

Farming fragile environments: low rainfall and difficult soils in South Australia

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Abstract

The Mallee and Eyre Peninsula regions of South Australia are characterised by low and variable rainfall, and soils with difficult chemical and physical problems. The farming systems traditionally used in these areas are designed to manage risk associated with this harsh environment, and involve multiple soil cultivation and a minimal cereal-pasture rotation. Questions have been asked about the sustainability of systems which have low water use and can degrade the soil, and these concerns are reinforced by evidence of no consistent trend for crop grain yields to increase. There are new cropping systems developed with increased productivity and water use efficiency which are significant departures from the classical cereal-pasture rotation, and offer opportunities for these environments. These systems involve more cropping intensity and may be more environmentally stable than the traditional set rotation. The challenge now is to adapt the new systems within the context of localised farming systems and to ensure that improved productivity is not degrading the land base.

Key words

farming systems, low rainfall, soil management

Introduction

Land degradation in South Australia is often associated with cropping and livestock enterprises in the regions with low and variable rainfall, and with soils having difficult chemical and physical characteristics. Frequently areas within these regions are considered unsuitable for cropping, based on assessments of soil loss, bare ground, low yields and low water use efficiency. However these areas which may be deemed adverse for cropping can be substantial in size and often contribute significantly to total farm product value. The traditional farming systems utilised for cropping these areas have depended on soil cultivation, and rotation with annual medic based pasture (8, 29). Whilst over time there have been changes in rotations and reductions in the extent of tillage, the concern remains about the sustainability of farming using systems which depend on multiple tillage operations and widely fluctuating dry matter production (10). Consequently questions about current land use in these fragile, semi-arid environments arise, and issues such as re-designing production systems and retiring lands are discussed at policy level (12). Hamblin and Williams (12) address the need to consider environmental problems within managed lands on a regional or ecosystem scale. However within these regions there are many examples of farmers utilising management practices which consider concerns about environmental sustainability. In this paper we focus on fragile environments in South Australia. Farm management examples are given from cropping regions with low and variable rainfall, with the purpose of establishing the scope for extrapolating or scaling out sustainable management practices in fragile environments.

Study areas

The agricultural-climate-terrain associations considered in this paper are within the Murray Mallee and Upper and Central Eyre Peninsula regions (16). These areas are classified as temperate, arid to semi-arid, wheat-pasture systems, with mean annual rainfall usually less than 350 mm. The soil land forms and soil properties vary between and within the regions, with considerable heterogeneity within the dominant dune-swale land systems and calcareous sandy loams which overlie sheet (calcrete) limestone (Table 1). These soils often have many attributes which adversely affect plant growth, and are susceptible to land degradation (Table 1). Rainfall variability is a common feature of these regions, with more variability in the drier west of the Upper Eyre Peninsula and the northern Mallee, a factor delineating the segregation of

the Mallee into two districts. Analysis of Eyre Peninsula rainfall data has demonstrated a close relationship, over the past 30-40 years, between April-May rainfall and grain yield. Huda et al. (13) have shown that at Minnipa rainfall of less than 40 mm in the April 1-June 15 period results in yields of less than 1.0 t ha⁻¹ in 90% of years. The development of cropping systems in these areas has primarily focussed on matching plant growth to water availability with the purpose of reducing yield variability. The stages of development of the cereal-pasture system are broadly as described by Williams et al. (35). The initial period of farming was associated with nutrient exhaustion, soil structure breakdown, water and wind erosion and weed ingress, followed by a stage characterised by the use of better adapted cereal varieties, application of superphosphate, fallowing or multiple cultivation and various configurations of pasture-legume and crop rotations. In much of the low rainfall farming areas traditional systems of farming are still practised, but are being challenged for continuing to degrade soil and restrict productivity improvement (10).

Table 1: Bio-physical attributes of the low rainfall cropping areas of South Australia

Major terrain features		Regional occurrence/ area
Infrequent parallel sandhills, narrow ridges, E-W direction, interspersed with flats, depressions and rises (dune-swale). (5)		Northern (13000km ²) and southern (5500km ²) mallee.
Shallow calcareous soil overlying pockets of sheet limestone. (5)		Southern mallee (6300km ²)
Land zones with parallel and jumbled siliceous sand ridges. (15)		Central and Eastern Eyre Peninsula (35560 km ²)
Land zones with calcareous soils. (15)		Central, Eastern and Upper Eyre Peninsula (16600 km ²)
5 Soil problems	Soil deficiencies/toxicities	Cereal disease
Alkalinity (CaCO ₃ content in top 10cm about 70%). (15)	Phosphorus (34)	Take-all (Gaemannomyces graminus var. tritici) (21, 29)
Sodicity. (19)	Zinc: common deficiency on most soils. (28)	Rhizoctonia (Rhizoctonia solani) (21, 29)
Dryland salinity (deeply weathered landscape with accumulated salt, and problems associated with rising watertables). (6)?	Manganese: deficiency restricted to coastal soils. (28)	Root lesion nematode (Pratylenchus spp) (32)

Texture mostly sand to sandy loam with a high potential for wind erosion.?	Boron: widespread toxicity problem in Eyre Peninsula and Mallee.	Cereal cyst nematode (<i>Heterodera avenae</i>) (21, 29)
High osmotic potential in subsoils (R. Holloway, pers. comm.)	?	?
Water repellency: Central and Eastern Eyre Peninsula and southern Mallee on the deep siliceous sands. Problems associated with poor crop establishment.	?	?

Traditional systems and yield potential

Long fallow is the traditional practice in the Mallee region with mechanical soil disturbance 6-12 months prior to seeding. The number of soil cultivations will vary with the frequency of summer cultivations associated with the need for weed control. The purpose of long fallow in crop rotations has been to increase stored soil water, raise soil mineral nitrogen levels, reduce the incidence of cereal root diseases and minimise grass and other weeds (7). The number of cultivation events will vary between 3-5 passes prior to sowing, and a set rotation of fallow-cereal-volunteer pasture is used. Mechanical fallowing is in some situations being partially or fully replaced with chemical fallowing. About 50% of farmers in the northern Mallee still utilise long fallows, and a higher proportion (80%) use the traditional set rotation. In the southern Mallee, with higher rainfall, the system of long fallow and set cereal-based rotation is still practised by about 30% of farmers. Long fallowing, in contrast, has rarely been used on the Eyre Peninsula. The traditional system in this region involves burning of plant residues in March-April and subsequent multiple cultivations, with a wheat-pasture or wheat-barley/oat-pasture rotation. This system is still dominant in the western areas of the Upper Eyre Peninsula, in lower rainfall and highly calcareous soil areas.

Low rainfall environments are often seen as being naturally fragile and at risk to soil degradation. Williams et al. (35) clarify the use of the term fragility within the concept of sustainability of farming lands, using principles developed for natural ecosystems, with the terms stability and resilience adapted to describe qualities of the bio-physical resource base. Sustainable systems are those in which the land condition is not reduced to a less productive state from which it cannot recover (resilience) either naturally, or with reasonable inputs. If a soil is repeatedly degraded then opportunities for resilient behaviour are lost. Farming systems with alternating enterprises (crop-pasture systems) will have a soil environment which fluctuates between different states and conditions. The pasture phase in the rotation can contribute to the resilience or the capacity of the soil to recover to an improved or equilibrium state. The fallow-cropping phase is a planned (controlled) biophysical environment, with a disrupted soil structure and soil biology.

With cropping systems, yield and associated water use efficiencies are common measures of the productive state of the system. The data given by Hamblin and Kyneur (11) show yields in the semi-arid environments have risen either slowly or not at all, and water use efficiency in all cropping areas in South Australia has been low (4-6 kg ha⁻¹ mm⁻¹, based on 1950-1990 ABS data). More recent analyses of regional data indicate an improvement in water use efficiency that is consistent with improving grain yields in all regions other than the low rainfall areas (W.Davies, pers. comm.), and some recent estimates of water use efficiency for the drier areas covered in this paper are given in Table 2. Crop yields have only increased by 10% over the last 30 years in the Mallee region, reaching only 30-50% of the potential yield (5). Whilst the majority of farmers still obtain low water use efficiencies, the results from some experimental areas and best farmers? paddocks demonstrate the objective of achieving high water use is attainable. With continuing low or even declining yields and poor water use efficiency there may be reason for concern about the resilience of cropping associated with traditional systems. Where

incremental and cumulative degradation have occurred with time, and in circumstances of increased intensity of cropping, the opportunity for the soil to return to a former state is restricted and a lower production threshold is established.

Table 2: Water use efficiency estimates from research plots and farmer paddocks

Region	Water use efficiency (kg grain ha ⁻¹ mm ⁻¹) (8)	Assemblage	Source
Mallee	10? 5	Reduced till? Long fallow	Research plots (18)
Southern Mallee	14? 7? 10	Top 25% farmers ¹ Bottom 25%? Average	TOPCROP data, 1996 season (J. Cummins, pers. comm.).
Northern Mallee	16? 9? 11	Top 25% farmers? Bottom 25%?? Average	?
Upper Eyre Peninsula?	12? 9? 10	Top 25% farmers? Bottom 25%?? Average	?
Upper Eyre Peninsula? (highly calcareous soil zone) Central Eyre Peninsula?	8? 11	Survey data averages	R. Holloway, pers. comm.

¹ The survey data are taken for farmers who are members of TOPCROP groups. The participants are usually better farmers, so the average and bottom 25% data for yield and water use are biased upwards.

Degradation assessment

There is sufficient evidence in cropping regions in Australia that farming has rapidly changed the soil environment, with water and nutrient source and sink imbalance, structural deterioration, fertility decline and changed biological condition. In the low rainfall regions surface soil loss has occurred in both dune and swale and calcareous terrains associated with 'blow-outs' and with overgrazing. Various measurements of the extent of soil loss have been undertaken, with an acceptance that frequent soil cultivation plus high incidence of unfavourable seasons and low dry matter input will degrade the soil resource (4). Whilst studies on soil loss relevant to the areas covered in this paper are relatively few, it has been consistently shown that reducing the number of soil cultivations and retaining plant residues decreases the potential for soil erosion (18). These findings also reflect the understanding of farmers in the Mallee region where 60-70% of a survey sample rated reducing cultivations and retaining residues as the main issue in reducing erosion (30). Similarly with measures of soil structure such as hydraulic conductivity, infiltration and compaction, all of which are associated with soil water parameters, improvements are recorded with reduced tillage compared with traditional cultivation methods. Again, in the higher rainfall regions, there are many examples of structure improvement associated with reduced

tillage (2), but in lower rainfall regions there are few published studies that give detailed soil measurements.

The extent and potential for soil structural improvement may be less in the low rainfall areas, as the more sandy soils have a naturally low organic matter content and there is a restricted opportunity for biomass input. Cultivation in the cropping phase in rotations does reduce the organic content of the soil, with the classical response in the rotation of the pasture component restoring soil organic matter and fertility (26). Within the Mallee and Eyre Peninsula there is concern amongst farmers about poor productivity or profitability of the medic component in pastures. (2, 20). Consequently in some areas the cropping intensity has increased substantially, both with the use in the rotation of more cereals, or grain legume or oilseed crops. In the southern Mallee vetch has in some situations taken the place of medic pasture on intensively cropped farms. It is likely that this decline in productivity of legume-based pastures and move to increased cropping intensity will impact negatively on soil organic matter, though evidence from unpublished long-term experiments suggest that crop productivity is not being affected (D.Roget, pers. comm.).

Mallee soils mostly have high water conductivity and the potential recharge from fallowing is high despite the dry environment (eg. long fallows resulted in an additional 36 mm soil water (0-120 cm depth) at sowing compared with short fallow, Wanbi, northern Mallee, South Australia (18); fallowing one year in three increased the potential recharge by 11 mm year⁻¹ compared with a pasture-wheat rotation, Walpeup, NW Victoria Mallee (22). Rates of drainage are much greater under fallowing compared with reduced tillage (17, 23). Whatever the tillage system, the land use changes associated with land clearing and agriculture have substantially altered the water balance of the Mallee regions, and over a long enough time the effects of vegetation changes will be significant in terms of rising watertables and potential salinity problems. Cropping soils have been taken out of production in the Cooke Plains area in South Australia due to rising watertables and salinity. Although fallowing does increase stored soil water, improvements in cereal yields in the Victorian Mallee are associated more with benefits from control of cereal root diseases and grass weeds rather than from soil water use (14). The low water use efficiency by crops reflects this under-utilisation of soil water (Table 2). The Upper Eyre Peninsula as a general rule has no rising watertable problem, with numerous deep drills taken in this area to bedrock without finding groundwater. Salt and boron in the subsoil in the calcareous soils in both the Mallee and Eyre Peninsula are associated with inefficient soil water use by crops.

The soil biological character will also have changed through introducing farmed systems. Although not specifically studied in the low rainfall environment, the transition from natural to farmed system will have led to substantial changes in content and expression of soil biota (24). Not least important in the low rainfall environment is the incidence and influence of crop and pasture diseases, both natural and introduced.

System development for low rainfall areas

The current phase of cereal-pasture system development, which has been underway since the mid-1960s, is characterised by mechanisation and reduced tillage, wider rotations with grain legumes and oilseeds and improved herbicide options for weed control (11, 35). Considerable sophistication and diversity are available with new systems which vary in configuration from continuous cropping systems to cropping integrated with specialist livestock systems (prime lambs, feedlotting). A feature of new systems is the departure from the 'bulk commodity' mentality, to participation in specialist market production, and a stronger emphasis on profitability. Throughout Australia many of the new systems are high input systems, and there is now an awareness that high input is not necessarily more environmentally damaging than low input systems. For example, high input systems may target a balance between nutrient and water input and output, land use and soil improvement and integrated pest and weed management. However, the new systems for crop production can still be short of the yield targets expected with optimal growing conditions (11).

An on-going problem for the low rainfall regions that is being reviewed in this paper is that agronomic research is often concentrated in the areas closer to the major centres, which coincide with the high

production areas. In addition to less research in low rainfall areas, research in these areas has to contend with slower rates of soil and landscape improvement, as well as the risk that any benefits can be quickly negated in extreme events which can occur often. As a consequence it often appears that there are fewer options of new systems specific to these low rainfall regions, and where new technology has been developed there are often doubts and conservatism amongst farmers on the relevance and portability of such technologies.

Tillage and crop rotation are the basis of cropping in the drier regions and have been the focus for innovation and change in the development of new cropping systems. A GRDC funded 'Technology Transfer' project has operated in the low rainfall Eyre Peninsula for two 3 year terms, beginning in 1993 with the aim of taking more water-use efficient tillage systems onto farms. Farmer co-operators were selected in each of nine districts. Paddocks were split in two, with half of the paddock sown conventionally, while on the other half, grass was treated with herbicide in the previous year. Summer weeds were controlled and wheat was direct drilled at the first opportunity in the new season (generally after 10 mm rain occurring within 3-4 days after April 20), without any attempt at weed control before sowing. Farmers have indicated that it is difficult to justify the high cost of controlling grass weeds with selective herbicides (5). The new technology was seen by farmers as radical and risky, so grass herbicides were funded by the project, and as new cereal varieties became available they too were supplied. Despite problems with persistent cereal root diseases on the highly calcareous soils, frequent drought and a series of late season opening rains, mean wheat yields in the project paddocks increased by 25% with earlier sowing, from 1.2 to 1.5 t/ha, over the period 1993-1996 inclusive. Mean gross margins increased from \$126/ha to \$161/ha. Results were equally positive in 1994 which was the driest year on record.

One of the most notable features of the new system was the lack of wind erosion in the direct drill paddocks compared with those conventionally prepared. A major problem on the highly calcareous soils was the root disease take-all which in some instances caused a 50% yield loss in the early sown paddocks, despite the removal of grass (and the indication of low levels of the fungus by DNA testing) in the previous season. It is possible that very low levels of take-all are much more damaging on these highly calcareous soils than on other soils because of interactions with other factors such as soil compaction (slowing root growth and hence reducing nutrient uptake) and low soil organic matter. The rate of adoption of early seeding direct-drill systems is increasing gradually in Central and Eastern Eyre Peninsula. This no-till technology has low acceptance in the calcareous soils areas because of root disease, nutritional and other problems, compounded by low rainfall. In a 1997 farmer survey (J.Cummins, unpublished data) the majority of farmer responses in both the Eyre Peninsula (76%) and Mallee (62%) indicated that they have now tried minimal tillage in some form, and cited problems with adapting technology to their own circumstance, unsuitable machinery and cost factors, and concern that the technology was not proven or suited to their area. Overall, the preparation of the land for cropping in low rainfall environments is of critical importance, with consideration of pre-crop weed control, optimising planting date, seeding density and placement and fertiliser rates and placement. Often it is the farmer who has modified existing machinery to accommodate change in tillage practice who is able to match specific local needs and remain cost effective.

Medic-based pasture has been an essential component in cropping systems in the low rainfall areas of South Australia, both for re-building soil fertility and providing non-host years of disease control. Increasingly though, farmers in both the Eyre Peninsula and Mallee are expressing dissatisfaction with both the productivity of the pasture phase and also concerns about disease carryover (5, 20). The proportion of pasture in crop rotations is declining in some areas. In 1992 in the southern Mallee 38% of the arable land area was devoted to pasture, and in the drier northern Mallee about 70% of the arable farm land was pasture (5). Similarly in the Eyre Peninsula, the proportion of arable land in pasture has declined, particularly in the relatively better rainfall areas such as the Central Eyre Peninsula. This shift in the rotation to more intensive cropping has not necessarily coincided with the availability of well suited alternative crop species.

Legumes and oilseeds are grown in the Central Eyre Peninsula and southern Mallee to some extent (Table 3), but there is still a requirement for new genetic material with adaptation to high pH soils, and low

and variable rainfall. So far the species available lack consistency in performance and, with the exception of field peas, have limited farmer acceptance. Field peas have been grown in plots at the Minnipa Research Centre since the 1970s, and are now being grown more widely by Eyre Peninsula farmers but have not performed well on the grey, highly calcareous soils. Peas are seen by farmers as a difficult crop to manage, requiring specialist reaping equipment and careful management of the stubble. Once the pea crop is reaped extreme care is needed to avoid wind damage. Many farmers still graze pea stubbles during summer, a risky practice, particularly with low yielding crops. Limestone and remnant tree stumps are a common feature of the terrain on both the Eyre Peninsula and Mallee, which restricts opportunities for the culture of field peas. Farmers need a crop plant which is sufficiently tall to allow the harvester comb to clear stones and sticks, and with a sufficiently resilient stubble to provide good soil cover and prevent wind erosion through summer and autumn.

Morphologically, lupins would be an ideal legume for the low rainfall areas. However, despite consistent species and cultivar evaluation, lupins (and particularly *L. angustifolius*) are not well adapted to the calcareous soils of Eyre Peninsula (J.Egan, pers. comm.). High concentrations of 'free lime' are generally cited as the cause of poor growth. On the highly calcareous soils, even in high rainfall years lupins rarely achieve a height of more than 15 cm. Lupins may have a place on the siliceous sandhills in Central Eyre Peninsula, and have been successful in some of the deeper sand areas in the southern Mallee, provided they are sown at the appropriate time. In the southern Mallee peas, lupins, vetch and canola, despite low yields in poorer seasons, have provided benefits to the yields of following crops (mainly wheat), with higher yield gains than obtained from the traditional pasture systems (J.Cummins, pers. comm.). Faba beans and other legume crops have not performed well in the low rainfall environment. Oilseed crops have faced similar adaptability problems, although there is some adoption of canola in the southern Mallee with the canola relatively successful in terms of rotation and profitability benefits.

Table 3: Crop production area estimates (ha) for 1988 and 1996. (Dept. Agric. S.A. Crop and Pasture Reports)

?	Upper Eyre Peninsula		Central Eyre Peninsula		Southern Mallee		Northern Mallee	
	1988	1996	1988	1996	1988	1996	1988	1996
Wheat	190000	200000	150000	140000	53000	60000	144000	180000
Barley	31000	42000	48000	55000	74000	90000	73000	100000
Oats	37000	30000	19000	13000	4700	4000	12000	12000
Peas	800	100	800	1400	270	4000	100	-
Lupins	-	-	100	650	9300	6000	-	-
Beans	-	-	?	-	580	250	-	-
Chickpeas	-	-	-	20	200	500	-	-

Vetch	-	-	-	200	-	4000	-	-
Canola	-	30	-	150	-	500	-	-

Specific system constraints

Disease

Cropping mainly with a single plant species will favour disease and decrease the diversity but not the abundance of soil micro-organisms. In the low rainfall areas disease can be particularly severe on cereal crop production, with both introduced and already present pathogens involved. Plant diseases exploit stresses imposed by the environment, and complex interactions affecting both pathogen and disease are common in low production environments (21, 31). There is evidence that the expression of cereal root diseases is particularly severe on the highly calcareous soils. For example, rotational control such as removing grass from pastures or field pea crops is not as effective on grey calcareous soils compared with other Eyre Peninsula soils, with examples of crops on the grey soils severely damaged even when DNA probe methods indicate low levels of take-all inoculum (R.Holloway, unpublished data).

Rotation of plant species is often difficult in the low rainfall environments. Problems may arise due to the restricted choice of rotation crops because of limited adaptability, and the pastures may not provide sufficient separation in host-specific relationships. Disease problems such as *Rhizoctonia* and root lesion nematode affect medicas as well as some cereal hosts. However the root lesion nematode can be controlled to some extent in the wheat phase of the rotation with use of resistant cultivars, which illustrates the complexity of matching rotation choice. Thus with various options for varying crop susceptibility to disease, broader disease management by genetic improvement must be considered when developing new systems. With more intensive cropping in low rainfall areas, particularly continuous cereal systems, a disease decline situation can develop (D.Roget, pers. comm.) which may also be an important consideration in some new systems.

Medic pasture decline

Traditionally the approach of rotation choice and management has been from the perspective of the cereal, but consideration must also be given to non-cereal rotation requirements. Clarification of concerns about the performance and role pastures have in low rainfall areas is a fundamental issue in system development. Legume pasture improvement with emphasis on cultivar, disease and nutrition factors is a priority. Medics do not grow productively and persist in situations where there is low P and Zn nutrient supply. There is a need also to understand the observation of many farmers that wheat performs poorly after good medic stands, an observation that is different from accepted understanding of benefits associated with legume-based pasture.

Soil factors

The Mallee and Upper Eyre Peninsula have alkaline and highly calcareous soils, with surface soil (0-15 cm) pH values of 8.0-8.5 and subsurface (15-100cm) with pH values of 8.5-9.5. Both surface and subsoil can be associated with sodicity (19). The light textured soils usually have low organic matter content, and low measured rates of organic matter accumulation with the farming systems (18; D.Roget pers. comm.). Frequently the soils in the Eyre Peninsula and Mallee regions have B toxicity in sodic subsoil (3). Deficiencies of the trace nutrients Zn and Mn are common in these soils, and P availability is affected by high pH (34). The selection for genetic tolerance to soil related stress and nutrient use efficiency will give more opportunity for crop choice on these soils (9, 25).

Zinc deficiency in cereals became a noticeable problem on Central Eyre Peninsula in the mid 1980s, possibly as a result of increasing use of high analysis P fertilisers. The incidence of Zn deficiency was severe enough to be identified by leaf symptoms and was increasing each year, which resulted in an

escalating demand for Zn fertilisers. In the 1997 season 83% of Mallee farmers and 89% of Eyre Peninsula farmers had adopted a Zn enriched fertiliser program (J.Cummins, unpublished data). Zinc uptake can be enhanced by deeper placement of the fertiliser, and there is evidence that new fertiliser formulations (including liquid fertilisers) will improve nutrient uptake on the calcareous soils. The importance of nutrient supply in crop production is well recognised by Eyre Peninsula farmers who could well be described as 'nutrient conscious'. In the low rainfall areas, fertiliser costs may amount to 30% of all variable costs and the opportunity exists in these areas to further improve the efficiency of nutrient delivery to plants.

The P requirements for crop production in the Eyre Peninsula clearly differ with soil type, with differences between the grey highly calcareous soils and the red calcareous soils. With the grey soil, yield response to available P (Colwell method) levels does not appear to plateau or relate to a critical level of soil available P. Wetherby and McCord (34) conclude that there was little point in attempting to increase soil available P levels above 20-25 mg P kg⁻¹. With the red soils, levels as low as 8 mg kg⁻¹ of available P may provide much better early vigour and higher P levels in wheat tissue. The sigmoidal nature of the grain yield response on the grey soils was a major determinant in deciding the economic rate of P fertiliser as 10 kg P ha⁻¹. The application rate of P fertiliser is 5-10 kg P ha⁻¹ in the northern Mallee and 10-15 kg P ha⁻¹ in the southern Mallee. These P requirement evaluations have been undertaken using traditional cropping systems and knowledge gaps exist for new technologies such as stubble retention and deep fertiliser placement (27).

Rainfall

The obvious need in dry areas is to ensure effective use of all available soil water. An important development in recent times has been the introduction of risk management theory to Eyre Peninsula. Huda et al. (13) have proposed that farmers adjust the area sown according to early season rainfall so that in years with less than 40 mm in the critical period (April-May) only 25% of the normal area would be sown. In years with more than 100 mm in that period 150% of the average area would be sown. Developments in this area have large implications for farmers in low rainfall areas. Besides a significant reduction in financial risk because the worst erosion years are invariably those associated with drought, opportunity cropping, as it is called, offers the prospect of environmental stability. There is also an opportunity to use strategic sowings of longer or shorter season wheat varieties based on season predictions, as well as timing of opening rains.

Future systems

A demanding task in fragile environments is to construct new and diverse systems of land use which integrate understanding of the interactions of the plant, soil, nutrition, disease and water variables, and consider economic production and long-term environmental consequences (35). A difficulty in these areas is that positive environmental changes may take more than 20 years to develop, making it difficult to predict future interactions and problems arising between farming practices and the environment. Crop systems have evolved in both the Eyre Peninsula and Mallee both as a result of technical improvement (reduced tillage systems, new herbicides, alternative crop development) and problems with the productivity of pasture and relative profitability of livestock systems.

Rotations have become more intense in the southern Mallee through increased grain legume and cereal production. The grain legume vetch has been favoured by farmers, in terms of fulfilling a dual role in grain and hay production as well as providing valued grazing. Some farmers have favoured all crop systems in the Eyre Peninsula, where continuous cropping has drastically improved the profitability (not only on a total farm basis but in individual paddocks) and sustainability of the farming operation on highly calcareous soils. At Minnipa Research Centre a paddock has been cropped continuously since 1976, the last 10 years mainly to cereals. The paddock is never burnt and organic carbon and available P levels have increased over time, and it is unlikely to have wind erosion because of the amount of residue present. A long-term site at Avon (Mallee soils) has developed disease suppression effects associated with continuous cropping (D.Roget, pers. comm.). Carefully managed continuous cropping systems may be more sustainable on fragile soils than systems in which livestock is a major component, which is a very

important consideration in a re-designed future system. When cropping systems are managed so that water use efficiency is maximised by reducing cultivation to the minimum, useable soil water is not wasted on weeds, weeds are managed so as not to allow herbicide resistance to develop, residues are managed so as to allow 100% soil protection without undue hindrance to seeding operations, then the most fragile of soils can be farmed successfully. However research has not yet defined the parameters for such an integrated all crop system for these low rainfall environments.

The most successful method of cropping at Minnipa Research Centre since 1983 has involved the use of seed broadcasting. In this method fertilisers are normally applied when the soil is given its only cultivation, and the grain is spread with a broadcaster and incorporated with harrows or prickle chain when the surface is damp. The method requires little capital investment and consistently produces the highest yielding crops. With large areas to sow, modifications in sowing methods which allow more timely sowing improve the flexibility and options at sowing time.

An option already utilised in the low rainfall areas is matching the production units to soil and land capability classes (10). The availability of information systems such as MIDAS, and expert knowledge on soils and yields integrated via remote sensing systems, should assist with these management decisions. Examples of possible sustainability indicators have been developed, though their emphasis is more for higher production farming areas or rangelands rather than low rainfall crop-pasture systems (33).

Implementation

Traditional farming practices have in many situations provided growers with the least-risk option of farming in the low and variable rainfall regions, in terms of providing a satisfactory level of farm income. Scientists and extension officers may perceive a longer time-frame for the adoption of new technology, however more often than not this may be the result of grower attitude to risk and concerns about the modification or adaptation of technology to local farming systems across a range of seasons. In these environments low biomass production and slow reaction times may mask benefits from technology. Thus the approach for adopting technology has been minimal change with complex technology and technology having a greater element of risk, and small progressive gains with simple technology. However, as shown in examples given in this paper, new systems can give higher productivity. These systems have been developed by utilisation of local data, often in an intuitive, adaptive approach. There are still difficulties with scaling out from locally produced data (?will the practice work for me??), with the requirement to integrate knowledge from many sources and extrapolate to the scale of land class or farm. The best farmers in these fragile environments do capture benefit from technology change, but often this technology change is not adopted by more than a small proportion of farmers. The new systems have to be given the best opportunity to work, and should be tried initially according to soil capabilities. Strategies such as TOPCROP and Right Rotations are designed to address localised production issues, and new technology is discussed and adapted within the context of localised farming systems and attitudinal and expertise circumstances. The level of participation in TOPCROP of farmers who responded to a cropping survey (1997 data) in the Mallee was 25% and in the Eyre Peninsula was 40% (J.Cummins, unpublished data). There is still a large group of farmers who are unlikely to be exposed to new system development.

Discussion

In much of the arid and semi-arid cropping areas in South Australia low grain yields and low water use efficiencies are identified with the traditional set crop-pasture systems. These systems use a controlled biophysical soil environment achieved through cultivation, with the aim to minimise yield variability, but this often results in a degraded and non-resilient soil state. The accepted role of the pasture legume in these rotations is to improve soil fertility (structure and organic matter), and enhance the resilience of the system. There are concerns about the productivity of medic pastures, and the role of pasture in new and evolving systems in low rainfall areas. The new systems, with cultivation reduced to the minimum, appropriate residue and weed management and long phases of continuous cropping have increased productivity and water use efficiency in the low rainfall areas. In some circumstances all crop systems are being utilised. Thus there is a changing role for pasture, with options of continuous cropping followed by a long pasture phase, or different parts of the farm retired from cropping (10, 26). There is a need to

reassess the role of pasture in low rainfall farming on a land-use and land-capability basis, recognising the different system and ecological requirements. An ongoing difficulty with new and evolving systems is knowing if the system is environmentally sound and, with more cropping intensity, that the land is not being mined or degraded. The early indication is that the changes occurring with more cropping intensity may be more environmentally stable than the crop-pasture traditional set rotation. Changes in a positive direction result from more dry matter production and retention, and less cultivation. On the negative side, with less pasture there is less spread of risk and increased potential of disease (though disease decline may be a factor within an all crop system). Without pasture inputs into soil fertility, there may be less resilience in the system. It is possible that a particular rotation or system in the low rainfall areas cannot be carried on long enough for equilibrium levels of improved soil conditions to be achieved. The process that is occurring in the South Australian low rainfall areas is the redesigning of the production system, with increasing complexity and increasing requirement for management and research inputs. There are quite specific difficulties in developing new systems because of the difficult nature of the soils and the low and variable rainfall. Throughout the paper we have mentioned key knowledge gaps with rotations, soil management and structure, soil alkalinity, nutrients and disease control. Future farming in these hostile and fragile environments will require more complex integration of the system components given above, as well as adaptation at district and farm level.

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