeable basic cations. Following cultivation, clods are prone to slake with heavy rain and form seals or caps upon drying (Arndt 1965 a,b).

Profitable crop production on these soils requires substantial inputs of fertilizer. On the loamy soils, a maize crop needs 50-100 kg N ha$^{-1}$ and 10-20 kg P ha$^{-1}$. On the sandy soils more N is required. Where a crop follows a legume pasture, much less N is required (Jones and McCown 1983). Phosphorus fixing by these soils is low (Jones et al. 1983).

Sulfur and zinc have been shown to be deficient on many of these soils. Where needed these elements are generally applied in a zinc-fortified single superphosphate.

Within this group of soils the most important differences in cropping use relate to differences in texture, which ranges from sand to clay loam. Soils at the heavier end of the range (loams) have properties that make tillage difficult. Dry soil has brick-like strength and abrasiveness that are strong deterrents to ploughing when dry. Under conditions wetter than field capacity, these soils are sticky. Soil at, or below, field capacity compacts readily under pressure with drastic loss in water permeability; this compacted soil forms strong surface seals that seriously impede seedling emergence (Arndt 1965a).

The sandy soils are much easier to cultivate. They can be worked when either very wet or dry. Strong seals are not a problem, although surfaces exposed to raindrop impact form thin seals which reduce infiltration.

A major problem on sandy soils is the extremely high temperatures that result as the soil surface dries. Under conditions of favourable soil moisture at seed depth, temperatures of over 65°C at 1 cm have been recorded on a sandy soil near Katherine. Such temperatures are lethal to seedlings and under such conditions emergence is very poor (Jones and McCown 1983).

A major difference related to texture is the more stable nitrogen balance on the loams. Wetselaar (1967) reported more rapid mineralization on the sands as well as a greater proportion of soluble N leached below the root zone (Wetselaar 1962). Jones and McCown (1983) have found the nitrogen contribution of a high yielding legume forage crop to a succeeding cereal crop, to be much less in the sand than in the clay loam.

Under a conventional cultivation system, the rates of soil erosion on the sandy soils have proved to be much higher than on the heavier soils. At present, legislation prevents the clearing and development of the sandier areas in this region of the Northern Territory. At the same time the search for a safe way to farm these soils is a high research priority because they occupy such a large fraction of the otherwise potentially arable area. Soil erosion on the heavier soils under cultivation appears less dramatic because there is less gullying, but surface soil is nevertheless being lost at an intolerable rate if agriculture is to be permanent. Cropping areas in which surface drainage is directed through sink holes to underground streams in the local limestone karst experience increasing frequency and duration of flooding back from sink holes, apparently from silting of the system.

The Northern Territory government is at present conducting a re-evaluation of dryland crop production on a carefully designed and monitored scheme of pilot farms. From the outset it was recognized that adequate soil conservation measures must be included, and farm development includes a terrace bank system designed according to widely accepted engineering codes. After several years, it is becoming clear that the costs of constructing such systems to even minimal standards are too high in relation to farm income to be economically feasible in an extended development scheme. In addition, there is an increased awareness of the physical and biological inadequacies of this approach. Attention now is turning to soil surface management strategies that may reduce the need for expensive structures and provide protective cover to soil so beneficial in this climate.

## Comparisons of Northern Australia and Eastern Africa

### Climate

Within the dryland agricultural areas of Eastern Africa where rainfall in an important constraint, climates vary both in relation to latitude and altitude. At the higher altitudes and close to the equator, e.g. Machakos, Kenya, rainfall is stongly bi-modal and temperatures are cool all year (Fig. 13). The most comparable climate to this in Australia is that represented by Dalby (Fig. 6). Here also there are two growing seasons, both dictated by rainfall distribution. However, summers are hotter and winters much colder than the frost-free equatorial highlands below about 1 800 m. In both places there is a high risk of water shortages for crops in both seasons. In Australia bare fallow is used to reduce this risk, but the price paid is a lowered intensity of land utilization and a high risk of soil erosion. In both places the climate is favourable for animal production on perennial pastures, since prolonged dry seasons are rare.

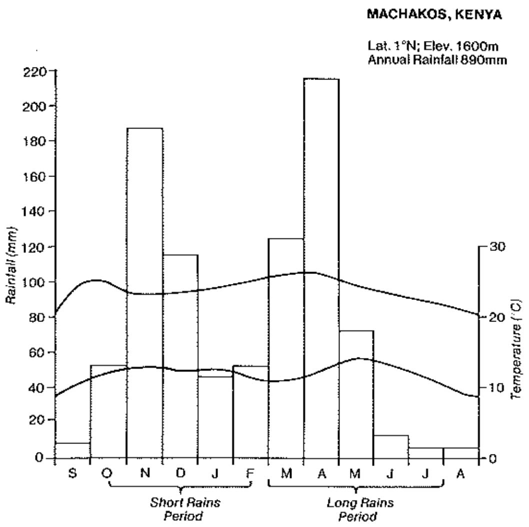

*Figure 13. Mean monthly rainfalls, maximum temperatures, and minimum temperatures at Machakos, Kenya.*

At lower elevations and further from the equator, Eastern Africa agricultural climates are very similar to those of the Australian tropics. The rainfall climate of the southern plateau of Tanzania, e.g. Nachingwea, Tanzania (Fig. 14), is very similar to Katherine (Fig. 12).

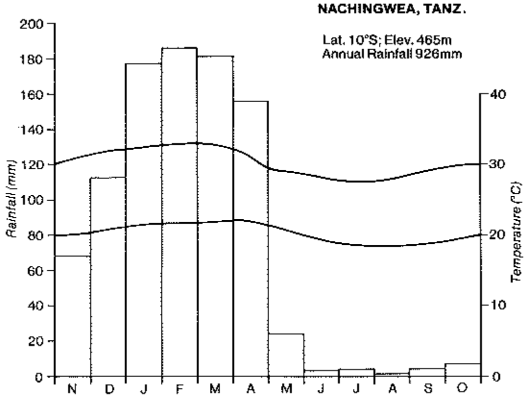

*Figure 14. Mean monthly rainfall, maximum temperature and minimum temperatures at Nachingwea, Tanzania.*

### Soil

Study of the FAO World Soil Map and the recent soil map of Kenya (Sombrock et al. 1982) suggests that many of the red soils on Basement Complex rocks are similar in texture (light to medium) and have similar fertility constraints to the red earths in tropical Australia. The Vertisols of the two continents are also probably very similar, but these soils appear to be much less widespread than the Basement Complex soils in the African zone under consideration in this workshop. The remainder of our paper is restricted to the lighter-textured red soils.

### 1. Fertility

The main soil fertility constraints to development on the medium and lighter-textured soils of northern Australia relate to the supply of the nutrients N, P, S, Zn, K, Cu, and Mo——in approximately that order of priority (Jones et al. 1983). In Eastern Africa on medium to light textured soils in the semi-arid areas, the soils are often low in total N and crops growing on them are very responsive to applied fertilizer N (Anderson 1969, 1970 a,b; Evans 1963; Singh and Uriyo 1980). Some of the soils appear to mineralize N quite rapidly on wetting up at the start of the rainy season(s) but it is inadequate for the expected yields and may be leached rapidly at least below a depth of 40 cm (Bennison and Evans 1968; Semb and Robinson 1969).

Phosphorus also appears to be quite deficient on many of these soils and some extremely low total soil P values are on record (Anderson 1969, 1970a). Crop reponses to P often go hand in hand with responses to N and there is usually a strong interaction between them, such that maximum responses to P are not achieved until the N deficiency has been at least partially overcome, and vice versa. Strong responses to P have been found in many experiments (Evans 1963; Le Mare 1974; Singh and Uriyo 1980). The P sorption, or fixation, characteristics of a few of the soils have now been examined (Hinga 1973; Uriyo et al. 1977) and these were found to be relatively low on a world scale. This is supported by the fact that the amounts of fertilizer P required to give acceptable crop yields seem modest.

Information on the S and Zn status of the semi-arid soils is very sparse. Anderson (1970b) suspected that S was a problem with groundnut at Sambwa in Tanzania; Singh et al. (1979) present some analytical data for several soils from the Arusha and Mbeya areas of Tanzania.

Zinc seems to have been rarely considered as a possible deficiency and so far we have seen no reports of experiments where it has been used as a treatment. The only soil data we have seen comes from the west Lake region of Tanzania where EDTA-extractable Zn values were low on many of the soils sampled (Moberg 1972).

Soil K levels seem to be moderate to high (Anderson 1969) and instances of crop responses to additions of K relatively infrequent, except under very intensive conditions (Anderson 1970 a,b). However, Anderson (1973) does mention some reponses to K in experiments on beans at Machakos and Kitui.

Copper and Mo seem to have received very little attention (or have not shown any signs of plant responses and this has not been reported). Soil Cu values by a range of methods are presented for numerous sites in Kenya by Nyandat and Ochieng (1976) and it would appear that soils derived from metamorphic rocks such as schists are in general adequately supplied with Cu.

From the information we have had available to us in preparing this paper, it would seem that there are many parallels as regards soil fertility between areas of semi-arid northern Australia and Eastern Africa.

## 2. Physical Aspects

In both Africa and northern Australia, less information is available on the physical characteristics of these soils, but the literature suggests that African soils have much in common with soils in northern Australia. They appear to have the same tendency to slake when wet and form seals or caps upon drying (Christianson 1981; Njihia 1979). This results in much reduced infiltration and soil profile recharge, and greater runoff with attendant soil erosion.

Although even less information (from either continent) is available to compare soils in terms of erodibility, it is abundantly clear that the soils in both places are prone to serious erosion under cultivation or heavy grazing (Christianson 1981; Moore 1979).

We share the need to learn to produce from these soils and yet keep them for posterity.

## Acknowledgements

We gratefully acknowledge the assistance of R.F. Isbell and John Williams of the CSIRO Division of Soils in preparing the sections on soils.

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# Soil and Crop Husbandry: Recent Trends in Production and Research

J.K. Leslie*

The production of field crops in Australia must remain price competitive in: (a) an international trading environment, where some major competitors provide commodity price supports to their farmers, and (b) against a domestic situation where there is virtually no effective assistance in prices paid to farmers for grains and oilseeds, and where there are strong inflationary pressures on farm-input costs. Economic viability of Australian agriculture has been maintained by the substitution of capital and fuel energy for labour by highly mechanized farming with large areas farmed per man unit, and by rigorous selection of cost-effective technology. Nevertheless, in recent years there has been a slow decline in the international competitiveness of Australian field crop agriculture. This background leads to a commercial emphasis on productivity (output:input) in the short term that can conflict with the essential long-term requirement of maintaining soil fertility against exploitive nutrient run-down and soil erosion.

The objectives of research and extension efforts are to increase productivity and achieve stability or improvement of soil resources. Achievement of these dual objectives is particularly challenging in the subhumid-semi-arid tropical and subtropical regions of Australia whose location and main soil and climatic characteristics have been outlined by McCown et al. (1983). There is substantial undeveloped potential in the two regions (Table 1). In the subtropics an extensive current agriculture provides a good base for relevance in research. In the tropics, we have learnt a great deal from research over several decades and from development failures, but there are difficulties in maintaining research relevance and momentum in the absence of a significant commercial agriculture. In both regions the present commercial farming systems are continuously arable with crop sequences determined by seasonal weather variations and market prospects. Cattle fattening is undertaken on annual forage crops or grain crop stubbles on these same lands, but rotation of sown pasture with crops is insignificant and when practised, it is primarily for control of tree regrowth in pastures rather than for soil stabilizing or fertility building objectives.

There is little direct affinity, agroclimatically or socio-economically, between this agriculture and that of Eastern Africa. The climatic affinities, at least in respect of rainfall, are closer than mean monthly data indicate because the marked year-to-year variability in monthly rainfall distribution in the Australian subtropics does create individual seasonal conditions that can be very similar to the unimodal or bimodal patterns variously characteristic of Eastern Africa (McCown et al. 1983, Figure 10). Further, for each crop species we are both striving in our generally semi-arid climates to achieve subhumid to humid conditions in respect of moisture supply and evapotranspiration demand during the yield-determining phases of crop growth and development, and to minimize the effects of moisture and temperature stresses when they do, inevitably, occur. Both regions are

**Table 1. Current and potential annual cultivated areas in tropical Australia (ha x $10^6$). (Adapted from Leslie and Doughton 1976.)**

| Region | Current | Potential |
|---|---|---|
| Wet tropics | 0.16 | 0.13 |
| Subhumid-semi-arid tropics | 0.03 | 1.95 |
| Subhumid-semi-arid subtropics[a] | 2.12 | 8.20 |
| Humid-subhumid subtropics | 0.51 | 0.65 |

a. North of latitude 29° S

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