The development of stable and profitable summer cropping systems in northern Australia

I.M. Wood[1] and S. Fukai[2]

[1] CSIRO Division of Tropical Crops and Pastures, The Cunningham Laboratory, 306 Carmody Road, St Lucia, Qld. 4067
[2] Department of Agriculture, University of Queensland, St Lucia, Qld. 4067

Introduction

Viewed globally, arable crop production in Australia is of very recent origin. Strategies for production have often been developed rapidly in response to social and economic pressures with little regard to their long-term consequences. Crop production in the tropical and subtropical areas of northern Australia is even more recent than in southern Australia, and in the semi-arid tropical areas of central Queensland and the Northern Territory it is still very much in the development phase. It is perhaps not surprising therefore that in northern Australia there have been serious difficulties in establishing stable crop production systems and that a number of large-scale commercial efforts have ended in failure. The temperate areas of southern Australia were fortunate in being able to draw heavily on the established technologies of Europe and North America. However, the possibilities for doing this in northern Australia were much less, as farming in those countries with comparable climates was almost invariably being conducted under smallholder-peasant conditions involving hand labour and subsistence crops.

The dynamic nature of crop production and the vagaries of weather and of pests and disease pose special problems for the development of cropping systems. The peasant cropping systems practised in many developing countries have often evolved over many hundreds of years and tend to provide relatively low yields with low physical inputs and with a low risk of crop failure. In Western countries the cropping systems generally involve higher inputs, a higher level of managerial skill and have a higher yield potential. Cropping systems in developed countries have changed greatly in the past few decades with marked improvements in equipment, fertilizers, herbicides, insecticides and cultivars. Despite these improvements many of the cropping systems practised today in developed countries, including Australia, are exploitive and are causing serious losses or deterioration of the soil resource. In many instances this damage is irreversible, as in cases where erosion or salting is very severe and the land becomes unproductive and has to be abandoned. In other cases the deterioration may be slower: nutrient status and soil structure may be adversely affected so that crop yields are reduced, but the damage is not irreversible and improved cultural practices can restore productivity.

The two essential features required of a cropping system in Western developed economies are that it be both stable and profitable. Stable in this context means long-term stability in productivity. Under rainfed conditions, production will obviously fluctuate from season to season depending on climatic factors, but with a stable cropping system yields should fluctuate around a constant mean figure. A decline in this mean yield would indicate a decline in the capacity of the soil for crop production; with an improving technology mean yields should in fact increase with time.

In this paper we consider cropping systems for northern Australia and particularly annual field crops sown during the spring and summer months (i.e. September to February) in the lower rainfall (i.e. semi-arid) tropics and subtropics. Some of these crops, however, can grow well at other times of the year in the region provided water supply is adequate, and are included in the statistics shown later. We define northern Australia as the whole of Queensland and the Northern Territory, and Western Australia north of latitude 26?S. Our considerations are mainly restricted to dryland cropping because the irrigable area is relatively small - about 10% of the total cropping area. In addition there are more problems and risks, and hence a greater need for research, associated with dryland cropping in northern Australia.

Production and potential for summer crops in northern Australia

2.1 Production

The area sown to crops in northern Australia topped 1 million ha in 1954/55, some 114 years after the first agricultural settlement in Queensland. The second million ha was reached in 1968/69, only 14 years later; the current (1980/81) level is 2.5 m ha. These represent an average annual increase in the area sown to crops since 1954/55 of 3.6%.

During the four years 1976/77 to 1980/81 the area sown to crops in northern Australia increased from 2.09 to 2.58 m ha, an average annual increase of 5.4%. Over the same period the area sown to summer crops (excluding summer forage crops) increased from 0.59 to 0.83 m ha, an average annual increase of 9.0% (Table 1). Much of the increase in the area sown to crops can be attributed to the decline in beef prices and the diversification to cropping on many pastoral properties. The area sown to individual crops fluctuates from year to year because of climatic factors and economic reasons. However, the area sown to cotton has increased steadily over the past five years. Rice, tobacco and a number of other summer crops have not been included in Table 1 because of the relatively small areas sown.

The total value of the major summer crops in the five years ended 1980/81 is also shown in Table 1, and the percentage this represents of the total value of crop production in northern Australia.

Although summer field crops constitute a fairly high proportion of the total area sown to crops they represent only a small proportion of the total value of crops grown in northern Australia. This is because of the large contribution to total value made by sugarcane, horticultural and vegetable crops in Queensland. In 1979/80 they occupied only about 16% of the total area cropped but contributed 63% of the total value. These high-value crops are grown in higher-rainfall areas along the coastal fringe of Queensland or with supplementary irrigation.

Of the summer field crops listed in Table 1 only soybeans and cotton are normally grown with irrigation, while maize may be supplemented with irrigation in some areas.

The areas sown and the average yield of the major summer crops in each statistical division in Queensland are shown in Table 2. It is clear from the table that the distribution of the areas sown to different crops varies within Queensland. Soybean is grown mostly in the south-east Divisions and about 80% of the area sown to peanuts is in the Wide Bay - Burnett Division. Sunflower is concentrated in the Fitzroy Division while sorghum is widely grown in the Darling Downs and Fitzroy Divisions. The Fitzroy Division is unique in that more than half of the total crop area is occupied by sorghum and sunflower.

Crop yield data illustrate the difficulty of growing summer crops in some Divisions; for example, dryland crops in the South-West Division. Rainfall in 1980/81 was generally favourable, and yields of the crops shown in the Table are higher than average. These yields are however lower than those generally obtained in developed countries.

2.2 Potential

2.2.1 Queensland

The area sown to summer crops is presently about one-quarter of the total area cropped in northern Australia; however, future crop development is expected to increase the proportion of summer crops.

Table 1. Areas sown and value of production of major summer crops in northern Australia for the five years 1976/77-1980/81. Data from Australian Bureau of Statistics.

State and Crop	Area Sown (ha)				
	1976/77	1977/78	1978/79	1979/80	1980/81
Queensland					
Grain sorghum	377,092	293,145	279,961	368,698	528,394
Sunflower	77,798	133,610	161,823	158,736	146,316
Peanuts	30,701	29,959	36,601	31,273	26,773
Soybeans	26,026	36,708	36,430	34,503	29,318
Cotton	10,286	10,977	14,442	20,550	24,182
Maize	32,898	28,733	34,122	41,205	42,566
Navybean	7,739	10,089	4,675	4,244	3,314
Panicum & millets	21,968	46,142	24,210	15,493	24,957
N.T.					
Grain sorghum	881	144	764	583	536
W.A.*					
Peanuts	43	n.p.	n.p.	n.p.	n.p.
Soybeans	n.p.**	n.p.	n.p.	171	115
Total area sown to major summer crops***	585,432	589,507	593,028	675,456	826,471
Area sown to selected summer crops as a % of total area cropped	28.0	27.0	25.0	27.9	32.0
Value of major summer crops ($000)	106,547	125,391	168,585	175,634	266,925p
Value of major summer crops as a % of value of all crops	12.0	15.2	15.3	15.5	18.3p

* Crops production in northern W.A. is restricted to the Ord Irrigation Area. Limited areas of grain sorghum and sunflowers are grown but largely as dry season (i.e. winter) crops.
** n.p. - not published - confidential.
*** excluding confidential areas.
p preliminary figures.

The Queensland Department of Primary Industries has recently completed a survey of the agricultural and pastoral potential of Queensland (1). This survey used information on soils, climate and landform to classify land into four land suitability groups. The first group included all land considered to be permanently arable, with no known impediments to continuous cultivation and cropping provided soil conservation practices were followed and fertilizer was applied. The second group covered land considered to be arable provided cropping was combined with a stabilizing pasture phase. The other two groups covered land considered as being generally non-arable. Data on current land use were recorded. The estimates of gross potential areas for specific summer crops in the rural statistical divisions of Queensland are given in Table 3; also included are the estimates of total areas assessed as suitable for arable cropping.

Table 2. Areas sown ('000 ha) and yield (t ha^{-1}) of major summer crops for the rural statistical divisions in Queensland in 1980/81 season. Data from Australian Bureau of Statistics.

Statistical Division	Crop					Total Crop Area
	Maize	Soybean	Peanuts	Sunflower	Grain Sorghum	
Moreton (Area)	2.3	11.5	-	0.4	7.8	87
(Yield)	3.43	2.24	-	0.98	3.45	
WB - Burnett+	19.9	7.3	21.1	1.9	51.8	239
	2.47	1.30	1.45	0.98	2.37	
Darling Downs	12.6	7.5	1.1	38.7	230.7	1294
	3.30	1.66	1.44	0.78	2.11	
South-West	-	1.4	-	0.7	11.1	164
	-	1.55	-	0.15	0.17	
Fitzroy	0.5	1.4	-	79.4	184.2	407
	1.66	1.98	-	0.68	1.83	
Central-West	-	-	-	-	-	-
	-	-	-	-	-	
Mackay	-	-	-	25.0	39.9	177
	-	-	-	0.68	1.76	
Northern	0.7	0.1	-	0.2	2.5	96
	3.67	1.47	-	0.37	1.70	
Far North	6.5	-	4.6	-	0.4	109
	3.27	-	2.22	-	1.32	
North West	-	-	-	-	-	-
	-	-	-	-	-	
Total Queensland	42.6	29.3	26.8	146.3	528.4	2574
	2.89	1.80	1.58	0.71	1.99	

+ Wide Bay - Burnett Division.

Table 3. Gross potential area ('000 ha) of summer crops for Queensland. Data from Weston et al. (1)

Statistical Division	Crops					Total all crops
	Maize	Soybean	Peanuts	Sunflower	Grain sorghum	
Moreton	262	278	6	97	271	374
WB - Burnett	368	297	145	180	381	582
Darling Downs	640	164	42	2621	3013	3230
South-West	-	-	-	708	862	3349
Fitzroy	290	176	44	1794	1852	1957
Central-West	-	-	-	-	-	303
Mackay	162	133	7	798	1078	1180
Northern	153	290	279	629	730	752
Far North	1020	861	1217	529	1631	1843
North-West	48	-	44	297	592	648
Total	2944	2200	1785	7653	10410	14217*

* Of this area 8.6 m ha was classified as permanently arable; the balance of 5.6 m ha is the annual arable portion of land involved in crop pasture rotation.

The data in Table 3 involve some duplication as some of the crops represent alternatives that could be grown on the one area. In order to estimate net potential areas the approach used was to allocate such areas to the crop which involved the most intensive land use or was more demanding in terms of water use or fertility. This generally meant allocation to the crop giving the highest return and profitability per unit area. The order was sugarcane, horticultural crops and other high water use crops, maize, grain sorghum and/or wheat and forage sorghum and/or oats. As grain sorghum and wheat are alternative crops in many areas a weighting factor, based on the expected long-term use of the land in particular production areas, was used in estimating the potential areas for these two crops.

The net potential areas for summer crops calculated in this way are shown in Table 4. The net areas shown for the reference crop maize in Table 4 includes the areas suitable for soybeans and peanuts; soybeans have a higher water requirement than maize and peanuts require a friable soil. Grain sorghum and sunflowers are adapted to the same areas.

Table 4. Net potential areas ('000 ha) of reference summer crops for the rural statistical divisions in Queensland. Data from Weston et al. (1)

Statistical Division	Reference crop Maize	Grain sorghum
Moreton	73	3
WB - Burnett	83	111
Darling Downs	365	591
South-West	-	1
Fitzroy	164	1311
Central-West	-	-
Mackay	3	736
Northern	5	316
Far North	669	667
North-West	-	102
Sub-Total	1361	3840

The data of Tables 1-4 clearly indicate the very large potential for increased production of summer crops in Queensland, particularly in the Darling Downs, Fitzroy, Mackay and Far North Divisions. Of a total area of 14.2 m ha with potential for cropping only 2.1 m ha were being cropped at the time of the survey. This left some 12.1 m ha with potential for development, but some of this, particularly in the South-West Division, is only suitable for winter grains. Much of the potential area for summer crops is erosion-prone or subject to physical degradation and protective measures will be needed to stabilize the soil and prevent irreversible loss or damage. A significant proportion of the areas currently being cropped was assessed as requiring a stabilizing pasture phase. However, such areas are presently being permanently cropped because this is the most profitable form of land use and many farmers are ignorant of, or are prepared to accept, the risk of permanent damage to the soil resource.

The clay soils comprise 1.2 m ha of the current cropping area and an additional 6.0 m ha have been assessed as having potential for cropping.

2.2.2 Northern Territory and northern Western Australia

Information on the areas with potential for cropping in the Northern Territory and northern W.A. is limited. According to Nix (2), terrain and soil are the major constraints for the agricultural development of the region. About 1 m ha in the Northern Territory and 0.025 m ha in northern Western Australia were considered suitable for dryland arable agriculture.

Broadscale reconnaissance surveys conducted by the CSIRO showed that the area with the greatest potential for arable cropping in the N.T. was the Daly Basin (3). More detailed mapping at a scale of 1:50,000 has since been made over an area of $21{,}395^2$ km lying within the Daly Basin (K. Day personal communication). The area was surveyed into "land units" within which the landform, soil and vegetation were relatively uniform. A land capability classification along the lines of the USDA Classification was developed for the region (4). Land was classified into eight categories based on the degree to which certain physical factors such as soil depth, rock outcrop, slope and erodibility of the soil limited its use for agricultural purposes. Categories 1 and 2 were considered as arable; Category 3 had more serious limitations but had some potential for cropping if soil conservation measures were implemented. With present conventional land preparation techniques this necessitates the construction of graded contour banks.

A summary of the areas of arable land of each category in the area surveyed in the Daly Basin is given in Table 5. A further area of 5850 km^2 on the western side of the Daly Basin has still to be surveyed, but the available data indicate the limited proportion of good arable land in the N.T. The estimates of arable land have assumed the use of conventional land preparation techniques; present high soil conservation costs involved in developing areas in Category 3, which are mainly sandy red earths, could be reduced if the practices of stubble retention and reduced tillage were adopted.

TABLE 5. Areas of land within the Daly River Basin classified as arable. Data supplied by K. Day (personal communication).

Category	Area (,000 ha)	% of total area
1 - arable with only slight limitations	106	4.9
2 - arable with moderate limitations	9	0.4
3 - arable with definite limitations	84	3.9
Total (Categories 1-3)	199	9.3
Total area surveyed	2139	-

In northern Western Australia surveys by the CSIRO in the Ord-Victoria area (5), North Kimberley (6) and West Kimberley (7) indicated that there was very little potential for dryland cropping. The area has limited potential for irrigation. Areas of 73000, 16500 and 2600 ha are planned for development under the Ord, Dunham River and Camballin irrigation schemes respectively.

Factors affecting production of summer crops

3.1 Climatic factors

A general discussion on the climate of the region is given by Fitzpatrick and Nix (8); more detailed descriptions are given in the reports of the reconnaisance surveys conducted by the CSIRO Division of Land Use Research and various climatological surveys published by the Australian Bureau of Meteorology.

The potential and existing areas of summer crops in northern Australia may be divided into three climatic zones using the Koppen classification system (9). The tropical climates with marked dry seasons in winter (Aw) occupy the northern tip of the Northern Territory, and the Far North and coastal areas of the Northern Divisions in Queensland. The inland part of the Northern Division and the whole of Mackay Division are classified as subtropical climates with moist summers (Cwa). The Fitzroy, Wide Bay-Burnett, Darling Downs and Moreton Division are classified as subtropical climates with uniform rainfall (Cfa), although summer rainfall tends to dominate in the region.

To illustrate the pattern of climate in northern Australia we have selected three type sites, Katherine in the Northern Territory, Emerald in central Queensland and Dalby in S.E. Queensland. Katherine at latitude 14? 28'S is typical of the strongly seasonal summer rainfall tropics. Emerald at latitude 23? 32'S in the Fitzroy Division has a climate typical of the current and projected areas of crop production in central Queensland. Dalby at latitude 27? 11'S is located in the Darling Downs in S.E. Queensland, the area of most intensive crop production in northern Australia. A summary of the mean monthly meteorological data for these three sites is given in Table 6.

In the following sections we offer some comments on the various climatic elements, particularly on aspects of major significance to the growth of summer crops.

3.1.1 Rainfall

The pattern of rainfall changes from one of very strongly seasonal summer rainfall in the northern areas (Aw) to one in which there is an increasing component of winter rainfall in the south (Cfa) (Table 6). Consequently the possibilities for growing winter crops increase as latitude increases. Because of the incidence of rain in the summer there are difficulties with land preparation for summer crops.

A feature of the rainfall is its variability, there being considerable variation between years in the total rainfall and in the pattern of incidence. Generally the variability in rainfall, measured as coefficients of variation of total rainfall, increases as mean rainfall decreases. The limited amount and the pattern of rainfall constitute the main constraints to crop production in northern Australia. These severely restrict the type of dryland crop which can be grown, necessitating the use of crops with growing seasons carefully matched to the expected rainfall and capable of withstanding periods of quite severe intra-seasonal drought. Another problem with the limited rainfall is the reduction in the number of days suitable for planting. Difficulties are often experienced in obtaining good establishment, particularly on larger holdings in central Queensland where crops are sown rapidly into roughly prepared seedbeds to take advantage of moist surface conditions.

Rainfall in the tropics and subtropics is often of high intensity. This can lead to serious erosion, especially if it occurs on an easily erodible soil not carrying a crop or a reasonable quantity of crop residues. Waterlogging can also cause serious problems in summer crops.

The lower rainfall limits for annual cropping are considered to be the 500 mm isohyet in S.E. and Central Queensland, 600 mm in northern Queensland and 700 mm in north-west Queensland, the Northern Territory and northern Western Australia.

3.1.2 Evaporation

Evaporative demand from soils and plants is high throughout the year in northern Australia and particularly in the summer months in central and southern Queensland (Cfa). Mean moisture index (8), which accounts for changing soil moisture storage with rainfall additions and evapotranspiration withdrawals, is over 0.8 in the Aw region of the north and is mostly in the range of 0.4 to 0.6 in the Cfa region of central and southern Queensland. This means that crops in the former areas can generally be grown largely on rainfall received during the period of crop growth, whereas crops in the latter areas are more prone to drought and must rely on soil water received and stored in a fallow period before sowing.

Growing summer crops in areas of high evaporative demand also implies that water use efficiency (the ratio of plant dry matter produced to amount of water evapotranspired) is generally low. Use of C4 plants (sorghum and maize) results in higher efficiency of water use.

Table 6. Mean monthly meteorological data for Katherine, Emerald and Dalby
(data from Commonwealth Meteorological Bureau and S.J. Cook personal communication)
Katherine records 1947-1980, Emerald rainfall 1883-1979, other records 1957-1979, Dalby 1957-1980

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Year
Katherine													
Rainfall (mm)													
Mean	213	223	165	44	5	2	2	1	7	28	50	156	896
Temperature (°C)													
Max	34.7	34.1	34.3	33.9	32.0	30.1	30.1	32.4	35.4	37.8	37.7	36.3	34.1
Min	23.7	23.4	22.4	19.5	16.2	12.8	12.1	14.0	18.4	23.1	24.3	23.9	19.5
Evaporation (mm)	199	146	168	195	197	165	193	232	273	313	277	247	2605
Median daylength (hr & min)	12 53	12 34	12 11	11 47	11 27	11 16	11 21	11 38	12 00	12 26	12 47	12 59	-
Radiation ($MJ\ m^{-2}d^{-1}$)	22.3	21.6	21.3	21.7	19.7	18.9	20.0	22.0	23.1	24.0	24.1	23.8	21.9
Emerald													
Rainfall	107	102	71	34	29	35	27	22	25	39	58	89	638
Temperature (°C)													
Max	33.7	32.8	31.7	29.6	25.7	22.9	22.4	24.7	27.9	31.5	33.7	34.2	29.2
Min	21.3	21.2	19.6	16.1	11.9	8.7	7.1	8.8	11.9	16.2	19.3	20.6	15.2
Evaporation (mm)						- data not available -							
Median daylength (hr & min)	13 25	12 55	12 14	11 34	10 59	10 42	10 49	11 18	11 57	12 38	13 15	13 34	-
Radiation						- data not available -							
Dalby													
Rainfall (mm)													
mean	83	66	73	31	33	41	38	34	42	66	87	102	698
Temperature (°C)													
Max	31.6	31.2	29.5	27.0	22.5	19.6	18.8	20.4	23.7	27.1	30.1	31.5	26.1
Min	18.8	18.4	16.7	12.9	8.2	5.7	4.0	5.4	8.5	12.6	15.7	17.7	12.1
Class A pan* Evaporation (mm)	218	180	191	172	115	77	82	95	132	166	198	231	1857
Median daylength (hr & min)	13 38	13 02	12 16	11 28	10 48	10 27	10 36	11 10	11 55	12 43	13 26	13 49	-
Radiation						- data not available -							

* Data available only for period 1969 to 1977 and some figures missing.

3.1.3 Temperature

Mean summer (November to March) temperatures increase from south to north and range from about 18 to 30?C. Daily maxima in excess of 38?C occur frequently throughout the region during periods of heat waves. Heat waves with low humidity have severe adverse effects on pollination of summer crops, and the planting time of sorghum and sunflower is often adjusted to avoid the critical development phase occurring during the period of frequent heat wave. However, the general growth of summer crops is less affected by high temperatures than that of winter crops. The effect of high temperature is often indirect through the increased evapotranspiration rate leading to rapid depletion of soil water. High temperature also dries the soil surface rapidly and soil temperature can become excessively high. McCown et al. (10) have clearly demonstrated the adverse effect of elevated soil temperatures on emergence and establishment of maize at Katherine.

On the other hand, low temperature also causes some problems in the establishment of summer crops in the Cfa region of southern Queensland. Crops differ in their responses to soil temperature during germination and sorghum requires a higher temperature than sunflower. This restricts the time of planting of sorghum in the region.

3.1.4 Frost

Areas with potential for cropping north of the Tropic of Capricorn are almost frost-free, but in central and southern Queensland frosts constitute a serious hazard to crop production. The risk is greatest with winter crops but summer crops such as soybeans can be affected, especially if sowing is late.

Mean dates for first and last frosts for sites throughout Queensland are given by Foley (11) and more recently for Dalby and Emerald by Hammer and Rosenthal (12). Data are presented for two frost categories: light frosts corresponding to screen temperatures between 0 and 2?C and heavy frosts corresponding to screen temperatures less than 0?C. Heavy frosts could be expected to cause severe damage in susceptible crops. For Emerald the mean dates for first and last light frosts are June 10 and August 17; the mean dates for first and last heavy frosts are July 8 and July 26, but there are some years that experience no heavy frosts. The corresponding dates for Dalby are May 17 and September 12 and June 4 and August 21.

3.1.5 Daylength

The seasonal variation in daylength increases with latitude (Table 6). Many summer crops are quantitative short-day plants, daylength directly affecting flowering and hence the growing season of the crop. This is important with crops such as soybeans and necessitates a careful matching of cultivar, sowing date and sowing rate to ensure adequate vegetative growth before flowering is initiated.

3.1.6 Radiation

Compared to the winter months in southern Australia, radiation levels in the summer months in the north are high and do not impose serious restrictions on the growth of most crop species (8). Radiation levels are high throughout the year, ranging from about 16 to 24 MJ in d , and are generally adequate for plant growth. However, in the more tropical areas subject to the monsoonal influence of the intertropical convergence zone there are periods of up to 10 days during the wet season when conditions are continuously overcast. During these periods, radiation levels can be low enough to affect plant growth and particularly floral development.

3.2 Soil factors 3.2.1 Soil fertility

Much of northern Australia has been subjected to extensive peneplanation, giving rise to a terrain which is generally of low relief with extensive rocky outcrops and shallow skeletal soils. Generally the soils have a low nutrient status, particularly in nitrogen and phosphorus, and their physical structure is often poor so that they set hard and seal on drying. The grey and brown self-mulching clays of the Darling Downs, the Central Highlands and in the Ord, and the areas of krasnozems formed on basalt in eastern Queensland, are of moderate fertility. Many of the areas with potential for cropping in Queensland carried the legume brigalow (Acacia harpophylla) and at the time of clearing the soils had good levels of soil nitrogen.

Data on the changes in soil fertility with cropping in the tropics and subtropics of northern Australia are limited. Dalal (13) reports preliminary estimates of 0.8 to 3.0% for the annual rate of nitrogen depletion on the clay soils of the Darling Downs under continuous cropping. The results of extensive fertilizer trials showed that most sites cropped more than 30 years were clearly nitrogen-deficient.

In long-term studies of land use on a cracking clay brigalow soil at Narayen Research Station (Latitude 25?41'S), Russell (14, 15) found that after ten years of continuous cropping with either wheat or sorghum, total soil nitrogen levels in the surface soil (0-10 cm) declined from about 0.33% to 0.23%, an average annual depletion rate of about 3.3%. Under continuous pasture, levels of soil nitrogen were maintained but inclusion of a cropping phase of 1 or 2 years in a 4-year cycle led to a marked decline. Decline in soil organic nitrogen means that in the absence of applied nitrogen potential crop yields must eventually decline. Changes in soil organic matter and organic carbon were found to parallel closely the changes in soil organic nitrogen on the various crop-pasture treatments. No detailed measurements were made of the effects of these changes on soil structure, but they could be expected to have some deleterious effects, although these are likely to be much less in the clays than on the already poorly-structured red earths and duplex soils used for cropping.

Graham et al. (16) examined the changes in total nitrogen, organic carbon and bulk density on solodized solonetz and solodic soils in Central Queensland following the clearing of brigalow forest and the establishment of pastures or cropping. On these soils, levels of soil nitrogen and organic carbon in the surface soil were low at 0.125% and 1.45% respectively. After ploughing and various periods of cropping they had declined to 0.102% and 1.26% respectively.

3.2.2 Soil erosion

The loss of the natural resource resulting from soil erosion makes this one of the major problems of crop production. Soil erosion is particularly insidious in that it often goes undetected, it is irreversible and it largely involves loss of the surface soil in which there is the greatest concentration of organic matter and plant nutrients. The consequence of soil erosion is an irreversible and often rapid decline in soil fertility and increasing difficulties with land preparation, establishment and crop growth.

Almost without exception, the soils of northern Australia are susceptible to erosion. In the N.T. and Cape York Peninsula, the main soil types with potential for cropping are the red earths with sandy to clay loam surface horizons. These soils lack pedality, and in the absence of ground cover the surface soil structure is readily broken down by raindrop action, causing puddling at the surface, reduced infiltration and increased runoff. The soils with sandy surface horizons are particularly prone to erosion under arable cropping, but serious erosion occurred on both the sandy and clay loams in the land development projects on Tipperary & Willeroo Stations in the Northern Territory (17).

Erosion is also a serious problem on the black earths, krasnozems and cracking clay soils of S.E. and Central Queensland. Run-off studies by Freebairn and Wockner (18) on the clay soils of the Eastern Darling Downs have clearly demonstrated the heavy soil loss that can occur from bare fallow. Their studies showed a linear relation between run-off and surface cover from mulch, but surface cover reduced soil loss proportionately more than run-off. In one storm event of 69 mm, soil loss was negligible on a stubble-mulched bay with 50% ground cover and 20-40 t h on a burnt stubble bay.

Whilst detailed data are limited it is clear that soil erosion poses the gravest risk to continued stable cropping in northern Australia, and its effective control poses one of the greatest challenges to agricultural scientists and soil conservation workers.

3.2.3 Salting

The term "salt-affected soils" refers to soils with defined saline, sodic and alkaline properties. The criteria used in Australia for soil salinity, sodicity and alkalinity respectively are chloride ion expressed as per cent sodium chloride equivalent, exchangeable sodium as a percentage of the total cation exchange capacity and pH of a 1:5 soil:water suspension (19). Soil salinity affects plant growth directly, whereas sodicity affects soil properties such as permeability, surface sealing, tendency to hardsetting and workability; high alkalinity is almost invariably indicative of high sodicity. The levels of soil salinity which affect plant performance vary considerably between crop species and are also affected by the composition of the salts, the moisture regime, nutrient status and mechanical composition of the soil, and the age and rooting habit of the crop.

Northcote and Skene (19) defined three categories for each criterion based on general experience with crops and soils. Of the possible 27 combinations they found that 12 accommodated most of the Australian profiles for which detailed data were available. They also showed a general relationship between these classes and the classes and principal profile forms used in preparing the "Atlas of Australian Soils" (20), and subsequently used these relationships to prepare a tentative map of salt-affected soils. Their map and data have some important implications for agricultural development in northern Australia. The Northern Territory and Cape York Peninsula, both of which are subject to the high leaching conditions of a tropical wet season, are two areas within Australia that are not salt-affected. However, large areas within central and southern Queensland, including the self-mulching cracking clays of the Darling Downs and the Central Highlands, are sodic to strongly sodic.

Salting by dryland seepage occurs following land clearing and a subsequent rise in the level of groundwater. Saline groundwater then causes soil salinization in areas of restricted drainage. In Queensland, 7,900 ha of land is affected by dryland seepage salting, mostly in basalt areas in the 500-1000 mm annual rainfall region (21). This type of salting becomes apparent several years after clearing, and the area of land affected gradually increases; Shaw and Hughes (21) report an average rate of increase of between 5 and 10% per year in the Grantham and Laidley catchment areas of the Lockyer Valley. Saline areas are also susceptible to erosion because of soil exposure to raindrop impact, increased run-off, and reduced structural stability of the soil.

Where surface water is used for irrigation, the level of groundwater rises and irrigation salting may result. This type of salting is relatively unimportant in Queensland because of the general use of underground water rather than surface water. Some problems are being experienced in the Emerald Irrigation Scheme in central Queensland. Use of saline groundwater for irrigation can cause accumulation of salts and may affect plant growth. Examples can be seen in the Bremer and Lockyer catchment areas in S.E. Queensland, where a wide range of vegetables is being grown with groundwater irrigation (22). It is necessary in some cases to restrict production to salt-tolerant crops such as beetroot, cotton and barley.

There seems little doubt that problems of salinity and sodicity will increase as cropping increases in northern Australia.

3.3 Biological problems

The problems of pests, diseases and weeds generally increase with intensification of land use and consequently are much greater with irrigation than with dryland crop production. Under dryland conditions the non-crop periods associated with the dry season in the tropics and the fallow period to conserve moisture in the subtropics are very effective in reducing a build-up of pests and diseases. Similarly the periods of low temperature in the winter in the subtropics, while possibly adversely affecting plant growth to some extent, probably serve a useful purpose by curtailing the build-up of pests and parasites.

Sorghum midge (Contarina sorghicola Coquillet) is probably the worst pest of the sorghum industry in Queensland. Damage by the midge occurs through larvae feeding on the developing seed, and large direct yield losses are observed every year. Growers often use quick-maturing hybrids or sow sorghum very early so that it flowers before a substantial build-up of midge population. These practices often lower the yield potential, and hence the indirect yield loss due to sorghum midge can be considerable.

The problem of weeds is essentially one of plant competition, the growth of weeds being encouraged by the practices of fertilization and cultivation associated with cropping. Fortunately the suite of herbicides that is now available greatly facilitates the control of most weeds in crops but, used regularly, can cause problems with some non-susceptible species. The judicious use of non-residual non-selective contact herbicides such as glyphosate, and the use of selective herbicides with alternating broadleaf and cereal crops, can be effective but can add substantially to the costs of production.

3.4 Social and economic factors

Although difficult to express in quantitative terms, social and economic factors are clearly important constraints to the development of stable and profitable cropping systems in northern Australia. Later we will be demonstrating the inadequacies of current technology and indicating the need to develop new technologies. Clearly, if these are to be widely adopted, the attitudes of many in the farming community will need to change from one of mining and degrading the soil resource to one of conservation and improvement. In the absence of any effective legislation controlling land use, the only hope for ensuring sustained crop production lies in educating farmers to adopt sound practices and in developing community attitudes which make exploitive practices socially unacceptable.

The economic difficulties of the region are associated with its size, low population density and general lack of manufacturing industries. The consequence is that labour costs are high relative to southern

Australia and incentives in the form of subsidized housing, additional allowances and leave and travel expenses are necessary to attract skilled labour. The position has been aggravated in recent years by the development of coal mines throughout the agricultural areas of Queensland and the consequent competition between the agricultural and mining industries for labour.

Most of the physical inputs for agricultural production must be transported into the region and produce must be transported out of the region to markets. Consequently production costs are substantially higher and the returns to the grower lower than for areas in southern Australia close to sources of supply and markets. Southern and central Queensland are well served by roads and rail, but in the N.T. the railway from Adelaide only comes as far north as Alice Springs and the bulk of goods are transported overland by road transport. The effect of freight on the costs of agricultural inputs is illustrated in Table 7, where the costs of both urea and superphosphate at Dalby, Emerald and Katherine are compared with the cost ex works Brisbane.

Table 7. Costs of bulk urea and superphosphate at Dalby, Emerald and Katherine compared with cost ex factory Brisbane. Costs quoted at 1st June, 1982.

	Urea - bulk $/t	Superphosphate - bulk $/t
Brisbane	249	94
Dalby	264	108
Emerald	302	144
Katherine	384	229

Current cropping systems for summer crops in northern Australia

Because of the limited rainfall, cropping in S.E. and Central Queensland is opportunistic and generally restricted to one crop per year. Both summer and winter crops can be grown and the decision on which to grow is generally based on the level of soil moisture of the time of sowing and the expected prices for the various alternative crops. Leslie (23) has reviewed the land preparation practices for winter cereal production in Australia; most of his comments are equally applicable to summer cropping systems.

Cropping intensity has been increased recently, partly because of increased economic pressure and partly improved technology, particularly in the wetter parts of the dryland crop regions in S.E. Queensland. It is still common to grow a particular crop for a few years and then switch to another crop for another few years. Planned rotation including legume crops is rare in the region, although a rotation including chickpea has become popular among SOME growers in recent years. Rotation with other crops is more widely practised with soybean and peanuts. Peanuts return very little organic matter to the soil and soil structure deteriorates under continuous peanut cultivation. Cereal crops are suitable as rotation crops, particularly maize on suitable soils.

To conserve water the land is maintained as a clean fallow during non-crop periods. This necessitates regular cultivation of the soil to kill weeds which would otherwise lose water by transpiration. In the past, crop stubbles were generally burnt or disced into the soil. However, the clear demonstration in experiments conducted by the Queensland Department of Primary Industries that surface stubble greatly reduced run-off and soil loss has led to a general acceptance by farmers of practices which retain the stubble on the surface. Weed control is achieved by using blade ploughs and sweep cultivators which destroy the weeds while retaining the stubble or the surface.

Another advantage of stubble retention is increased soil water content due to reduced run-off. Since yields of most dryland crops in southern and central Queensland are limited by available water, increased stored water at the time of sowing frequently results in higher yield. Some growers think this is the prime reason for stubble retention rather than for the control of erosion.

Contour banks and grassed waterways are also widely used by farmers to reduce erosion. Unfortunately in recent years the resources available to the Soil Conservation Sections in the State Departments of Agriculture to assist farmers with the planning of conservation structures have declined and many new cropping areas are being cropped without the protection of contour banks. It should also be pointed out that current legislation in Queensland gives only limited control over clearing on leasehold areas and no control over clearing on freehold or leases being purchased. There is no legislation requiring landowners to adopt conservation practices or to install conservation structures.

In the tropical regions of Queensland and the Northern Territory, where the rainfall is much more reliable and restricted largely to the period December to March, the land is cultivated following the opening rains of the season. There is little moisture in the soil profile at the end of the dry season and crops are sown when the surface soil has been wetted to 20 to 30 cm. The crop is therefore sown on the expectation of rain rather than on stored water as in central and southern Queensland. Conventional cultivation and sowing practices in the tropics pose a serious threat of erosion and present serious logistical problems in achieving timely sowing of crops. Timeliness in sowing is critical in obtaining high yields, especially with daylength sensitive crops such as soybeans.

The "cropping system" concept and the need for research

The term "cropping system" is used in the title of this paper and has been used in a general sense in the preceding sections. The concept is an important one that has implications for the planning and conduct of crop research and for the application of research results. In this section we define the term and indicate the areas where research is needed in northern Australia.

The word "system" derives from a Greek word meaning an "organized whole" and is defined by the Oxford Dictionary as "a whole composed of parts in orderly arrangement according to some scheme or plan". This definition well describes the essential features of a farming system. It is the mix of physical resources and inputs utilized by a farmer over time and space according to an organized plan with the objective of producing a specified agricultural product(s). It embraces considerations of social, economic, ecological and biological factors and particularly the interaction of these factors. More explicit descriptions and definitions are given by Norman (24) and in a report prepared on farming systems research at the international agricultural research centres (25). The following definitions are largely taken from the latter report. The components of a "farming system" can be viewed as subsystems i.e. social (farmer, family, labour, culture), biological (plants, animals, pests and diseases), technical (tools, machines, inputs), environmental (soil, weather, climate) and managerial (knowledge, skill, economic infrastructure). A feature of the farming system is the organization of these various components and their interactions.

The term "cropping system" can be considered as synonymous with "farming system" if the farming operation involves only crops. If non-crop activities are involved the "cropping system" can be considered as a subsystem of the farming system. As most cropping systems will involve more than one crop it is convenient to use the term "crop system" to describe the components required for the production of a particular crop and the interaction between these components and the environment. If this convention is accepted the "cropping system" becomes the set of crop systems making up the cropping activities of a farming system.

A methodology for farming systems research proposed by CGIAR (25) involves initial analysis of base data followed by on-farm and research station studies. The aim of the base data analysis is to delineate agro-climatic zones, to evaluate resource potentials, and to assess agro-ecosystems from a resource-base and land-use point of view. The analysis is seen as providing the information to permit purposeful planning of the research and on-farm studies.

The basic requirement of a cropping system is that it should maximize profitability on a sustained basis while conserving the resource. A consideration of this objective indicates the type of research required in northern Australia. Recent studies by the Australian Institute of Agricultural Science (26) highlight the ten priority research areas for agricultural development in northern Australia. Some of the recommended areas of research are relevant to cropping systems research, and include (a) development of crops and pasture production systems that maintain soil fertility and prevent soil erosion, (b) development of wider range of crop plants that are adapted to the suite of northern Australian environments, (c) definition of tropical energy crop options and development of crop and processing technology for promising species, and (d) investigations of factors affecting pest populations of animals, birds, insects, diseases and weeds in the tropics.

The requirement to conserve the soil resource requires studies on the processes of physical loss and soil degradation and the development of management practices to avoid these. The management practices may involve the use of appropriate engineering structures, such as contour banks and terraces, as well as appropriate cultural practices such as stubble mulching and strip cropping. Detailed soil studies are required to establish the processes involved in erosion and soil degradation and methods of identifying and dealing with problem soils. The degradation studies will need to cover the reduction of soil fertility and the changes in soil structure associated with regular cropping and the build up of toxic substances such as salt.

The requirement to maximize profitability necessitates the selection of crop species and cultivars and cultural practices that will give maximum crop production under the particular climatic and edaphic conditions of an area. This requires a matching of the growth characteristics, particularly flowering response, of the cultivar to the environment. Under Australian dryland farming conditions this usually involves matching the growing period of the crop with the period during which soil moisture is adequate for plant growth. However, it may also involve considerations of the risk of frost damage, particularly at anthesis, and a consideration of daylength in the case of crops sensitive to photoperiod. As rainfall is generally very variable from year to year, in both total amount and distribution, the matching of growing period of the crop with the growing season according to soil moisture requires an examination of historical rainfall records and the use of some form of water balance model. Probabilities that a growing season will or will not exceed a particular period can then be calculated and an appropriate cultivar selected. In selecting the cultivar it is possible to make allowance for risk; reducing the length of the growing season will reduce the risk of crop failure but will also generally reduce the potential yield.

In addition to the matching of existing cultivars to the environment, research is also required to introduce new crops or to breed new cultivars that are suitable for the environment. It appears there is a large genotypic variation in response to the availability of some microelements in the soil, and hence it is possible to produce cultivars which can grow well under relatively low concentrations of particular elements. On the other hand drought-resistant cultivars are more difficult to breed, probably because many genetic factors contribute to the resistance. Research is needed here to identify morphological and physiological characteristics which are responsible for drought resistance. New crops increase the options available to farmers, spread the risks of both production and marketing and facilitate the development of rotations, which in turn can substantially reduce the problems of insects, disease and weeds. Unfortunately difficulties arise in deciding which of the many potential new crops to concentrate the research effort on and also in deciding how long to continue the research program. A procedure for selecting new crops is given by Wood et al. (27) and some of the problems of research and development are described in Wood (28).

The requirement to maximize profitability also requires research to establish the response function to particular inputs such as fertilizer, herbicides and insecticides to the production system. If the response relating yield to a particular input can be established then the optimum input can be calculated using the costs of inputs and the value of output. The problems of insects are much more complex, strong interactions occurring between pest and beneficial species and particular control chemicals. This necessitates studies to identify the particular species of insects present, their role as pests or beneficials and, in the case of pest species, the relationship between level of infestation and yield of crop product. Subsequently research is required to establish how levels of particular pests, predators or weeds can be kept below levels causing economic damage. Research is also required to ensure that the crop product meets the quality requirements of the market.

Conclusions and recommendations

The greatest potential for crop production in northern Australia lies in Queensland, where some 14 m ha have been assessed as suitable for cropping. This represents a 6-fold increase of the current cropped area, and at the average rate of increase of the past 25 years development will take about 50 years. In both Queensland and the Northern Territory soil erosion and soil degradation pose the most serious problems for sustained profitable crop production. We consider these problems to be soluble by research but recommend changes in the approach to research planning and in the scope of research programs.

We see an urgent need to adopt the systems approach discussed in Section 5 when planning research programs on cropping systems. In particular we stress the need to consider economics, marketing and particularly the role of farmers in the farming system. Too often the fact that the success of a new agricultural technology depends on its acceptance and adoption by farmers is overlooked. If it fails to win acceptance among farmers the innovation will fail irrespective of the excellence of the research.

We see the needs for research as falling into two categories. The first is conservation research aimed at maintaining or improving the soil resource. The second is agronomic research aimed at matching crop, soil, environment and management to maximize profitability. Because of the risk of irreparable damage arising from the mismanagement of the soil we see conservation research, along the lines discussed in Section 5, as having the highest priority. We also set a high priority on studies by social scientists aimed at gaining general acceptance by the farming community of practices to conserve the soil. Education is seen as likely to achieve more effective results than legislation aimed at forcing farmers to adopt conservation practices.

We see an urgent need for a detailed appraisal of the problems of developing sustainable and profitable farming systems in Queensland and the preparation of a coordinated long-term plan for research and development. Such a plan would provide a framework within which the activities of CSIRO, the Queensland Department of Primary Industries and possibly some of the tertiary institutions could be planned and coordinated. We find it ironic that a coordinated plan for the storage and transport of grain from Queensland over the next 50 years has been prepared by consultants and is presently being widely considered by farmers in the grain industry. In contrast there is no coordinated plan for the necessary research that will ensure that the grain that is to be transported and stored will be produced. Some estimates suggest that the productive life of some cropping areas in Queensland will be much less than 50 years if current practices are continued.

We see a number of serious omissions in current research programs. The following suggestions are not meant to be exhaustive but merely to illustrate some of the omissions and some of the possibilities for a farming system research program.

The survey of the Queensland Department of Primary Industries has shown that much of the area in Queensland with potential for arable cropping is prone to erosion or physical degradation. More detailed surveys are required to identify and map these soils for the guidance of farmers, researchers and extension officers. In addition, detailed soil studies are required to identify clearly the soil characteristics that make soils prone to erosion, and to establish criteria which permit quantitative assessments of erosivity. Basic soil studies are also required to determine the processes that lead to changes in soil structure, organic matter content, infiltration, workability and nutrient availability when land is cleared and cropped. These basic studies need to be complemented with agronomic studies that examine the effect of different cropping practices on these processes.

More detailed analyses of climatic and soil data are required to establish the pattern and duration of periods when soil water conditions are suitable for crop growth. This information can then be used to select appropriate genotypes and plan cropping strategies.

Minimum tillage is now an established and proven technique in many countries. In northern Australia the technique has the potential for reducing both costs of production and erosion, two of the major problems of cropping in this region. Consequently a much greater effort to develop minimum tillage equipment for the region is warranted. In developing the equipment particular attention is required to overcome the problems of establishment that occur so often with current practices.

The proven superiority of intercropping over sole cropping, both in absolute yields and in stability of yields from season to season (29), indicates the need for much more research effort to determine whether the practice can be incorporated into the highly mechanized system of crop production practised in northern Australia. Economic studies and surveys of farmers and graziers are also required to establish the relative research effort that should be directed towards cattle/crop farming systems and crops-only farming systems.

References

1. Weston, E.J., Harbison, J., Leslie, J.K., Rosenthal, K.M., and Mayer, R.J. 1981. Agric. Branch Rep. No. 27. Queensl. Dep. Primary Ind. : Brisbane.

2. Nix, H.A. 1978. Conference on Alcohol Fuels. Sydney, Aust. Aug. 9-11.

3. Speck, N.H., Wright, R.L., Van de Graaf, R.H.M., Fitzpatrick, E.A., Mabbutt, J.A., and Stewart, G.A. 1965. CSIRO Aust. Land Res. Series No. 13.

4. Aldrick, J.M., and Robinson, C.S. 1972. Dept. of the Interior. Land Conservation Series No. 1.

5. Stewart, G.A., Perry, R.A., Paterson, S.J., Traves, D.M., Slatyer, R.O., Dunn, P.R., Jones, P.J., and Sleeman, J.R. 1970. CSIRO Aust. Land Res. Series No. 28.

6. Speck, N.H., Bradley, Janice, Lazarides, M., Paterson, R.A., Slatyer, R.O., Stewart, G.A., and Twidale, C.R. 1960. CSIRO Aust. Land Res. Series No. 4.

7. Speck, N.H., Wright, R.L., Rutherford, G.K., Fitzgerald, K., Thomas, F., Arnold, Jennifer M., Basinski, J.J., Fitzpatrick, E.A., Lazarides, M., and Perry, R.A. 1964. CSIRO Aust. Land Res. Series No. 9.

8. Fitzpatrick, E.A., and Nix, H.A. 1970. "Australian Grasslands" Ed. R.M. Moore. ANU Press. 3-26.

9. Commonwealth of Australia. 1973. Atlas of Australian Resources. Second Series. Climate. Division of National Mapping, Canberra.

10. McCown, R.L., Jones, R.K., and Peake, D.C.I. 1981. CSIRO Div. Tropical Crops & Pastures Div. Rep. 1980-81. 131-134.

11. Foley, J.C. 1945. Commonw. Meteorol. Bur. Bull. No. 32.

12. Hammer, G.L., and Rosenthal, K.M. 1978. Queensl. Agric. J. 104 : 177-201.

13. Dalal, R.C. 1980. Queensl. Wheat Res. Inst. Bienn. Rep. 1978-80. p. 53.

14. Russell, J.S. 1980. Proc. Aust. Agron. Conf. Lawes. 15-29. -100-

15. Russell, J.S. 1981. "Simulation of nitrogen behaviour of soil-plant systems" Ed. M.J. Frissel and J.A. van Neen Pudoc, Centre for Agricultural Publishing and Documentation, Wageningen. 222-232.

16. Graham, T.W.G., Webb, A.A., and Waring, S.A. 1981. Aust. J. Exper. Agric. & Anim. Husb. 21 : 109-118.

17. Fisher, M.J., Garside, A.L., Skerman, P.J., Chapman, A.L., Strickland, R.W., Myers, R.J.K., Wood, I.M.W., Beech, D.F., and Henzell, E.F. 1978. "Cropping in North Australia: Anatomy of Success and Failure" Ed. F.H. Bauer. Aust. Nat. Univ. Canberra. 35-82.

18. Freebairn, D.M., and Wockner, G.H. 1980. Proc. Aust. Agron. Conf. Lawes. p. 214.

19. Northcote, K.H., and Skene, J.K.M. 1972. CSIRO Aust. Soils Publ. No. 27.

20. Northcote, K.H., Beckman, G.G., Bettenay, E., Churchward, H.M., Van Dijk, D.C., Dimmock, G.M., Hubble, G.D., Isbell, R.F., McArthur, W.M., Murtha, G.G., Nicolls, K.D., Paton, T.R., Thompson, C.H., Webb, A.A., and Wright, M.J. 1960-68. Atlas of Australian Soils. CSIRO (Aust.) and Melbourne University Press : Melbourne.

21. Shaw, R.J., and Hughes, K.K. 1981. Paper presented at the 51st ANZAAS Congress, Brisbane, May 1981, Section 13 - Agric. and For.

22. Johnson, P.J.M., and Stephens, R.M. 1980. Proc. Aust. Agr. Conf. Lawes. p. 200.

23. Leslie, J.K. 1974. Proc. 2nd Regional Wheat Workshop, Ankara, Turkey, May 6-11.

24. Norman, M.J.T. 1979. Annual cropping systems in the tropics. Gainesville. A University of Florida Book.

25. CGIAR (Consultative Group in International Agricultural Research). 1978. Farming systems research at the International Agricultural Research Centers. I. Analysis by the TAC Review Team of Farming Systems Research at CIAT, IITA, ICRISAT and IRRI.

26. The Australian Institute of Agricultural Science. 1979. Potential Contribution of Research to Agricultural Development in Northern Australia.

27. Wood, I.M., Angus, J.F., and Wilson, A.G.L. 1974. CSIRO Aust. Div. Land Use Res. Tech. Pap. No. 35.

28. Wood, I.M. 1982. Aust. Agron. Conf. July 11-14, Wagga Wagga. 29.

29. ICRISAT (International Crops Research Institute for the Semi-Arid Tropics). 1981. Annual Report 1979-80. Pattancheru, A.P. India. ICRISAT.