Farming systems in the Australian semi-arid tropics — a recent history

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Summary. The recent history of dryland farming in the Australian semi-arid tropics is discussed briefly against the background of national and state policies, established following World War II, aimed at increasing the population and development of northern Australia. Some reference is also made to irrigation as a means of overcoming limitations imposed by rainfall and to complement dryland farming systems.

The environmental and socio-economic constraints which have so far limited commercial agriculture in the Australian semi-arid tropics are highlighted. Efforts, particularly in north-west Australia, to develop sustainable farming systems based on legume pasture leys and livestock production in conjunction with annual cropping, as a basis for closer settlement, are reviewed. These attempts, which began in the 1960s and stemmed from earlier post-war agricultural research in the region, initially relied on a pasture legume (*Stylosanthes humilis* cv. Townsville stylo) and conventional tillage. Farming system development continues today using new legume species (e.g. *Stylosanthes hamata* cv. Verano and *Centrosema pascuorum* cv. Cavalcade) and no-tillage cropping technology.

This paper documents the history of agricultural and research development, and commercial practice in the Australian semi-arid tropics.

Introduction

Other than the narrow strip along the east coast, the climate of tropical Australia is semi-arid to arid. The semi-arid tropics have 2–7 humid months when rainfall exceeds potential evaporation, and climates resemble those of the major monsoonal regions of the world (Troll 1965; Monteith and Virmani 1990). In Australia, the boundary between arid and semi-arid tropical climates was taken by Henzell (1980) to be the 750 mm mean annual rainfall isohyet (Fig. 1). However, this boundary, which is really a zone of transition, is an artifice of convenience. The semi-arid tropics include 50 countries and are home to more than 600 million people (60% in India; Monteith and Virmani 1990), but in Australia the population in the semi-arid tropics numbers only a few hundred thousand.

Rainfall in the semi-arid tropics is highly seasonal and quite variable in time and space (e.g. Williams *et al.* 1985; Mollah 1986; Monteith and Virmani 1990; Mollah *et al.* 1991). In the Australian semi-arid tropics, ≥75% of the rain falls in the 'summer' (December–March) or 'wet season', which is hot and humid. The 'winter' or 'dry season' is warm to hot and usually dry. Average annual rainfall (which is less useful than seasonal rainfall) ranges from 1540 and 1650 mm at Darwin (12°26'S, 130°52'E, elevation 29 m) and Weipa (12°41'S, 141°58'E, elevation 18 m), respectively, to 800 mm at Kununurra (15°39'S, 128°42'E, elevation 46 m), 950 mm at Katherine (14°28'S, 132°16'E, elevation 107 m) and 800 mm at Mt Surprise (18°09'S, 144°19'E, elevation 453 m) (Anon. 1977).

Much of the Australian semi-arid tropics is classed as tropical savanna. This term refers to a vegetation type characterised by a largely perennial, grass-dominant ground stratum with a variable overstorey of trees, usually eucalypts, in which alternating wet and dry seasons determine annual growth patterns (Bourliere and Hadley 1983; Tothill and Mott 1985). The apparent reliability of the wet season with its seemingly prolific growth has often been promoted as a major asset and has predisposed agricultural developers towards cropping.

About 1 million hectares of land in the north-west of Australia are considered to be suitable for dryland agriculture, with the largest area of potentially arable soils (about 200 000 ha) being in the Daly Basin of the Northern Territory (Williams *et al.* 1985). A large area

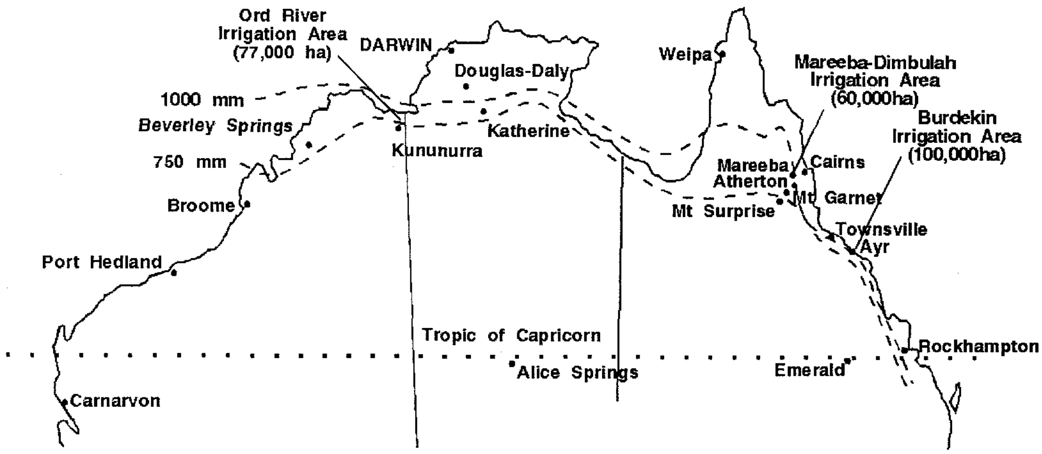

Figure 1. Locality map.

(425 000 ha) of potentially arable land has also been identified in North Queensland between 15°S and 18°S (Weston *et al.* 1981).

Attempts to develop arable farming in the Australian semi-arid tropics have, with a few notable exceptions (e.g. on the Atherton Tableland and Central Highlands in Queensland), been unsuccessful (e.g. Tipperary and Willeroo in the Northern Territory; Bauer 1977; Muchow 1985).

The economic viability of farming in the short term and its sustainability in the long term depends on production systems that minimise or avoid adverse impacts on the resource base, maintain or enhance productivity over time, maximise net social benefits, and are sufficiently flexible to cope with climatic and market risks (Anon. 1991). Nowhere else in Australia has it proved more difficult to devise such agricultural systems that are flexible enough to accommodate climate and market fluctuations. The history of developments in farming systems in this region is the subject of this paper.

The objectives of this paper are to: (i) highlight the constraints which have limited the development of farming systems in the semi-arid tropics; (ii) briefly describe the events originating from the end of World War II that revived national interest in agricultural development in northern Australia; and (iii) briefly review the literature concerning agricultural development in the semi-arid tropics, especially since 1980 when interest in ley farming was stimulated by government support for more intensive agriculture in the Northern Territory.

Constraints on farming systems in the Australian semi-arid tropics

Factors which have constrained the development of more intensive dryland farming systems in semi-arid tropical Australia have been well documented (e.g. Prescott 1938*a,* 1938*b*; Bauer 1964, 1977; Mollah 1980; Muchow 1985; Anon. 1993*a*). These factors are environmental and socio-economic.

Most of the potentially arable soils (the majority of which are massive sesquioxidic) are relatively infertile especially with regard to nitrogen and phosphorus, and they typically form strong surface seals during wetting and drying cycles after tillage, have a low capacity to hold water, and are highly erodible (Williams *et al.* 1985).

Rainfall is variable and often of high intensity, leading to rapid runoff, low soil water recharge and low efficiency of rainfall utilisation by plants; coefficient of variation for rainfall at Katherine is 24% on a whole-season basis but ranges from 47 to 135% on a fortnightly basis during December–March (Williams *et al.* 1985; Mollah 1986; Mollah *et al.* 1991). The higher rainfall intensity in the north-west than in the south-east is evident from Table 1.

High solar radiation, resulting in high (40–60°C) bare soil surface and seed bed temperature (in clay loams and loamy sands), impairs crop establishment (Williams *et al.* 1985; Bristow and Abrecht 1989, 1991; Abrecht and Bristow 1990). There is little cloud cover during the day and most of the rain falls in the late afternoon and at night (Chapman and Kininmonth 1972).

In areas with no previous history of cultivation, pest and disease incidence during the growing season is often unknown, but may be high (insect pests were the major cause of the collapse of the cotton industry in the Ord River Irrigation Area in the early 1970s). These constraints are less important in dryland systems and where integrated pest management is adopted (Allwood *et al.* 1985).

Adding to these environmental constraints on farming success are limitations imposed by socio-economic

Table 1. Rainfall intensity (mm/h to nearest 5 mm) for 6-min and 1-h durations and average return intervals (ARI) of 2 and 50 years for selected locations in north-western and south-eastern Australia

Data from Canterford (1987)

Station	6-min duration		1-h duration	
	ARI 2	ARI 50	ARI 2	ARI 50
Darwin	180	310	60	105
Kununurra	135	280	50	100
Katherine	130	255	45	85
Emerald	125	240	45	80
Dalby	105	210	35	65
Moree	90	200	30	65

factors. Poorly developed communications and agricultural transport infrastructure are exacerbated by distance from the main centres of population. The local population, although expanding, is small and dispersed, leading to a dependence on external markets.

The financial structure of enterprises has been poor, with emphasis on quick returns (rather than long-term development), which is typical of poorly managed, speculative ventures (both private and government) (e.g. Fisher *et al.* 1977; Gunn 1977). The pioneering industries have also been small.

There was no local traditional agriculture, the knowledge base was limited, the workforce poorly skilled and agribusiness support services were inadequate. Most economic activity has been dependent on exploitation of natural resources (Anon. 1993*a*).

Fluctuating political support for northern development, poor social facilities (e.g. schools, hospital facilities), and the hot climate have also restricted the expansion of agriculture in the region.

Farming system development in the semi-arid tropics pre-1980

The agricultural achievements in northern Australia, pre-World War II, have been chronicled by Bauer (1959*a*, 1959*b*, 1964, 1985), Mollah (1982*a*), and by others in Bauer (1977). Early settlers lacked knowledge of the cultivation of tropical crops, and were pitted against a climate characterised by high temperatures, with high human heat stress (Kalma and Auliciems 1979; MacFarlane 1981).

Australia's attitude to its tropical regions was changed profoundly by World War II. In 1945, the Commonwealth government set up, in conjunction with the states of Western Australia and Queensland, the Northern Australian Development Committee (NADC) chaired by Dr H. C. Coombs. The purpose was to examine and initiate proposals to be financed entirely by the individual states or jointly with the Commonwealth government in order to: (i) increase the population and value of production, (ii) ensure the best utilisation of land and other resources, and (iii) improve the welfare and development of native inhabitants of the area (Bauer 1977).

At the request of NADC, CSIRO (CSIR, as it was until 1949) undertook a series of scientific inventories of the land resources of northern Australia, including their agricultural potential. These reconnaisance surveys began in the Katherine–Darwin region of the Northern Territory (Christian and Stewart 1953). They led to the Land System–Land Unit approach to land classification and had a major influence on site evaluation and selection for agricultural development in the Australian semi-arid tropics and on land mapping elsewhere. The CSIRO view of land as the integration of soil, vegetation, topography and climate, gave rise to the 'habitat–site' concept developed by Moss (1968, 1978) for land evaluation and rural land use planning in tropical Africa, and also underpins much of what are today called agro-ecosystems.

Agricultural research stations remote from, although linked to, the main centres of agricultural science were established by State and Federal governments. The adoption of a more scientific and co-ordinated approach, although in itself no guarantee of success, was thought by policy-makers to provide a sounder basis for future exploitation of tropical Australian resources than the largely trial and error efforts before World War II.

Accounts of the success or otherwise of the post-war phase of agricultural research and development in northern Australia can be found in Bauer (1977), Mollah (1980, 1982*b*), Basinski *et al.* (1985), Eyles *et al.* (1985), Muchow (1985), Anon. (1993*a*, 1993*b*, 1993*c*, 1993*d*, 1994) and Taylor (1994). The emphasis on crop research and production, evident in 9 of these 12 publications, reflects the continuing belief of policy-makers since World War II that cropping is more likely to provide a basis for closer settlement and development of the Australian tropics than are low-input pastoral industries. However, there is also a strong belief in the desirability of more intensive beef production from improved pastures (Winter *et al.* 1985).

The nature of the northern challenge has been described by Prescott (1938*a*, 1938*b*), Forster *et al.* (1961), Bauer (1964), Davidson (1965), various authors in Anon. (1981) and Jull and Roberts (1991). It is clear that socio-economic factors added significantly to technical difficulties as causes of failure at closer settlement in the past.

Dryland farming systems

Extensive livestock production

The most common form of land use in the semi-arid tropics is the extensive grazing of livestock (mainly cattle) on native pastures. This system, which has managed to cope with the environmental and socio-economic constraints, is most robust when based on the exploitation of native perennial grasses. That animals can be grown to maturity over a number of years, despite a loss in liveweight each dry season, with extremely low capital investment and management costs has made livestock production practicable in the semi-arid tropics. Animals and animal products account for three-quarters of the gross value of agricultural production in the Northern Territory and about one-third in each of northern Western Australia and tropical Queensland (Anon. 1993*a*).

While this system of extensive animal production is widespread in the Australian semi-arid (and arid) tropics, and has persisted for 100 years or so, its profitability has often been marginal on the poorer pastures in the wetter, northern parts of the semi-arid zone. The sustainability of this system is now being questioned, given the increased capital expenditure required for stricter animal disease control, the alleged degradation of the native pastures as a consequence of inadequate animal control, the need to turn off animals of marketable weight sooner than in the past (which requires the provision of better feed during the dry season), and dependence on a single product (e.g. Mott and Edwards 1992).

In the semi-arid tropics of Queensland, dryland farming systems which include pasture improvement (although not legume leys), cropping, and more intensive management and capital investment are well established in the Central Highlands of the Capricornia region (20–25°S, 146–151°E, elevation 150–600 m) and on the Atherton Tableland (about 16–19°S, 144–146°E, elevation 350–1100 m). Attempts to develop dryland cropping in conjunction with cattle raising are also being made in other parts of the semi-arid tropics, most persistently in the Katherine–Darwin region of the Northern Territory, but also in similar areas in northern Queensland and in the North Kimberley region of Western Australia.

Commercial dryland grain and other crops

Katherine–Darwin region. Since the granting of self-government in 1978, the Northern Territory has sought to expand its economic base in various ways, one of which is through more intensive agricultural development. In 1979, the Northern Territory government commissioned D. P. Lapidge, Queensland Department of Primary Industries (QDPI), to review the factors limiting the production and marketing of agricultural and horticultural crops in the Northern Territory, and to make recommendations for future increased production. Lapidge did not, however, specifically examine the commercial desirability of integrating dryland cropping with more intensive cattle production. Subsequent to the release of the Lapidge Reports in 1979 (and soon after research into a new ley farming system had begun, see below), the Northern Territory government established the Agricultural Development and Marketing Authority (ADMA) (Cameron and Hooper 1985) to: (i) develop a number of 'family-sized' farms as demonstration units, (ii) provide grain storage facilities and marketing services, and (iii) develop a horticultural industry.

Virgin land was acquired in the Douglas–Daly district (about half-way between Katherine and Darwin) (Fig. 1), cleared, and allocated in blocks of 4000–6000 ha to 6 farmers for the growing of cereal and other annual crops. The block size was designed to ensure that each farmer had sufficient arable land for commercial operations. Evidence of farming experience and access to substantial equity capital were essential prerequisites in the selection of farmers. These farmers were to constitute the first, and proving, stage of a much larger dryland farming project, once estimated to cost about $A60 million. The development project, known as the ADMA Scheme, commenced in 1980 and its impetus was political rather than commercial. Contingent on the results of the first stage, a second, 10-year phase of farm development was envisaged, but this never eventuated. Instead, the initial 5-year proving stage was later extended with a limit of 10 years. The ADMA Scheme operated throughout the 1980s with the government bearing all development costs and the farmers the annual operating costs. Non-ADMA farmers in the Katherine–Darwin region were also able to take advantage of the grain storage facilities, marketing and financial services provided by the scheme.

Notwithstanding the potential advantage to be gained by including livestock in intensive farming systems as a means of spreading climatic and other risk (a point recognised by those involved in the earlier failures of large-scale cropping at Tipperary and Willeroo in the 1960s and 1970s), emphasis in the ADMA Scheme was on the production of crops such as sorghum, maize, peanut, soybean, mungbean and sesame. However, it soon became apparent that the introduction of cattle into the system (i.e. diversification of income) was essential if the farmers were to stay in business. It had been agreed that cattle should be excluded initially (during the first 1–2 years), on the grounds that the farmers developing land and farm infrastructure for cropping would have more than enough to handle without the additional work that livestock would entail, but the ADMA administrators continued to exclude cattle from the project farms for as long as they remained in control.

The ADMA Scheme was a pilot experiment (Cameron and Hooper 1985). As with the earlier large-scale cropping schemes at Tipperary and Willeroo, farmers were wholly dependent on cropping for their income and were obliged to scale up cropping operations in line with capitalisation, which ultimately proved futile. While the crop yields obtained were often satisfactory, the ADMA experience confirmed the unreliability of crop establishment under conventional cultivation. From the beginning, the project farms were closely monitored and much information on farm development costs and operation, crop establishment and yield, soil fertility and soil erosion was gained. Some of this information is reported by other authors in this issue and in Sturtz and Chapman (1996).

Tropical Queensland. The Capricornia region of Queensland, where dryland cropping has been long-established, is also one of the most rapidly developing areas of Australia. Within the Central Highlands, the area being cropped increased from 250 000 ha in 1982–83 to 512 000 ha in 1986–87 and further increases have occurred since (Sallaway *et al.* 1988). The soils most favoured for cropping are cracking clays (Vertisols) but other soil types, including non-cracking clays, structured earths, duplex soils, and shallow sands and loams, are also used. The dominant agricultural enterprises, excluding irrigated cotton, are based on beef and grain production. However, little integration of these activities has occurred (Garside 1993). Major limitations to dryland agriculture in this region are rainfall variability, as exemplified by the recent (1992–95) drought, and the rapid decline in soil fertility (a 50% reduction in total soil nitrogen after 10–15 years of cultivation; Cowie 1993).

The dominant dryland crops are grain sorghum, wheat and sunflower. There are some areas of chickpea, barley, mungbean, cotton and various forages (Hamilton and Lobegeiger 1984; D. Blackett pers. comm.). As cropping is largely opportunistic, no particular crop rotation is followed. Reduced tillage and no-tillage have become more common in recent years, while controlled traffic is an innovation also stimulating some interest (Yule 1993). The increased soil water retention, decreased soil erosion and higher yields which result are the major reasons for the changes in farming practice. Restoration and maintenance of soil fertility in these cropping areas depends on nutrient return, especially of nitrogen, to the system. Fertiliser application and the use of rotations which incorporate pasture or grain legumes are important options (Cowie 1993), although the lack of suitable pasture species makes the introduction of a legume ley difficult to achieve (Lloyd *et al.* 1993).

Although not directly comparable with the northern Australian semi-arid tropics, successful agricultural development in the Capricornia region of Queensland illustrates the importance of proximity to large urban centres and the existence of suitable infrastructure (both a consequence of the expansion of the coal mining industry and of the agricultural areas to the south).

In Far North Queensland, dryland cropping has long been successful on the basaltic soils around Atherton and Tolga on the Atherton Tableland and, more recently, in the Lakeland district about 150 km north of Mareeba (see Fisher *et al.* 1977 for a brief account of an earlier attempt to combine grain cropping with beef production at Lakeland Downs during 1968–74). Crops include peanut, maize, pasture seed, potato, heavy vegetables and other horticultural crops.

At various times over the past 35 years, land on the fringes of the Atherton Tableland has been cleared for attempts at dryland cropping. In 1949, summer crops were grown on black soils at Wrotham Park, 150 km north-west of Mareeba to provide feed for beef cattle (Compton 1967). The potential for cropping was confirmed but many difficulties were encountered.

Recently, following the assessment of the agricultural and pastoral potential of land in Queensland by Weston *et al.* (1981), field studies have centred on some 166 000 ha of red earth soils south-west of the Atherton Tableland (Grundy and Bryde 1989). This work started in the early 1980s, when grain sorghum cropping was expanded into the drier margins of the Atherton Tableland following a loss of confidence in the cattle industry. Cropping practices and success frequency varied greatly, and soil erosion was widespread (Bateman and Wade 1986; East 1989). Aware of the no-tillage, ley farming studies being conducted by CSIRO and the Department of Primary Industry and Fisheries (DPIF) in the Northern Territory, and in anticipation of the further expansion of dryland cropping south-west of the Atherton Tableland, QDPI researchers set out to test conservation tillage practices, including a no-tillage, legume ley system, under their conditions but with the primary objective of managing the soils in order to minimise erosion. The results indicate that, using conservation farming practices, crop yields, although sometimes reasonable, are very susceptible to highly variable rainfall. There is also the danger of land degradation due to erosion and declining soil carbon and nitrogen levels (Cogle *et al.* 1991, 1995).

More recent studies using crop growth models have shown that in the region south-west of the Atherton Tableland, maize and sorghum cropping are less reliable than on the Tableland itself or in areas to the north. Grain yield from maize or sorghum was estimated to equal or exceed the economic threshold of 3 t/ha in 70% of the years at Walkamin (elevation 591 m, 15 km south of Mareeba), 50% of years at Mareeba (elevation 396 m) but in only 30% of years at Mt Garnet (elevation 670 m, 135 km south-west of Mareeba) (Carberry *et al.* 1992). Farming system simulation studies by CSIRO–QDPI Agricultural Production Systems Unit and QDPI Resource Management Group have shown that at Mt Surprise (elevation 453 m, 290 km south-west of Mareeba), dryland maize, on the red earth soils typical of the area, would be expected to fail in most years. Thus, the prospects for successful dryland cropping on the red earth soils south-west of the Atherton Tableland seem to be poor. Rainfall is lower and more variable in this region than at Katherine in the Northern Territory, although the higher elevation, compared with Katherine, provides a more favourable environment for crop establishment (Carberry *et al.* 1992).

Kimberley region. In the North Kimberley, the constraints to dryland cropping are similar to those in other parts of the north-western semi-arid tropics. Cereals, grain legumes and other crops have been sown at Beverley Springs (16°43'S, 125°16'E, elevation 385 m) each year for more than a decade. The results have been variable but the attempts continue (Barrett 1996). Some pastoralists occasionally sow a wet season crop for hay (Anon. 1993*b*).

Alternative cropping strategies

Most attempts to develop more intensive dryland farming systems in the semi-arid tropics have been based on cereal and other annual grain crops. However, it has been postulated that an annual species such as kenaf (*Hibiscus cannabinus*), in which the stem (a source of fibre for paper pulp) rather than the reproductive organs constitutes the economic yield, may have advantages as a dryland crop over cereals or other grains, at least in the wetter, northern semi-arid tropics (Kirschbaum 1991). The results of a crop simulation study (Carberry and Muchow 1992; Carberry *et al.* 1993) in which kenaf was sown at the beginning of the wet season after 30 mm of rain in any 5-day period after 1 November and harvested 2 weeks after flowering, show that in 50% of years stem yield is likely to be about 8 t/ha at Katherine (range 1–17 t/ha) and 12 t/ha at Douglas–Daly (range 4–19 t/ha). Sowing strategy had little effect on cumulative yield probability at any of 4 sites. Irrigated kenaf yielded 40–70% more than dryland kenaf in the same region (Muchow *et al.* 1990), indicating the deleterious effect of intra-seasonal water shortage on kenaf growth, and that variability in the supply of raw material to a processor is likely. The kenaf model with its predictive capability provides a good basis for evaluating the prospects for commercial production. So far, however, the commercial viability of dryland kenaf in the semi-arid tropics, compared with cereals and other grain crops, remains untested and unproven.

Other crops that are less vulnerable to drought than those grown primarily for their seeds or fruits, are forages (sown annually or self-regenerating), including perennial browse shrub legumes, which can be produced either for hay or grazing. These may also be important for developing more intensive dryland farming systems for the semi-arid tropics. At present, however, forage crops are utilised only to a small extent.

Integration of crops and livestock

The development of mixed farming systems that include crops, pastures and livestock has probably been an unstated goal in the semi-arid tropics ever since the early failures with 'plantation' crops such as sugarcane, rubber, cinchona and cotton in the Northern Territory (Prescott 1938*b*; Bauer 1964); and the early attempts at dryland cropping in the Kimberley (Millington 1977), the Central Highlands, Central West and North-West regions of Queensland (Skerman 1977), beginning late last century.

Ley farming systems and the integration of annual crops and livestock have a history in the Katherine–Darwin region going back some 30 years. Work conducted at Katherine Research Station in the 1940s and 1950s led to the recognition and subsequent promotion of Townsville stylo (*Stylosanthes humilis*) as a pasture legume for cattle (Norman 1966). Stylo's potential value as a source of biologically fixed nitrogen when grown in rotation with grain sorghum on the red earth soils of the Katherine–Daly Basin and with rice on floodplain soils along the upper Adelaide river (about 100 km south of Darwin), was demonstrated by researchers in the Agriculture Branch of the former Northern Territory Adminstration during the early 1960s (Nemestothy 1970; Doughton 1974). The results were quickly applied by the operators of the Northmeat Abattoir on their property at Katherine. During the second half of the 1960s, Northmeat confirmed that Townsville stylo was a valuable forage for cattle and found that sorghum grown on land that had been under stylo for a few years yielded 50% more than sorghum grown on virgin soil. Sorghum grain and stover were fed to cattle. The legume pasture regenerated from hard seed and stylo plants that grew as an intercrop with the grain sorghum (Dempsey 1969). Northmeat's achievement in combining cattle with cropping is all the more notable because it was done using traditional tillage and sowing practices. In the mid 1960s, a rice–Townsville stylo ley farming system was to be tested on a commercial pilot farm established by the Northern Territory Administration on the upper Adelaide River, but the idea was later abandoned. By the mid 1970s, it was estimated that about 117 000 ha in the Northern Territory had been sown with Townsville stylo (Eyles *et al.* 1985). In the 1960s and early 1970s, estimates of the area ultimately suitable for Townsville stylo ranged from 40–113 million hectares (Staples 1981).

Further exploitation of Townsville stylo either in pure grazing or mixed farming enterprises ceased in the mid 1970s. Beef cattle prices fell, fertiliser (superphosphate) costs increased, and the productivity of Townsville stylo declined due to its susceptibility to anthracnose disease and to invasion of pastures by weeds (Winter *et al.* 1985). However, large areas of Townsville stylo persisted and formed an important pasture resource on many properties in northern Australia throughout the 1970s (Staples 1981). Townsville stylo failed to live up to the commercial expectations of agricultural scientists because of the reasons above and also because of the added infrastructure costs (fencing, water supply and construction of firebreaks) and the difficulty of maintaining relatively pure swards of the legume by controlled grazing during the wet season. At the time, the introduction and use of Townsville stylo required a revolution in the rangeland cattle industry rather than an incremental change in traditional practices (Mollah 1987).

The fall in cattle prices in the mid 1970s highlighted the need for income diversification by graziers in northern Australia (Henzell 1977). In 1978, the CSIRO Division of Tropical Crops and Pastures embarked on a research project at Katherine 'to devise and test a system of agriculture that features the integration of annual grain cropping and extensive beef cattle grazing' incorporating new agricultural technologies developed since the 1960s and early 1970s (McCown and Jones 1980). The project, described by McCown *et al.* (1985), also took into account the work of Lal and co-workers in Nigeria (Lal 1985) which showed that, in a tropical climate, crop establishment and growth can be improved by maintaining a mulch cover on the soil surface. Benefits included the amelioration of problems arising from high soil temperature, rapid drying and soil crusting, and there was less soil loss.

New agricultural technologies tested in this research program included: (i) machines capable of sowing seeds reliably through a trash or mulch cover at a controlled depth with minimal disturbance of the soil without the need for prior cultivation; (ii) the use of glyphosate, a herbicide which is toxic to a wide range of plant species but has few, if any, known undesirable side effects at the levels (<2 kg a.i./ha) commonly used for no-tillage crop establishment; and (iii) new, well-adapted legume pasture species such as *Stylosanthes hamata* cv. Verano, *Centrosema pascuorum* (Centurion) cvv. Cavalcade and Bundey and *Macroptilium gracile* cv. Maldonado.

As envisaged in this legume ley farming system, grain crops (e.g. maize and sorghum) are sown using no-tillage into a 1–3 year legume pasture chemically killed with glyphosate. Cattle are grazed on native pastures during the wet season and on crop residues and legume leys during the dry season. The legume pasture then regenerates (as in the earlier Townsville stylo system) during the subsequent wet season from hard seed carried over in the soil during the cropping phase and from seed shed from legume plants which grow as an intercrop with the cereal (McCown *et al.* 1985).

Research on the components of the new ley farming system was conducted both independently and collaboratively by CSIRO and the Northern Territory DPIF and Department of Lands, Planning and Environment. CSIRO researchers worked mainly at Katherine Research Station, at the drier end of the Daly Basin, while the Northern Territory government departments worked primarily at the Douglas–Daly Research Farm about 150 km further north, in the higher rainfall zone, where the ADMA project farms were located.

Because this new, no-tillage, ley farming system technology was not immediately available in 1980, when the ADMA Scheme began, the project farmers were obliged to rely mainly on conventional cultivation, despite its recognised disadvantages, which were exacerbated when the areas cropped per farm were increased to as much as 1000 ha annually in an attempt to solve emerging economic difficulties. Despite these difficulties, researchers and farmers worked together to test and adapt the new technology. By the end of the decade, when the ADMA Scheme was terminated, all project farms had been privatised and ADMA's other functions had reverted to the normal government departments. By this time, the new farming system technology had been fairly well demonstrated on the project farms, although the cropped area had declined considerably.

The legume ley farming system has not yet been adopted significantly on a commercial scale, and continues to be adapted. Farmers' experiences with elements of the system in the Katherine–Darwin region are given in Price *et al.* (1996) and O'Gara (1996). Although the no-tillage technology came too late for the ADMA Scheme in its original form, it may take another generation to demonstrate the full production potential of the new technology and of the Douglas–Daly district. Since termination of the ADMA Scheme, farmers have concentrated on more intensive cattle production from improved pastures (legumes and grasses) which are being used for both grazing and hay. The ratio of the crop and animal components in future farming systems in the Katherine–Darwin region will depend on farmers' management skills and reflect their responses to market and climatic risks as well as their personal preferences.

The ley farming system depends, for success in the short term and sustainability in the long term, on the application of fertilisers (mainly phosphorus) to pasture legumes, which raises the nitrogen status of infertile soils to provide most of the nitrogen required for cropping of cereals and the protein-rich forage supplements which are especially needed in the dry season. Application of some nitrogen fertiliser will probably always be necessary because of leaching and other losses, especially on the lighter textured soils (Thiagalingam *et al.* 1996). The efficiencies with which the nutrient conversions are made will determine the economic success of the mixed farming enterprise. Critical aspects, such as the evaluation of pasture legumes for nitrogen-fixing ability and growth and persistence in short-term leys, the cycling of nitrogen between soil and crops, and prospective benefits to livestock, are the subjects of accompanying papers (Cameron *et al.* 1996; Dimes *et al.* 1996; Jones *et al.* 1996; McCown *et al.* 1996).

While the principle of the ley farming system as now proposed remains the same, the key factor that has transformed the outlook for the integration of dryland cropping with livestock production in the Katherine–Darwin region (apart from the current demand for live cattle in South-East Asia), is no-tillage sowing. This technique ensures that soil disturbance is minimised and, when used in conjunction with a surface mulch, creates a more favourable environment for crop establishment than can be achieved using conventional cultivation (Price *et al.* 1996). Associated improvements in soil water relations, structure, stability, fertility and trafficability from no-tillage, new methods of weed management on arable lands (Medd 1987; Martin *et al.* 1996) have raised hopes that sustainable mixed farming systems are within sight. Economic analysis of the risks and returns for selected ley crop systems, based on limited experimental data from the Douglas–Daly district, has shown that the use of no-tillage reduced the risk in soybean and maize by 47 and 60%, respectively, compared with conventional tillage (Bateman 1996). In the Katherine–Darwin region, much effort has gone into studies of no-tillage planters and their operating requirements, seed placement, characterisation of the environment of the germinating and emerging seedling, mulch management, and weed control.

Managing the interface between the animal and crop components will be crucial to the success of the ley farming system as envisaged. Overgrazing of crop and ley pasture residues during the dry season may leave too little mulch for no-tillage sowing of the following wet season crop, although in some wet seasons early pasture regeneration and weed growth will be sufficient for this purpose. Unattached plant residues may float away during heavy rain exposing bare soil, and nitrogen-rich plant residues (legume or grass) may decompose too rapidly to be effective in no-tillage crop establishment. These critical aspects and others mentioned above are discussed by Abrecht *et al.* (1996), Gould *et al.* (1996), Martin *et al.* (1996), McCown *et al.* (1996), Thiagalingam *et al.* (1996) and Yeates *et al.* (1996).

Although no-tillage farming systems have numerous advantages over those based on traditional tillage, complete abolition of tillage may not always be desirable or practicable, for example when new land is to be developed. Abolition of tillage creates new agro-ecosystems and, while many changes in the associated biota are beneficial, no-tillage systems have their own suites of pest, disease, weed and operational problems (Price *et al.* 1996), some of which may be ameliorated by strategic tillage. Comparison of no-tillage with conventional cultivation (Thiagalingam *et al.* 1996), and farmer experience in attempting to apply no-tillage principles (Price *et al.* 1996), is essential if farm layout and design are to be improved for long-term sustainability (see Dilshad *et al.* 1996). The conservative no-tillage principle is applicable to a wide range of possible dryland farming systems in the semi-arid tropics, some of which may be based on grain legumes or non-legume crops, instead of legume pasture leys, in conjunction with livestock raising.

Finally, the key elements of the legume ley farming system have been combined in crop growth and economic system models, validated against field response, and used in conjunction with historical climatic and economic data to estimate the probability of future success (Carberry *et al.* 1996; McCown *et al.* 1996). These analyses, together with the recognition of economic issues (Kirby *et al.* 1996) and a critical appraisal of the system's current use by farmers should give a better indication of its commercial prospects. Most larger-scale grain producers in the Katherine–Darwin region engage in some form of mixed farming (Price *et al.* 1996). In a concluding paper, McCown (1996) has tried to give a realistic assessment of the scope for dryland, legume ley farming in the semi-arid tropics.

Irrigated farming systems

The focus of this and accompanying papers is specifically on dryland farming systems. However, since World War II, considerable efforts have also been made to develop irrigated farming in the Australian semi-arid tropics (as a means of overcoming rainfall limitations and to complement dryland pastoral systems) in pursuance of the post-war national objectives for tropical Australia given to NADC. A few comments here about irrigated farming systems in the Australian semi-arid tropics are, therefore, appropriate.

The reliable supply of water for irrigation removes a major constraint to farming system development in the semi-arid tropics. It enables the harmful effects of dry spells during the wet season to be mitigated (although untimely rain can cause problems due to water excess), facilitates year-round cropping, and allows integrated animal production using irrigated pastures as well as crop products and residues.

The Ord River Irrigation Project, in the East Kimberley of Western Australia (Fig. 1), is perhaps, the most controversial of the post-war efforts to develop irrigated farming in the Australia semi-arid tropics. This is probably because of sustained opposition to the project by Davidson (1965), the environmental impact of heavy reliance on chemical insecticides by the former cotton industry, and the potential hazards to human health posed by large dams in the tropics (Stanley 1975). In contrast, the Burdekin Irrigation Scheme (whose main dam was completed only in 1987) in northern Queensland has a similar aim but has attracted much less criticism than the Ord.

Supplementary irrigation during the wet season, however, does not necessarily allow farmers to maximise the use of the natural growing season through the production of annual crops, as shown by the history of the Ord River Irrigation Area. On the Ord, the dry season is presently the preferred season for annual cropping, partly because the cooler weather permits the growing of temperate crops which command high prices during the off-season in southern Australia but also because, in the absence of rain, cultural operations are easier and waterlogging on the clay soils can be minimised. Also, crop yields under the lower temperatures are higher (shorter daylengths notwithstanding), and insect, disease and weed pressures are lower. The extent to which annual species once regarded as typical wet season (tropical) crops (such as sorghum, rice, maize, peanut, soybean and cotton) have been or are being grown in the dry season on the Ord, is remarkable.

The Australian Science and Technology Council (Anon. 1993*a*) saw the Ord today as a relatively prosperous community growing a diverse range of mainly horticultural crops (most of which were not considered seriously by the researchers and planners of earlier decades, indicating a need for strong commercial orientation) whose profitable production and marketing have been made possible by improvements in transport and communications technology. Subsidies to farmers have long gone and full recovery of water costs is likely to be sought by government in the future. The decision by the CSR company in 1994 to build a sugarcane mill on the Ord (a decision highly dependent on recent advances in milling technology and changes in government regulations), has been followed by the joint announcement by the Western Australian and Northern Territory governments that they intend to support expansion of the Ord River Irrigation Project from the existing 13 000 ha to about 77 000 ha (Anon. 1994).

In North Queensland, the Burdekin Falls Dam, with a capacity of 1.87 million megalitres (Donnollan *et al.* 1990), services a total irrigation area of 100 000 ha (about 50 000 ha channel fed and 50 000 ha bore fed). Historically, the area has been the centre of the Burdekin sugarcane industry and some associated crops such as heavy vegetables, horticultural crops and rice. During the 1980s, cropping systems research (Garside *et al.* 1992) centred on rice in rotation with grain legumes such as soybean (Borell 1993; Ockerby 1994; Dowling 1995), using innovative land management practices such as controlled traffic (Braunack *et al.* 1995). Rice is no longer grown on the Burkekin.

The Mareeba–Dimbulah Irrigation Area, also in North Queensland and centred on Mareeba (Fig. 1), uses water collected at the Tinaroo Falls Dam. This dam was built in 1958 and services an area of 60 000 ha (Currie and Lloyd 1978), of which currently only about 11 000 ha are irrigated. The dominant irrigated crop, until recently, was tobacco. However, with government support for the tobacco industry declining, alternative crops are being sought. An important horticultural industry has developed based on mango, avocado and other species. Sugarcane is viewed as a major new crop, currently producing more than 200 000 t cane/year.

Current irrigated cropping systems in the Queensland semi-arid tropics are regarded as commercially successful as all irrigation areas are close to markets and a substantial population base. As a consequence of the latter, the Tinaroo and Burdekin Dams are seen as major sources of domestic water for the growing urban centres of Cairns and Townsville.

The advantage of the semi-arid tropics for out-of-season (relative to both southern and northern hemispheres), and especially perennial, crops, where irrigation water is available, is also shown by the expansion in recent years of banana and mango production in the Katherine–Darwin region. Although the destructive termite *Mastotermes darwiniensis* remains a problem for growers of tropical tree crops in this region, the commercial prospects for high-value tropical horticultural tree crops like cashew, mangosteen and possibly others, have improved in recent years as a result of new technological developments. Even on the Ord, where irrigation water has been available for many years, perennial crops such as banana, tropical tree (fruit) crops, and sugarcane have advantages over annual crops, especially in regard to establishment and management costs, as well as serving to reduce soil and nutrient loss. Also on the Ord, the long-desired integration of the rangeland cattle industry with irrigated cropping is now occurring through the growing of weaner rangeland cattle on irrigated leucaena (*Leucaena leucocephala*), a perennial, browse shrub legume. Rangeland cattle, 3–4 months old and 110–130 kg liveweight, are put on irrigated leucaena in April and gain about 0.7 kg/head.day until they are turned off at 300–350 kg liveweight in the following February, mainly for live export to Indonesia (J. Sherrard pers. comm.).

The provision of a reliable supply of water for irrigation has greatly increased the diversity of farming systems that are now possible in some parts of the Australian semi-arid tropics. Further expansion (e.g. sugarcane, and perhaps cotton, on the Ord) is being accelerated by technological and other changes and a prospective shortage of water and land for agriculture in temperate and eastern Australia. However, the sustainability of agricultural production from these and any future irrigation schemes will only be assured if the well-known soil and water salinity problems that affect irrigated land in temperate Australia and in other countries are avoided.

The groundwater level under parts of the Ord River Irrigation Area has risen considerably over the past 30 years, mainly as a consequence of seepage from supply channels and Lake Kununurra. Although salinity is not considered to be a hazard at this stage, careful management of irrigation practice will be essential to minimise soil waterlogging and salinisation in future (Clews 1994). Salinity problems in irrigation areas in the semi-arid tropics of Queensland have generally been confined to groundwater supplies (Bevin and Shaw 1980). There is little evidence of salinity in areas irrigated from surface water storages. Conjunctive use of groundwater and surface water has been used in the Burdekin Irrigation Area to lower rising watertables. The watertable may also rise under the, as yet, undeveloped areas on the right bank of the river (R. J. Shaw pers. comm.).

While the dangers inherent in irrigated farming (including issues of sustainability) are well recognised in all irrigation areas in the Australian semi-arid tropics (e.g. Robinson *et al.* 1994; Shaw and Gordon 1994; Carroll *et al.* 1995; Lait *et al.* 1995) and measures are now being taken to improve water-use efficiency by means of allocation, pricing and more careful irrigation scheduling, it remains to be seen whether water management in these schemes will be good enough to avoid, or at least minimise, the land degradation that irrigation has caused elsewhere.

Conclusion

Notwithstanding the many difficulties encountered by commercial agricultural enterprises, both dryland and irrigated, the farming system development begun after World War II in the Australian semi-arid tropics, continues. The past 20 years have seen big changes in the socio-economic environment. The population in the Australian semi-arid tropics has increased considerably and there are better transport and service industries and training facilities. These factors, together with the opening of new markets for animal and plant products in South-East Asia, have improved the prospects for agricultural development in northern Australia.

Dryland farmers can use new technology (e.g. no-tillage sowing) to reduce risk due to rainfall variability. The range of potential crops, including pastures, has been increased and, along with the additional options for livestock production, should help to reduce the hazards of market fluctuations. Likewise, new technologies and new crops and varieties have changed the outlook for irrigation farmers, e.g. on the Ord River.

Opportunities are there. It is up to farm managers in conjunction with researchers and others to put the new technologies into practice. The Northern Territory government's proposed new Farm Development Strategy, the implementation of which includes the subdivision of more land in the Katherine–Daly Basin, is a reflection of renewed optimism regarding dryland agriculture in this region. Provided the socio-economic lessons of history are not ignored, the objectives of the of the post-war Northern Australian Development Committee will gradually be achieved through progress towards more sustainable farming systems.

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