Crop Sequences, Crop Pasture Rotations and Soil Fertility

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Introduction

Management of crop sequences and crop pasture rotations is one of the ways by which man can change soil fertility. Soil and climatic factors establish the major management options available and markets and prices determine their profitability. Science and technology can also affect the options available, by understanding the long term effects of various practices, by developing new crop and pasture plants and by overcoming nutritional limitations.

One of the distinctive features of dryland agriculture in Australia is the combination of cropping and livestock enterprises. Of the 46,300 enterprises growing cereal grains and oilseeds in Australia in 1977-78, 63 percent were also involved in livestock production.<[2] This involvement ranged from 33 percent in Queensland to 79 percent in Western Australia. In such enterprises pasture leys play an important role in maintaining soil fertility.

The development of cropping-livestock enterprises was strongly advocated in the early 1940's following a period of intensive cropping in the 1920's and 1930's. Thus Callaghan (1944) stated "under our wheat belt conditions ... the only means of protecting the productivity of the soil is to develop a system of arable livestock farming. By this means coupled with the best use possible of leguminous species it should be possible to protect the soil and replenish its mineral-organic matter status".

After a period of relatively stable patterns of land use which persisted into the 1960's there is evidence of significant recent change. These changes have important implications for the maintenance of fertility in Australian soils.

In this paper it is proposed (1.) to reiterate what is known about the effect of various crop pasture sequences on soil fertility (2.) to indicate regional differences in our capacity to manage soil fertility (3.) to discuss recent changes in cropping patterns and (4.) to suggest opportunities for intensification. The main emphasis will be on rainfed field crops and pastures in both winter and summer rainfall areas.

1. Effect of Crop Pasture Sequences on Soil Fertility

Arable agriculture is practised principally on the more fertile soils with initially moderate to high soil organic matter levels. Invariably cultivation results in a decline in soil organic matter levels which continues until a new equilibrium is established. This equilibrium level is affected by intrinsic environmental factors such as climate and soil but is also affected by cultivation practices, crops grown, crop pasture sequences and fertilizer practices.

Studies carried out in Australia on the interrelationships of soil properties and crop and pasture yields allow general conclusions to be made as to factors affecting soil fertility. Most of the information concerns the winter rainfall areas

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<[2] Regional and national crop, livestock and fertilizer statistics are from Australian Bureau of Statistics sources unless otherwise noted.

and less data is available on the summer rainfall areas.

One of the oldest continuing experiments on crop and pasture sequences is the permanent rotation trial at the Waite Agricultural Research Institute. This experiment was established in 1926 and although a number of winter growing crops were included the main emphasis has been on fallow, wheat and pasture (Waite Institute Reports 1925-1979, Woodroffe 1949, and Greenland 1962, 1971). Although detailed plant yield information is available, less soil data has been collected and early data in particular is sparse. Using available soil and plant data Russell (1980) fitted a model to the main fallow, wheat, pasture treatments and estimated parameters for soil nitrogen change. The trend lines of seven treatments including three that were begun in 1949 are shown in Figure 1. Then, using the estimated parameters the effect of eleven different sequences involving fallow, wheat and pasture on soil nitrogen was simulated over 100 years using a starting soil nitrogen value of 0.10 percent and the mean crop and pasture yields recorded during the experiment (Fig. 2). The results are useful in summarizing some of the main effects of crop and pasture sequences on soil fertility as follows.

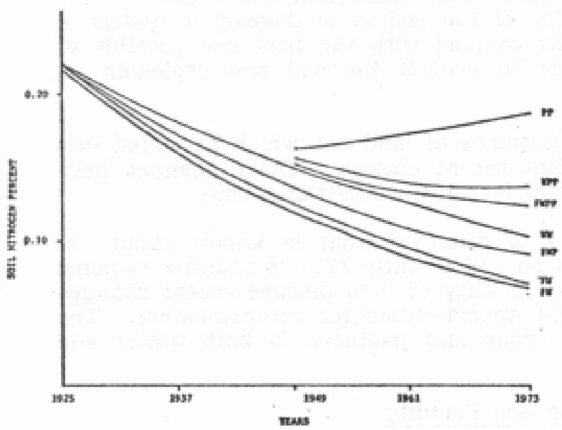

Figure 1. Trend lines of change in soil nitrogen with time of main fallow-wheat-pasture treatments in the permanent rotation experiment at Waite Institute. (F = Fallow, W = Wheat, P = Pasture)

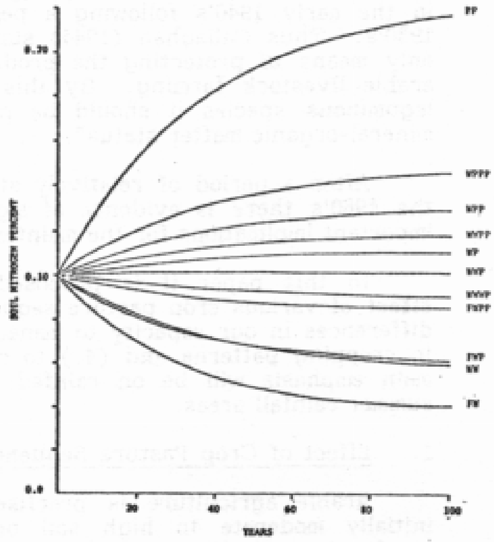

Figure 2. Simulation of expected soil nitrogen changes with different sequences based on parameters estimated from the permanent rotation experiment at Waite Institute.

(a) Effect of cultivation

Substantial losses of soil nitrogen have occurred in the Waite plots as a result of cultivation. Fallow was particularly destructive and, in the simulation, none of the treatments with fallow maintained soil nitrogen at 0.10 percent. Although continuous wheat also resulted in losses of soil nitrogen these were less than for fallow wheat even though wheat yields were invariably higher in the latter.

This relative effect of fallow on soil organic matter loss is broadly similar to that found in other Australian experiments in the winter rainfall areas (Table 1) with rates of loss varying with location.

Table 1. Relative annual loss rate of organic soil nitrogen as affected by fallow-wheat as compared with wheat-wheat rotations.

Station	State	Initial Soil N%	Rotation	Years of Expt.	Relative[<1] Annual Loss Rate %	Source
Werribee	Vic.	0.073	FW WW	35	0.05 0.00	Penman 1949
Rutherglen	Vic.	0.063	FW WW	36	0.01 0.00	Penman 1949
Chapman	W.A.	0.053	FW WW	23	4.0 1.0	Drover 1956
Wongan Hills	W.A.	0.027	FW WW	23	1.1 0.3	Drover 1956

[<1] Relative annual loss rate calculated by the equation $\frac{\log N_2 - \log N_1}{t_2 - t_1}$ where N_1 and N_2 are soil nitrogen contents at years t_1 and t_2.

Data for subtropical areas in Australia are not plentiful but what is available suggests high loss rates with cultivation. Studies at Narayen Research Station in Queensland on newly developed brigalow soils indicates annual soil nitrogen loss rates with continuous wheat and continuous sorghum over a 10 year period of 3.5 and 3.3. percent respectively (Russell unpublished data).

(b) Time taken for soil changes.

The Waite Institute plots also illustrate that soil fertility changes occur over decades. Thus even after nearly a half century of cropping soil organic nitrogen appears to be still declining on some plots. Whilst this slow change is an advantage when high fertility virgin soils are being cropped it also means that once soils are depleted it will take a long time to increase soil organic nitrogen levels.

Once parameters are estimated it is possible to calculate how long it takes for soils to lose half of the nitrogen they will lose before reaching equilibrium. The half life of fallow-wheat at the Waite Institute is 32 years. At Narayen change is more rapid and the half-lives of continuous wheat and continuous sorghum are 21 and 20 years respectively.

(c) Effect of ley periods

The beneficial effects of ley periods on soil organic nitrogen levels are well illustrated by the Waite plots. From a low level of initial soil nitrogen pasture can result in soil organic nitrogen increases with the highest equilibrium level recorded by permanent pasture. However, the objective in most situations is to maintain soil organic nitrogen commensurate with moderate cropping intensity. The simulation suggests that for the Waite plots this can be achieved with a wheat-pasture or wheat-wheat-pasture sequence i.e. cropping intensities of 50 and 67 percent respectively.[1]

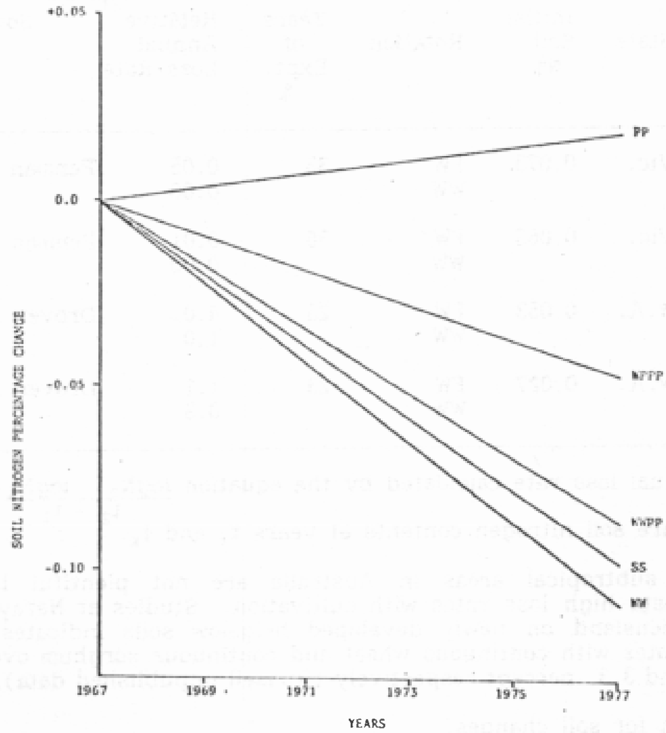

Figure 3. Linear trends of soil nitrogen changes in long term land use studies on clay soils previously carrying brigalow (Acacia harpophylla) at Narayen Research Station. Abbreviations as for Fig. 1 with addition of S = Sorghum.

[1] Cropping intensity of 100 percent refers to one crop per year over a period of years; 50 percent is one crop every two years etc.

Crop-pasture studies have been carried out at Narayen Research Station (lat. 25°41'S long. 150°52'E) since 1967. Linear trends of soil nitrogen for continuous wheat, continuous pasture, two years wheat-two years pasture and one year wheat and three years pasture treatments are shown in Figure 3. The effect of ley periods in this instance has been to slow the rate of loss of organic nitrogen. This experiment was established on a site with a high initial level of soil nitrogen (> 0.3 percent). Even with the low cropping intensity of 25 percent soil nitrogen declined on this soil although continuous pasture maintained levels.

Soil nitrogen increases following the use of ley periods have been recorded for a large range of situations in Australia (Clarke and Russell 1977). Increase of the order of 20-50 kg N/ha/year have frequently been recorded for short periods of time and instances of continued increase at this rate for decades have also been reported (Williams and Donald 1954, Russell 1960).

(d) Relative nutrient and physical effects of soil organic matter

This paper so far has concentrated on the effects of crop-pasture treatments on soil organic nitrogen. However, changes in soil organic nitrogen in arable soils closely parallel those of organic carbon and organic matter[1].

Soil organic matter levels affect both the availability of plant nutrients and soil physical conditions, especially structure. The relative importance of the nutrient and physical effects are likely to vary with soil and environment. Nutrient benefits are more easily measured and simulated than physical benefits.

Yield differences in test crops following pasture leys at Rothamsted could be explained entirely in nutrient terms (Boyd 1967, Gasser 1968). Basically this came down to improvements in available soil nitrogen status. Gasser found that wheat yielded most after leguminous leys, but given enough nitrogen fertilizer equally large yields were obtained after a sequence of arable crops. The results indicate that the physical effects of leys were unimportant on these soils - although, it may be noted that the experiments were carried out on structurally stable soils with moderate organic matter levels.

Equivalent Australian data to these experiments is not available. But situations have been observed (Greenland 1971) where nitrogen applied to poorly structured soils was insufficient to produce crop yields equivalent to those given on adjacent pasture land.

Physical effects are of considerable importance in some Australian soils such as the red brown earths used for cropping (Greenland 1971). These soils often have high fine sand or silt contents and a tendency to develop surface crusting and sealing. Deleterious effects on seedling emergence are not uncommon. Less information is available on other soils and one situation that is not resolved is the relative importance of nutrient and physical effects on the black earth and gray clay soils of Eastern Australia as soil organic matter levels decline with continued cropping.

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[1] With a carbon/nitrogen ratio of approximately 10:1 in cultivated soils organic carbon can be estimated by multiplying organic nitrogen by 10. Since organic matter contains approximately 58 percent carbon, organic matter can be estimated by multiplying organic nitrogen by 17.2.

Intrinsic soil properties clearly determine whether leys affect physical conditions and crop yield but climatic conditions are also important particularly as these affect the amount of plant growth and equilibrium soil organic nitrogen levels. Under semiarid conditions many Australian arable soils have low equilibrium soil nitrogen levels with values of 0.02 to 0.04 percent N not uncommon. Comparisons can be made with the equilibrium soil nitrogen content of 0.10 percent N for the Broadbalk experimental soil at Rothamsted (Johnson 1968) found under more humid conditions. With such low equilibrium levels in semiarid areas it is likely that physical effects of leys may at least be as important as nutrient effects in these areas. Certainly more attention to defining these effects is needed.

(e) Effect of grain legumes

The effect of pasture and ley periods on soil nitrogen status and subsequent crop yields in Australia has been well documented but there is very little information on the effects of grain legumes. This is partly because of the minor role that grain legumes play in Australian agriculture (Wood and Russell 1979). Thus only 1.3 percent of the area in crops in 1977-78 was sown to grain legumes although the proportion of the area sown and diversity of grain legumes grown has increased in recent years.

Some field evidence is available indicating beneficial effects of grain legumes on crop yields and soil organic nitrogen status. A wheat-peas (*Pisum sativum*) treatment was included in the permanent rotation experiment at the Waite Institute in 1926. Based on 50 years data (Waite Institute biennial report 1974-75) mean wheat yields from wheat-fallow were 1840kg/ha compared with 1526kg/ha from wheat-peas. However additional production of 970kg/ha of peas was obtained every alternate year. Mean annual dry matter production of the wheat-peas rotation was almost 50 percent greater than with fallow-wheat (3718 compared with 2546kg/ha). Analyses of soil organic nitrogen status (Greenland 1971) showed that although soil nitrogen levels had declined with the wheat-peas rotation the losses were not as great as with the wheat-fallow rotation. The use of a fallow-wheat-lupins-lupins rotation at Chapman and Wongan Hills in Western Australia over a period of 24 years gave higher wheat yields and a higher final soil organic nitrogen status than the fallow-wheat-pasture treatment (Drover 1956). White *et al*. (1978) with short term experiments in Victoria also found beneficial effects of wheat following lupins. Wetselaar (1967) found that after growing guar, peanuts and cowpeas for three years at Katherine in the Northern Territory only the soil from the guar plots had shown a significant increase in nitrogen content. The nitrogen content of soil from the peanut and cowpea plots was in fact, below the initial content but part of this difference was accounted for by the removal of nitrogen in the produce of these legumes.

The conventional wisdom is that grain legumes invariably have positive effects on short and long term soil nitrogen status but there is some evidence that substantial negative effects occur with some legumes in some situations. Soybeans and field beans are two grain legumes that have been shown to have negative effects on soil nitrogen status. Lucas *et al*. (1977) in Michigan found that soybeans and field beans returned less carbon to the soil than wheat, maize, grass and lucerne and soil organic matter depletion was greater with these legumes.

The information available suggests that we should cease to expect to make generalizations about the effect of grain legumes as a group on soil nitrogen status. The differences between grain legumes in nitrogen harvest index, amount of nitrogen removed in the grain (very high with soybeans) and in the efficiency of nitrogen fixation (very low in field beans) is so great that it is not surprising that, when added to site and season differences, there is conflicting evidence as to their effects. A first step in clarifying this situation would be to define the effects of each grain legume on short term nitrogen status for a range of environmental conditions in relation to nitrogen harvest index and dry matter returned to the soil.

There are a number of papers in this Conference which provide some data on the effects of grain legumes on soil nitrogen status which should assist in defining this problem. The unequivocal advantage of well nodulated grain legumes is their ability to grow in low available nitrogen situations (e.g. in stubbles) and to add nitrogen to the ecosystem.

2. Regional differences in the availability of pasture legumes

The usefulness of crop-pasture rotations depends upon the availability of self-regenerating annual or perennial legumes. Significant regional differences occur in Australia in the availability of such legumes.

The areas with effective winter rainfall are well supplied with pasture legumes, although local deficiencies may occur particularly in the lower rainfall areas. The general statement can be made that crop-pasture technology is available to maintain soil fertility in the predominantly winter rainfall areas at cropping intensities of 30 to 50 percent even if it is not always used in practice. The major pasture legumes are the annual *Trifolium* spp, particularly *T. subterraneum*, the annual *Medicago* spp especially *M. truncatula* and in some areas the perennial *M. sativa*.

In contrast a large part of the predominantly summer rainfall cropping areas does not have either the pasture legumes or the practices to maintain soil fertility at current levels with present cropping intensities. The major cropping soils in the subtropics are clays, particularly black earths and grey and brown clay soils. So far no productive summer growing self regenerating annual or perennial pasture legumes have been found for these soils. Soil organic nitrogen contents in the black earths and grey clays were initially high at 0.15-0.25 percent (Reeve *et al*. 1960, Reeve *et al*. 1963). Cropping has reduced these levels (Martin and Cox 1956) and in the absence of productive pasture leys or the use of applied nitrogen to increase crop production predicted equilibrium levels are very low (Russell 1980).

In the southern part of the subtropics annual medics (*Medicago* spp) do provide some nitrogen input and grow well where winter rainfall exceeds 230 mm (Clarkson 1977). The northern and western limits of useful growth of medics has been taken as 200 mm of April to September rainfall (Fig. 4). This covers a considerable portion of the subtropical cropping areas but not central Queensland. Also the medics are at the northern limits of their range and dry matter production is highly variable from year to year.

Lucerne (*M. sativa*) also has a similar inland limit to the annual medics and can make a useful contribution to soil fertility and subsequent crop yields (Whitehouse 1967). However lucerne is short lived unless specially managed (Leach 1978) and it is not entirely satisfactory as a pasture legume in leys.

More than 65 percent of rainfall over much of the region in Fig. 4 falls in the summer and much greater plant production (and nitrogen fixation) could be expected from a well adapted tropical pasture legume. Such growth is obtained from annual grain legumes such as Vigna unguiculata (cowpea) and Vigna radiata (green gram), Vigna mungo (black gram) and Lablab purpureus (lablab bean) but, growth beyond the first year is negligible. Perennial legumes such as Macroptilium atropurpureum can be established on the higher rainfall areas but perenniation does not occur on the clay soils. One of the possible reasons for this is the high soil salinity level at depths of 60 to 80 cm on many of the grey clay soils (Russell 1976, Fisher 1979).

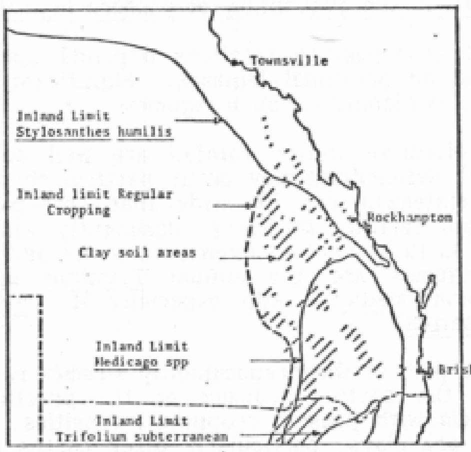

Figure 4. Inland limits of annual pasture legumes Trifolium subterraneum, Medicago spp and Stylosanthes humilis and areas of clay soils in north-eastern Australia.

A number of plant expeditions have searched for pasture legumes suitable for this area, mostly in South America without success. This search is continuing and expedition is currently in Mexico and Central America and one of its aims is collecting pasture legumes for clay soils of the subtropics.

Although a deficiency of pasture legumes occurs in the semi arid subtropical areas, the situation in the tropics is much brighter particularly on the non clay soils. A suite of pasture legumes including Stylosanthes hamata, Alysicarpus vaginalis and Centrosema pascuorum are adapted to these areas and could combine well in crop-pasture sequences. Experiments are currently underway at Katherine in the Northern Territory (McCown, Jones and Peake 1980).

One other aspect that should be mentioned is the possibility of grass- Azospirillum associations (Day 1977) contributing to the soil nitrogen status. Some of the grasses which have been noted as having an association with Azospirillum, such as Panicum maximum, are widely grown in the Australian subtropics. The precise contribution of nitrogen by these organisms to the ecosystem is not known, nor are the conditions under which their nitrogen fixation can be enhanced. It is probable that nitrogen fixation by Azospirillum occurs in a narrow window of environmental conditions, and takes place more readily under high than low fertility conditions and at temperatures exceeding 25°C. Its potential for useful manipulation by man is questionable although plant selection and breeding may be of value.

3. Recent Changes in Australian Crop and Pasture Patterns

Although crop and pasture technology has been gradually evolving over the last half century significant recent changes suggest a major shift in Australian crop and pasture patterns. These changes include increased cropping intensities, different fertilizer strategies and the development of new crops.

(a) Changes in cropping intensity

Areas planted to crops increased from 10.6 m ha in 1959-60 to 17.4 ha in 1978-79. Some of this increase has been due to the development of new areas of land. Some was former pasture land brought into cultivation, but some appears due to increases in cropping intensity in established areas. With record areas planted to wheat in 1979-80 this increased emphasis on cropping is continuing although some substitution from other cereal crops such as barley also appears to be occurring.

Associated with this increase in cropping has been a decline in sheep numbers from a high of 180.1 millions in 1970 to 135.3 millions in 1977. Although cattle numbers increased from 22.1 m in 1970 to 33.4 m in 1976 they have subsequently declined to a current estimated number of 26 m.

These data indicate increased cultivation of soils for crops and less emphasis on pastures and livestock. Such trends suggest increased pressure on soil fertility reserves and, in some areas, shorter ley periods. This has long term implications for equilibrium soil organic matter levels and ultimately crop yields and fertilizer practice.

(b) Changes in fertilizer application

There have been marked changes in the amount of nitrogen and phosphorus fertilizer applied in recent years (Fig. 5). Very marked decreases in phosphate use occurred in 1974-75 associated with relative price changes in superphosphate and various commodities. There has been some recovery in phosphate usage during the subsequent period but it is still lower than in the mid 1960's. Most of the decline in the use of phosphate has occurred in pastures whereas crops have been less affected. Thus in 1970 10.3 m ha of crops and 15.1 m ha of pastures were fertilized with superphosphate whereas in 1977 12.5 m ha of crops and 11.8 m ha of pastures were fertilized.

Nitrogen usage increased ninefold between 1960 and 1977. As a result the N:P ratio has undergone substantial changes (Fig. 6). The current Australian ratio of 1:1.3 is much lower than 15 years ago although still higher than that of the United States (1:0.23) and the United Kingdom (1:0.15). One of the largest recent changes has been in the amount of nitrogen applied to wheat. Between 1973 and 1978 the amount of elemental nitrogen applied to wheat increased more than fivefold from 32 to 178 thousand tonnes with much of the increase occurring in Western Australia. This suggests a fundamental change in cereal areas from a reliance of available nitrogen derived from biological nitrogen fixation in ley periods to applied nitrogen, associated at least partly, with increased cropping intensity. It may be significant that the very large increase is occurring in the area of the wheat belt with the highest rainfall certainty and the lowest soil nitrogen levels.

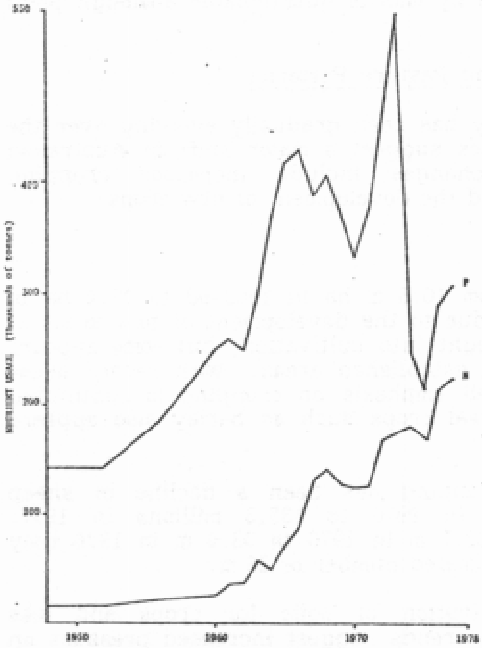

Figure 5. Changes in elemental N and P usage in Australia.

Figure 6. Changes in relative N:P fertilizer ratios in Australia, United States of America and the United Kingdom since 1948. (U.S. and U.K. data from FAO sources).

The effect of less phosphorus on pastures and on long term soil fertility maintenance is open to question. There is little doubt that the unfavourable phosphorus fertilizer/beef price ratios effectively halted development of new pasture lands in northern Australia (Australian Institute of Agricultural Science 1979). It is also likely that deterioration in the legume content of some of the pastures on new lands has occurred with less applied phosphorus. The effect on established temperate pastures is not as clear. It is certain that some luxury consumption of phosphate occurred when the price of superphosphate was as low as $17 per tonne in 1971-72. In some areas superphosphate was clearly being applied because of response to sulphur rather than phosphorus, particularly in areas where the residual value of sulphur is less than phosphorus. Also residual soil phosphorus levels steadily increased during the quarter century to 1975 and some decline in current use could have been predicted on this basis. It is likely to be some time before the significance and extent of soil fertility changes due to these changes in fertilizer strategy become clear.

(c) New crop and pasture plants

The last 15 years has seen a large number of new crop and pasture plants become available to Australian agriculture. This has been partly due to vigorous research in plant introduction, selection and breeding in Australia and partly due to overseas research in crops such as sorghum, soybean, sunflowers and rapeseed, which resulted in improved cultivars, basic knowledge of crop agronomy and the establishment of world-wide markets. Changes in crops have been marked particularly in summer rainfall areas. These new crops are significantly broadening the base of Australian agriculture and filling the need for diversification shown by the wheat and wool crises of the late 1960's.

Comparisons of areas sown of some of the newer crops are shown in Table 2. For some of these crops (e.g. rapeseed and green gram) such small areas were grown 15 years ago that early statistics are not available. Other new crops such as black gram, chickpea (Cicer arietinum) and pigeon pea (Cajanus cajan) are still in the very early stages of development.

Table 2. Recent changes in area of some of the newer crops in Australia.

Crop	Area in ha		Relative Annual Growth Rate (%)
	1964-67	1974-77	
Sorghum	188540	476716	11.3
Sunflower	4560	163986	35.8
Soybean	1610	36946	31.3
Lupins	800<[1]	118558	50.0

<[1] Estimated

These new crops have increased both farmers options and the options for new crop sequences and frequently have resulted in increases in cropping intensity. With legumes there is the benefit of increased nitrogen input to the ecosystem. The longer term effects of these crops on soil fertility will not be obvious for at least a decade.

The new pasture plants have extended the soil-climatic environments where improved pastures can be grown and increased the yield of established pastures. The Australian Herbage Plant Register shows that since 1965, 78 new legume cultivars have been released in Australia. Not only have new cultivars of established species been released but species new to Australian agriculture and in some cases world agriculture have become available. This is particularly significant in northern areas where the availability of new Stylosanthes species adapted to low soil phosphorus levels opens up large areas to pasture improvement. These new legumes increase our ability to develop new crop and pasture sequences and to maintain and increase soil fertility in the semi arid areas in Australia.

4. Opportunities for Intensification

Any view of opportunities for intensification has to take into account present trends, consider the implication of recent events, such as the high cost of liquid fuels, make predictions on the basis of research currently in progress and consider the soil fertility implications.

One of the present trends is an increase in cropping intensity. This trend is likely to continue with the greatest opportunities in the irrigated and higher rainfall areas. Intensities of 200 percent have been achieved in northern irrigation areas such as the Ord and Burdekin where sequences of rice-rice, soybeans-rice and soybeans-sunflower are practicable. Although agronomically feasible a more realistic intensity is three crops in two years as the management problems of large irrigated areas at high cropping intensities are considerable.

There is also scope for an increased cropping intensity in southern irrigated areas particularly where land is currently in pastures and cereal crops. In 1975-76 these areas comprised 80 percent of Australia's 1.47M ha of irrigated land. Opportunities exist in these areas in the development of adapted summer growing crops, such as soybeans and sunflowers, and integration with winter crops. Soil fertility maintenance is less difficult in both higher rainfall and irrigated areas than in lower rainfall areas because of the higher plant production and the greater range of soil and crop management options available.

In the rainfed areas of Eastern Australia both double cropping and intercropping present opportunities for further intensification. Over the period 1973-78 double cropped areas in Australia averaged 99,400 ha per year and, in 1978, 71 percent of the double cropped area was in Queensland and 21 percent in New South Wales. As the name implies double cropping involves growing two crops in the one year i.e. wheat and sorghum. In the past it has been used mainly in change over situations from a series of winter crops to a series of summer crops and it is rare for this practice to be used year in and year out. However, there is a scope for a more consistent use of double cropping by planting grain legumes after winter cereals. Such a practice is possible in areas with a predominantly summer rainfall, with total rainfall exceeding 650 mm and with available soil water storage capacity exceeding 150 mm. An example of double cropping is planting mungbeans after wheat, a practice which is used on the Darling Downs. The low available nitrogen status of the soil does not affect the legume but the lack of stored water means that the crop is very dependent on seasonal rainfall. With an increased range of grain legumes available opportunites for double cropping should increase in summer rainfall areas.

There is less scope for double cropping in the predominantly winter rainfall areas, but even here there are opportunities on the wetter fringes of the wheat belt and in areas where the effective rainfall exceeds 7.5 months particularly in relation to spring planted crops such as sunflowers.

Intercropping is widely used in areas of the world where hand harvesting overcomes the problems of crops maturing at different times. Advantages of intercropping for crops such as sorghum-pigeon pea and sorghum-chickpea include higher overall combined yield, more effective use of annual rainfall by occupying the land for a longer period, reduced soil erosion risks and soil fertility benefits due to the association of cereals and legumes. A large area of eastern Australia receives both summer and winter rainfall where intercropping is feasible and, with the development of new crops, the components of potential intercropped systems are now becoming available. The main limitation lies in the need for cultivars with complementary growth patterns so that the first crop can be harvested mechanically without damaging the slower maturing second crop.

Another recent trend already noted has been the increased use of nitrogen fertilizer. Nitrogen fertilizer usage is greatly affected by relative cost/return ratios and the risk factor in dryland areas. As cropping intensities increase in cereal growing areas it is likely that equilibrium soil organic nitrogen levels will be lowered and further fertilizer nitrogen application will be necessary if yields are to be maintained. This should result in a continuation of present trends to lower N:P ratios.

The high and increasing cost of liquid fuels is also likely to affect crop patterns. Two outcomes are possible. Firstly, it is likely there will be moves towards lower energy inputs into cultivation including approaches such as minimum tillage and the development of "once over" equipment. Secondly, crop plants are likely to be grown as a source of ethanol. Ethanol could be derived from new specialized crops, such as sweet sorghums, from established crops, such as cereal grains or from crop residues. Eventual cropping patterns will depend on both political and economic factors, with extraction technology also playing a part. Agronomically it is likely that the amount of plant material removed from the soil will be higher than at present and soil organic matter levels are likely to decrease. Increases in cropping intensity and greater use of nitrogen should also occur in any move into energy production from crops.

The trend to increasing crop diversity also seems likely to continue with the development of new crops. The grain legumes hold particular promise in dryland cropping areas and more than 30 species are available in world agriculture. Research into the processing of grain proteins may extend markets for some of these legumes just as the development of soybean processing technology has increased the world-wide markets for soybean. A major limitation to the wider use of grain legumes in Australia is the lack of stable, profitable and established markets.

CONCLUSIONS

There is little doubt that Australian agriculture is in a period of change in its crop and pasture patterns with increased crop intensification and diversification likely to continue into the 1980's and beyond. Agricultural research has played a significant role in increasing the range of crop and pasture options available. However further information is required on the effect of these options and of crop intensification on soil fertility.

Essentially this means a greater emphasis on long term land system experiments and more intensive monitoring of those experiments that are in operation. Long term experiments are not popular with either scientists or administrators. For scientists such experiments do not fit into the usual pattern of completion and publication of research. In fact opportunities for publication may be very sparse in the early stages of such experiments although they may be prolific in later stages (e.g. Rothamsted). Also institutional rather than individual commitment is necessary if work is to continue as staff changes occur. For administrators it involves taking a long term view and this may appear to be a luxury when resources are limited and there is pressure for immediate results. Nevertheless from a national point of view information on long term effects of different land use practices in key agroecosystems is necessary.

Crop sequences and crop-pasture sequences represent a major management option for affecting soil fertility in rainfed areas. It is important that both the short and long term implications of these sequences on soil fertility is known and understood.

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