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Farrer Memorial Oration*

The Progress of Australian Agriculture and the Role of Pastures in Environmental Change

C. M. Donald

Professor of Agriculture, University of Adelaide

Ecologists recognize that man may strive to achieve a more rewarding relationship with his environment in two ways. He may seek to adapt himself more closely to the conditions he finds or he may attempt to modify the environment to his particular needs. In the history of the two great sectors of agriculture—cropping on the one hand and the grazing of animals on the other—there are marked differences in the incidence of adaptation and change. Though the cropper probably began without tillage of the soil, he learned some six or seven thousand years ago to modify the environment for the growth of his crops by the use of simple tools for soil cultivation. Other modifications followed, irrigation, the clearing of forest and the use of organic manures. Simultaneously, adaptive measures were being devised, such as the introduction of crops from other regions, the definition of times and rates of sowing, and the development of implements, but throughout most of the history of cropping, purposeful change of the environment has been characteristic.

Contrast the herdsman. His terrain was mainly those lands unsuited for cropping and often regarded as wasteland. All grazing was communal and was frequently nomadic. In these circumstances the individual herdsman had little sense of proprietorship or of the need to conserve grazing resources or improve the environment. Great harm was done to much grazing land, especially in drier regions. Yet the herdsman cannot be censured, for many of the changes in vegetation under grazing pressure were slow or of considerable subtlety, so that they were recognized only in retrospect.

When grazing became settled, at first in more favoured regions, modest environmental changes were made through the construction of hedges, fences and watering points, but though these permitted livestock management—the control of numbers, and of mating and weaning—they did little to improve the productivity of the environment. All positive cultural practices were still confined to cropping, and pastures continued to be regarded as the spontaneous growth of herbage on untilled land.

It is only in the past three hundred years, and in significant degree only in the past fifty years, that the grazier has set out in a purposeful way to improve the environment of his pastures. The sowing of pasture seeds began on a few farms in northern Europe in the sixteenth century, and clover seed, doubtless poorly identified or cleaned, was on sale in London by 1620 (Fussell, 1964). But the use of organic residues was still confined to crops, and when the inorganic fertilizers were developed, they were used solely for crop production for over half a century. It was not until the eighteen nineties that useful sown pasture species were properly recognized and that experiments were conducted on the use of fertilizers on pastures. Not until the nineteen twenties was there any widespread acceptance of a positive approach to pastures, of planned environmental change. Davies (1952) wrote, 'It does need to be emphasized that this country (the United Kingdom) and with it the world at large, had until the past quarter-century, given no thought to grass as a crop. It cannot be too often repeated that grass *is* a crop.'

Yet the recent emphasis on improving the environment for pasture growth has in turn had remarkable consequences. The culture of pastures containing leguminous species is characterized by a heavy input of nitrogen and organic matter, a relatively small outgo of nutrients and the non-cultivation of the soil. These in turn have given environmental change vastly beyond expectation. Pasture legumes were at first grown primarily because they yielded well and gave good quality fodder even on poor soils. We now realize that this is but a part of their contribution; fertilized leguminous pastures can so raise the chemical and physical fertility of soils that a powerful instrument is available to transform the environment and productivity of many regions of the earth—notably so in Australia.

Adaptation and Change in Australian Agriculture

To appreciate the impact of sown pastures on the Australian scene, it is necessary to trace the changes in Australian agriculture since 1788. These can conveniently be reviewed in three periods, 1788–1900, 1900–1930 and 1930–1964, and in terms of the livestock industries and cereal production.

From European settlement in 1788 up to 1900, the principal adaptive measures and the main changes

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imposed on the environment of crops, animals and pastures were as follows:

Attempted adaptation to environment	*Purposive change of environment*
Introduction of British breeds of livestock	Clearing of trees
Development of Australian Merino	Destruction of native fauna
Introduction of the rabbit	Fencing, watering points
Introduction of northern European, Mediterranean and tropical crop plants	Ploughing, cultivation
Introduction of northern European pasture plants	Irrigation
Development of suitable cultural methods, e.g. time of sowing, stump jump implements, ring-barking, log rollers for clearing, stripper, header	

In brief, useful plants and animals were introduced, land was cleared and cultivated for cropping, cultural and harvest techniques were developed and transport facilities provided. The crop acreage reached 8·8 million by 1900; sheep numbers were 71 million and cattle numbers 8·6 million, a fall from 91 million and 11·7 million in 1895, due to a series of drought years.

There were, however, other great changes in the agricultural environment during this period, unappreciated or unplanned by land-holders. The most notable of these was the depletion of the fertility of the cereal areas, with a decline in decennial wheat yield from 12·8 bushels per acre in the eighteen sixties to 10·8 bushels in the eighteen seventies, 8·3 in the eighteen eighties and a desperately low

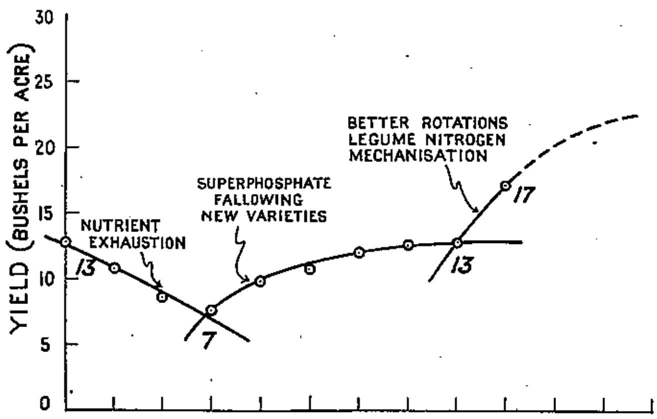

Figure 1

The trend in Australian wheat yields (decennial means) during the past century

7·3 bushels in the eighteen nineties (Figure 1). While part of this was due to the extension of wheat production into climatically less suitable areas, the depletion of soil fertility, especially the soil phosphorus and nitrogen, was the paramount factor. Despite some technical advances in cereal growing, the environment of the cereal areas deteriorated to a serious degree.

Marked changes also occurred in our pastures. In southern Australia, pastures of native perennial grasses, unadapted to grazing by sheep and cattle, were extensively invaded and even permanently replaced (especially following cultivation) by chance introductions from the Mediterranean basin of many annual plants—grasses, clovers and other species. This massive invasion may, on balance, have been slightly favourable in total effect.

Many other pastures of perennial grasses underwent notable change, even where little invasion by exotic species occurred. Taller grasses (e.g. *Themeda*, *Panicum* and taller *Stipa* spp.) were reduced or eliminated by grazing, leaving a community of short grasses (e.g. *Danthonia*, *Chloris* and short *Stipa* spp.). Nevertheless, though carrying capacity was low, the native pastures of southern Australia were generally well suited for grazing by Merino sheep, as noted by Charles Darwin (1845): 'The secret of the rapidly growing prosperity of Bathurst is that the thin brown pasture, which appears to the stranger's eye so wretched, is excellent for sheep grazing.' In coastal and sub-coastal Queensland the annual burning of pastures, together with grazing pressure, reduced mixed grass communities almost to monospecific swards of the inferior, fire-resistant speargrass (*Heteropogon contortus*) (Shaw, 1957). Some of these changes, which are reviewed in detail by Moore (1962), may have slightly increased the carrying capacity of the native pastures; most were disadvantageous.

In the semi-arid areas, there was notable failure in the adaptation by settlers to the new environment. Especially in regions in which tree or shrub species constituted a large part of the available forage, the rates of stocking were unknowingly based on the total quantity of forage present, rather than on the annual growth increment. The outcome, as in many other dry regions of the world, was inevitable and disastrous. By 1900 the numbers of animals vastly exceeded the capacity of the environment to support them, so that destruction or damage of the vegetation was followed by a precipitous decline in animal numbers when drought occurred. Thus in the western division of New South Wales, with its semi-arid or arid climate, sheep numbers fell from 13·6 million in 1891 to 5·4 million in 1900, and have subsequently never exceeded 9·1 million. Under sedentary use, the deterioration of much of this low rainfall country proceeded far more rapidly than had occurred in 'older areas' of the world grazed by nomadic flocks.

It was in this period that the rabbit, introduced from Europe, multiplied to cause huge losses through its direct competition with domestic livestock for fodder supplies. Here was a notable example of a deliberate measure which was to prove seriously injurious to Australian agriculture. Many of our weeds were also deliberate introductions during this period, notably prickly pear which was to occupy 60 million acres by 1925 (Dodd, 1940).

It can be said of our first hundred years that we greatly damaged our croplands, and induced many changes in our native pastures, most of them disadvantageous, none of them strongly beneficial.

The second period we can conveniently recognize is from 1900 to 1930, and again developments may be listed in the two categories:

Attempted adaptation to environment

- Further progress in cultural methods
- The bare fallow in cereal production
- The Farrer wheat varieties and locally bred varieties of other crops
- Progress in the control of animal diseases
- First introductions of Zebu cattle
- Expansion of systematic plant introduction
- Use of pasture legumes for better fodder production
- Growing use of insecticides and pesticides

Purposive change of environment

- Use of superphosphate on cereals
- Limited use of potassium and nitrogen fertilizers
- Earliest use of trace elements on cereals
- Control of prickly pear
- Further clearing and irrigation

In the central cereal areas the acute deficiencies of phosphorus and nitrogen of the late nineteenth century were respectively met by quite different means. The use of superphosphate (the first experiments were by Custance at Roseworthy Agricultural College in 1882) was widely adopted by wheat growers during the early part of this century and represented the first amelioration of the adverse soil environment of southern Australia. Forty-five trials in several States gave an increase in mean yield from 8·1 to 13·4 bushels of wheat per acre. The nitrogen deficiency was partially met, not by any improvement of the environment but by adaptation—by greatly extending an ancient technique for the more rapid exploitation of the soil, namely the bare cultivated fallow. It was erroneously thought that the fallow gave its benefit exclusively by water conservation and weed control, but we now realize that in many areas its principal stimulus to yield was by accelerated oxidation of the soil organic matter to give readily available nitrogen to the ensuing crop. Thus phosphorus and nitrogen were provided. Concurrently, the first wheats bred for the Australian cereal environment were released by Farrer, to dominate the industry for two decades because of their adaptation to Australian conditions. Under the influence of these factors, the wheat yields of 7·3 bushels/acre in the eighteen nineties rose to 9·8 bushels/acre in 1900–1910, 10·7 bushels/acre in 1910–1920 and 12·0 bushels in the nineteen twenties (Figure 1).

But these increases depended heavily on maladaptation to the environment, on the fallow as the means of providing available nitrogen by exhaustion of the native soil organic matter. Though yields rose from 7 to 12 bushels due to superphosphate, fallowing and the breeding of new varieties, the system proved unstable and in many districts there was a decline in yield from 1920 onwards (Cornish, 1949). The depletion of organic matter, loss of soil structure and exposure of over-cultivated soil to wind and water, led to erosion on a scale that threatened the stability of agriculture both in well-watered and less favoured cereal areas.

The use of fertilizers on pastures had its beginnings in this period, with emphasis on greater feed production and with little appreciation of its influence on fertility. The principal text on pastures (Breakwell, 1926) emphasized the prospects for increased fodder production both by grasses and legumes, but made only slight reference to possible influences on soil fertility.

Thus despite a modest input of phosphorus, due to the cumulative value of the fertilizer used on crops, this second period, 1900–1930, showed further deterioration of cereal environments because of exploitive agriculture, and of damage to many native pastures due to continued overstocking of swards of inherently low carrying capacity. In all, despite higher cereal yields due to accelerated soil exploitation, this was a further period of decline of the agricultural environment.

In this period there was growing recognition of the extreme poverty of most Australian soils. Probably because of the impact on European settlers of deficient rainfall as a major limitation to agricultural production, the greater limitation imposed in many areas by low soil fertility was either unrecognized or not squarely faced.

The third period, 1930–1964, marks the advent of remarkable positive environmental change, as shown by again listing the two sets of factors:

Attempted adaptation to environment

- Reduction in bare fallow
- Extensive measures for soil conservation
- Continued plant breeding, especially for disease resistance in cereals
- Organic weedicides, insecticides and fungicides
- Plant collection missions overseas
- Development of many pasture ecotypes
- Studies of pasture utilization
- Control of rabbits by myxomatosis
- Great progress in animal disease control
- Advances in drought feeding
- Mechanization of clearing, crop culture, harvesting, dairying
- Use of the aeroplane in agriculture

Purposive change of environment

- Clearing of extensive infertile lands
- Use of superphosphate on pastures as well as crops
- Increased use of other major elements on pastures
- Extensive use of trace elements
- Fertility lift due to fertilized leguminous pastures:
  - (*a*) by replacement of native pastures
  - (*b*) on areas cleared from low value forest and scrubland
  - (*c*) within cereal rotations
- Further development of irrigation

A dominant new factor in environmental change emerged in this period, namely the raising of the fertility of vast areas of poor soils through fertilized leguminous pastures. Here was a major reversal from the deterioration of the agricultural environment which had continued, with only local exception, from the first settlement until 1930. Pasture development is giving a change in our agriculture quite unparalleled by any development of the past, whether viewed in terms of soil fertility, crop yields, animal production or the stability of farming systems. While many other important factors, including the adaptive measures listed above, have increased both efficiency and output to a marked degree, and while irrigation has improved the environment of relatively restricted areas, *the use of fertilized, leguminous pastures stands as the greatest factor of favourable environmental change in our agriculture since first settlement.*

The Impact of Sown Pastures

The transformation of the poor soils of southern Australia through fertilized leguminous pastures is wholly comparable to the reclamation of lands from beneath the Zuider Zee. Though less spectacular, and fortunately less expensive, it is not only raising the productivity of settled areas, but is enabling the conversion of useless scrub and poor forest into pasture lands of satisfactory productivity. The effect of these sown pastures has been to provide relief from the intense soil nutrient deficiencies of most of Australia, notably the deficiency of nitrogen. The input of elements to the soil is occurring through the fixation of nitrogen and carbon from the air by the legumes of the sown pasture and through the added phosphorus, sulphur, potassium and the trace elements of the fertilizers. But the total effect on soil fertility is much more far-reaching than a mere list of elements ; there is a marked increase in the level of soil organic matter with all the consequences in terms of steady nutrient supply, cation-exchange capacity, improved structure, more ready tilth and resistance to erosion.

While there is no wholly satisfactory single index of soil fertility, the level of organic matter, or of the dependent nitrogen or carbon of the soil, is the most reliable. Studies at Crookwell, New South Wales, showed a threefold lift in the nitrogen in the surface four inches of the soil from 0·06 to 0·18% under the influence of subterranean clover and superphosphate (Donald and Williams, 1954), equivalent to an input of 1400 lb. nitrogen per acre. Russell (1960) in his studies at Kybybolite, South Australia, recorded increases from 0·06 to 0·25% nitrogen in the 0–2 inch horizon. These changes are in progress on more than thirty million acres of Australian soils. On land used for cropping, where there is an outgo of nitrogen during the cropping phase, the introduction of ley pastures with the rotation is nevertheless giving a heavy net input of soil nitrogen, as illustrated by the rise from 0·089 to 0·132% soil nitrogen during six years of leys and crops on a South Australian wheat farm (Goode, 1963). This is equivalent to a net input of over 80 lb. nitrogen per acre per annum over the six-year period.

Some impression of the total addition of nitrogen by the fertilized sown pastures of southern Australia, a measure of the environmental change, is given by the estimate that in the quarter century, 1935 to 1960, the value of the nitrogen added to the soils under sown pastures was of the order of £1,600,000,000 (Donald, 1960). Clearly, however, soil fertility has no value *per se*. The worth of this environmental change is the extent to which it can be converted into saleable products, into crops, meat or wool. It is necessary to distinguish between permanent pasture, with sustained use by grazing stock, and the temporary ley, a short-term (1 to 4 years) pasture used in rotations in which there is emphasis on crop production. The permanent pasture is assessed simply by its output of livestock products, the pasture ley both by livestock products and its influence on crop yields.

In the case of animal products, the nitrogen input by pasture legumes is effective in raising livestock production both through the quantity and quality of the fodder produced by the legumes themselves and through the influence of the improved fertility on the growth, edibility and nutritive value of other pasture species. As a single example one may compare the yield and rates of growth of native pasture (*Danthonia* spp.) with that of a neighbouring fertilized sown pasture of grasses and legumes on the southern tablelands of New South Wales. During a four-year period the maximum yields (dry weights) recorded were 29 and 75 cwt per acre respectively, and the highest growth rates 29 and 148 lb per day (Donald, unpublished). It is these increases in pasture growth, commonly associated with improvement in nutritive value, which have given such notable increases in carrying capacity.

Figure 2 shows the relationship between the extent of pasture improvement and the increase in livestock numbers (cattle × 7 + sheep) in each of the States in the period 1947 to 1963. Calculation from the fitted regression shows that each additional

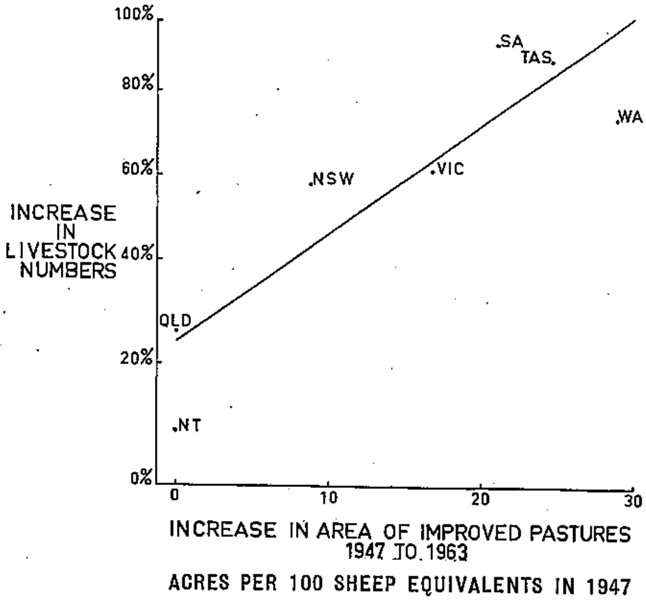

Figure 2

The relationship between the increase in the area of improved pastures and the increase in livestock numbers (cattle × 7 + sheep) in all Australian States from 1947 to 1963

improved acre has led to an increase of 1·6 sheep, and that of the total increase in numbers throughout the Commonwealth, 48% is associated with pasture improvement, while 52% is due to all other factors combined—to myxomatosis, disease control, fodder conservation, fencing, watering, irrigation, improved transport and so on. This value conforms closely to that of Kinsman and McLennan (1961), who examined the dependence of gains in stock numbers on pasture improvement in the major statistical divisions of four States (New South Wales, Victoria, South Australia and Western Australia) in the period 1950 to 1959. Their figure for the component of the increase in numbers due to pasture improvement was 46%, with an increase of 1·3 sheep per acre of improved pasture.

It will be seen in Figure 2 that the value for Western Australia lies appreciably below the line which would give the best fit to the values for the other States.

This may be a reflection of two aspects of pasture development in Western Australia, first the great rapidity with which sown pastures have extended in recent years through the development of new areas, and secondly the wide incidence in Western Australia of the infertility disease of sheep on pastures with a high content of subterranean clover. As a consequence, flock increase has not been able to keep pace with the new potential of the pastures.

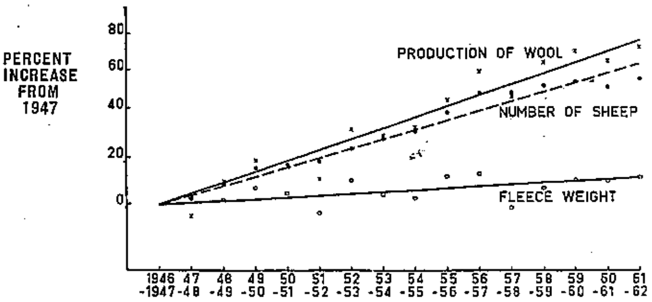

Figure 3

The increase in wool production, number of sheep and fleece weight from 1946/47 to 1961/62. The scale on the left is a log scale of relative numbers compared to 1947 (i.e. log 100 to log 180)

If we consider total wool production, sheep numbers alone do not provide the full story. Figure 3 shows the cumulative rates of increase of wool production, sheep numbers and fleece weight for the period 1947 to 1963. The rates are:

Wool production:	4·0% per annum
Numbers of sheep:	3·3% per annum
Fleece weight:	0·7% per annum.

On this basis we can allocate 83% of the increase in wool production since 1948 to sheep numbers and 17% to the increase in fleece weight. If we accept that 48% of the Commonwealth increase in sheep numbers is due to pasture improvement (the percentage will in fact be somewhat greater for sheep and less for cattle due to the relative distribution of the two classes of livestock), we can then proceed to the analysis shown in Figure 4. Of the total increase in wool production (=100), 40% is then due to the effect of pasture improvement on numbers, 43% to the effect of other factors on numbers and 17% due to the increase in fleece weight. Because of the considerable seasonal fluctuation in fleece weight from year to year, analysis of the cause of the upward trend from 1948 to 1963 is difficult. There is no evidence of any genetic change in the Australian flock during this period, though some slight contribution cannot be discounted. It is suggested that a great part (perhaps nearly all) of the increase is due to pasture improvement. This conclusion is based on the considerable, though very variable, increases which have been recorded in comparisons of fleece weight on sown pasture compared with native or volunteer pasture. They range from increases of 11% (10·2 lb on native pasture, 11·3 lb on sown pasture, Canberra (C.S.I.R.O. Leaflet, 1953)) to about 20% (9·9 lb to 11·8 lb, Table 3; 8·4 to 10·5 lb Crookwell, N.S.W. (Clunies-Ross *et al.*, 1937)) and even to a spectacular increase from 5·5 lb to 10 lb (Armidale, N.S.W. (Rural Research in C.S.I.R.O., No. 7, 1954)). In each instance the rate of stocking was substantially higher on the sown pasture than on the native pasture.

It is considered, therefore, that at least half the increase in Australian wool production in the past fifteen years has been due to the influence of pasture improvement on sheep numbers and on fleece weight.

The increase in milk production in Victoria due to pasture development would be of particular interest but cannot be assessed because figures for milk production are available only on a State basis; however, there can be no doubt that a very substantial part of the gain is due to improved pastures. As yet pasture development has had less influence on Commonwealth beef production because Queensland and the Northern Territory, which have 55% of all the beef cattle, are just beginning a pasture development program.

When we turn to the cereal areas, the influence of introducing temporary leguminous leys into the rotation is very striking. The immediate consequence is that dependence on a meagre store of soil nitrogen for crop growth is replaced by a substantial input of nitrogen through the ley. This is associated with the building of organic matter, giving also a greatly increased resistance to soil erosion. A secondary consequence of great importance in many districts

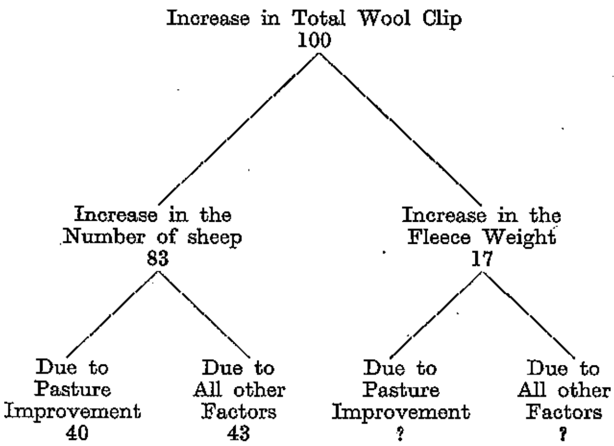

Figure 4

An analysis of the component factors in the increase in the Australian Wool Clip, 1947 to 1963

has been the discontinuance or modification of the use of the bare fallow, which loses significance for the nitrogen nutrition of crops when legumes are grown in the ley. For example, the proportion of wheat sown on bare fallow in South Australia declined from 76% in 1950 to 46% in 1958 (French, 1963); in Western Australia the ratio of fallow to crop in the cereal belt fell from about 1 : 2 in 1935 to 1 : 3 in 1955 in the drier parts of the wheat belt and to as low as 1 : 7 and even 1 : 18 in wetter sectors (Baron-Hay, 1958). The simple wheat-fallow rotation has been extensively replaced by rotations in which there is an alternation of a pasture phase and a cropping phase, the latter either with or without a fallow component. Furthermore, the specific conditions under which the fallow is useful, within a framework of crop-ley farming, either for moisture conservation or for nitrogen release, are being defined in relation to

TABLE 1

Surveys of the influence of leguminous leys in cereal rotations on the yield and protein content of wheat

Region	Detail	Yield (Bush/Ac) No Leguminous Ley	Yield (Bush/Ac) After Leguminous Ley	Protein (Percentage in grain) No Leguminous Ley	Protein (Percentage in grain) After Leguminous Ley	Reference
(a) Southern wheat belt of New South Wales	Comparison of 'paired crops' (i.e. on 'clover land' and 'non-clover land' in the same paddock) 14 pairs. 1959, 1960, 1961	21·4	35·6	9·3	11·4	A. C. Taylor*
(b) Southern wheat belt, New South Wales, Lockhart Shire	306 crops on 81 farms; 159 after clover, 147 no clover	—	—	10·2	12·0	A. C. Taylor*
(c) Western Australia	Survey of 5,956 cereal crops	12·0	15·2	—	—	H. Fisher*
Lower North cereal area of South Australia	(i) County Gawler, 15–17 inch, mallee and black soils, high pH, initial fertility low; pasture legumes (medics) very successful in leys since about 1950	1931–40 15·7	1951–60 23·8	—	—	Webber, 1964
	(ii) County Light, 18–21 inch, red brown earths, initial fertility moderate; less progress in use of leguminous (sub-clover) leys	17·4	19·8	—	—	

* Private communication.

rainfall and soil type (French, 1963). The consequence of the fertility improvement, and especially of the better nitrogen nutrition of the crop, has been a notable rise in wheat yields. Following more or less static values throughout the nineteen twenties (12·0 bushels), nineteen thirties (12·5 bushels) and nineteen forties (12·8 bushels), there was a remarkable increase to 17·1 bushels in the nineteen fifties (Figure 1). The statistical returns do not permit any analysis of how much of this gain may have been due to the introduction of temporary leguminous pastures (leys) into cereal rotations, but there is ample evidence of the major contribution by leys to soil fertility and the yield of cereal crops.

Two types of data are available; firstly, there are surveys in particular seasons over a considerable number of properties or over a district, permitting comparison of the yields of crops grown after leguminous leys with those of crops grown in rotations without such leys (Table 1). Secondly, yield trends can be examined on a few properties which have kept good records; here production before and after the introduction of leguminous leys can be compared (Table 2). These show remarkable increases in yield due to the changed environment of the cereal crop; individual properties have shown increases up to 100%; a comparison over 14 farms at Wagga, New South Wales, showed an increase of 68%, and a survey over nearly 6,000 crops in Western Australia an increase of 27%. Perhaps the most striking evidence of the value of pasture leys is provided by the trend of wheat yields in two counties in South Australia. County Gawler, with lower rainfall and poorer virgin soils, has overtaken County Light, with its more favourable environment, simply because of the greater progress in the use of leguminous leys.

In one sector of the Australian cereal belt, the north-west wheat areas of New South Wales and the Darling Downs and grain sorghum districts of Queensland, this pattern of change has not occurred. Here the soils, mainly black earths, are of much higher natural fertility; continuous cropping, often incorporating a short summer fallow for moisture conservation, has continued unchanged with apparently satisfactory maintenance of yields. Yield trends tend to be obscured by high rainfall variability, but there is nevertheless evidence of declining soil fertility. Interest in the nitrogen nutrition of crops here tends to be directed towards the use of nitrogenous fertilizers, but the form of land use giving long-term stability has yet to be fully defined for this region.

In considering the contribution of leguminous leys to cereal production, it is not sufficient to consider crop yield alone. If cereal land is sown to pasture, and the pasture is left down for two or three years, then the area of crop on the farm will be reduced compared with that under a wheat-fallow rotation. This in fact is characteristic of the early years of ley farming. But as fertility is raised, the soil shows capacity to carry several successive crops after a ley period, so that the number of crops within any period of years becomes greater than the 50% of the fallow-wheat rotation, or the 33% of the fallow-wheat-oats or fallow-wheat-rest-a-year rotation. For example on Yorke Peninsula, South Australia, a two-year rotation of barley and leguminous pasture (*Medicago tribuloides*) has given such a continuing increase in fertility that it is being replaced on many properties by a pasture-wheat-barley rotation, with two crops in three years. Similarly, A. T. Pugsley (private communication) writes of the southern wheat belt of New South Wales: 'A striking reflection of the fertility build-up is apparent in this region, where farmers are successfully growing 2, 3 and 4 successive crops after a ley period. A stepping-up of intensive cropping is in itself more important than wheat-yield increases, since we realize that climate sets a very definite limit to our yield ceiling.' While all may not endorse this relative evaluation of these two components of increased production, the cropping intensity factor is clearly of great importance as another outcome of fertility lift.

The other major factors in increased yields during the past 15 years are the release of new varieties and mechanization. In Victoria, where average yields are now 50% greater than in pre-war years, it is considered (W. J. B. McDonald, private communication) that about half the total increase in yield can be attributed to increases in soil fertility associated with leguminous leys; and half to new varieties and the greater timeliness of cultural operations made possible by mechanization. Table 3 shows a quantitative analysis for South Australia indicating that new varieties have contributed less than one-quarter of the increased yield between 1921–40 and 1951–60, with the balance

TABLE 2

Examples of the influence of leguminous leys on cereal and wool production on individual wheat and sheep farms

(a) Property at Rosedale, South Australia, 18 inch rainfall (Goode, 1963, and private communication)

	Yield of Wheat (Bush/Ac)	Wheat Production (1947–50 = 100)	No. of Sheep	Fleece Weight (lb/head)	Total Clip (lb)
1947–50 ..	22·0	100	251	9·1	2294
1951–54 (leys sown)	25·7	77	403	9·9	3990
1955–58 (leys first cropped)	43·3	117	587	10·3	6075
1959–62 ..	45·1	139	625	11·8	7431

'Such effects as improvements in operating plant, subdivision, control of rabbits, weeds and insect pests, change of sheep breed and proportion of ewes to wethers, and responses to fertilizers have all been relatively minor during the period under review.' (For other South Australian properties see Webber, 1964; Bicknell, 1964; Michelmore, 1964; Tiver, 1964.)

(b) Wongan Hills Research Station, Western Australia, 14 inch rainfall (H. Fisher, personal communication).

Period	Development	Yield (Bush/Ac) Wheat	Yield (Bush/Ac) Oats	Wool per Cleared Acre (lb)
1926–35	Development commenced 1925	13·5	10·5	—
1936–45		13·9	15·0	2·6
1946–50	Clover estab. commenced 1946	13·3	19·1	3·8
1951–55	First crops on clover land, 1951	19·5	21·8	5·5
1956–62		21·1	25·3	5·7

(c) Research Stations in Victoria (Experimental plots, not whole property, Sims, 1964)

	Rutherglen 22½ inch rainfall		Longerenong 16½ inch rainfall		Walpeup 13 inch rainfall	
	Yield (Bush/Ac)	Protein (Percentage)	Yield (Bush/Ac)	Protein (Percentage)	Yield (Bush/Ac)	Protein (Percentage)
On regularly cropped land, fallowed	13·8	7·7	45·9	9·6	21·8	8·5
After 2-year ley, no fallow	24·5	8·7	47·9	10·5	26·9	11·1

TABLE 3

A partial analysis of the factors influencing wheat production in South Australia in the period 1920 to 1960

	1921–40	1941–50	1951–60
Relative yield of varieties in use*	100	103	116
All other factors affecting yield (environmental and management)	100	123	156
Yield per acre	100	127	181
Area of crop	100	65	50
Total production	100	82	90

* The relative yield of the varieties is based on data kindly provided by Dr. K. W. Finlay, Waite Institute, South Australia, who has recently compared a considerable number of Australian varieties in six trials. The above values for relative yield are calculated from the mean yield of varieties which were sown on at least 50% of the State wheat acreage in 1929–30, 1946–47 and 1955–56 respectively (based on variety lists published by Macindoe, 1958); these seasons represent an approximate mid-point for each of the three periods. The values for 'all other factors affecting yield' are determined by division of line 3 by line 1.

attributable to environmental and management factors. The gain of 13% in yield due to new varieties in the 10 years from 1945 to 1955 (mid-points of the second and third periods) represents a mean annual yield increment of 1·2% compared with values ranging from 1·0% to 2·5% for wheat and barley in European countries during this period (Elliott, 1962). Our progress in this sphere has not been notable. Improved fertility due to leys is undoubtedly the main component of the environmental and management factors, and has perhaps contributed as much as 60–70% of all gains in wheat yields in South Australia during this period.

We should feel no little dismay that some fifty years were to elapse from the time William Farrer made the following observation (1893) until his viewpoint came to be realized on any substantial scale in the Australian cereal industry. 'I will conclude this letter by expressing my belief that if we hit upon a leguminous plant that can be economically grown with wheat, the yield of the latter would be so greatly increased that wheat growing would become a highly profitable industry.'

The evidence is clear that the sowing of fertilized, leguminous pastures, either as permanent pasture or as temporary leys, is changing our environment and our agriculture in a manner unprecedented in Australian history and perhaps without precedent elsewhere.

The Future Role of Pasture Development in Australia

Predictions of the future of pasture development in Australia and its consequences in terms of production, are subject to many limitations, in particular to the uncertainty of export prices for our principal products. Suitable land, in terms of climate, soil and topography, on which improved pastures can be developed, is available in all States though with a considerable variation between regions. There are some districts, such as parts of Gippsland, Victoria, in which production is moving towards the ceiling of development in terms of current knowledge, but such districts are few. In all southern States there remains great opportunity for further gains through pasture development both by the application of existing knowledge and by the further definition of species, fertilizers and techniques. Most of this development does not involve 'new land' in the sense of unoccupied, uncleared Crown land. Most of it lies on existing properties, often involving the replacement of inferior natural swards by improved pastures. As a single, crude, but nevertheless real example, we can compare Victoria with 77,000 square miles of country receiving over 15 inches of rainfall and with 16,400 square miles of topdressed pasture, and New South Wales with 177,000 square miles receiving over 15 inches but with only 14,200 square miles of fertilized pasture. Unimproved properties and those which have doubled or trebled their carrying capacity lie cheek-by-jowl. In addition there are considerable areas of uncleared country, such as the Pilliga scrub in New South Wales, parts of south-west Victoria and the tableland of New South Wales, which still call for effective, and economic development.

In the sub-tropical and tropical regions, notably the better rainfall areas of Queensland, pasture development is now at a stage comparable with that in southern Australia 40 years ago, but with the difference that research and extension are already defining the tremendous prospects for the next few decades. Again the technical problems revolve around the definition of suitable species and fertilizer practice; in some areas, such as the brigalow, the use of fertilizers is less critical, but for great tracts of country, fertilized leguminous pastures must be the means of changing the environment to attain an enhanced level of fertility and production. A broad vista for future development lies in the improvement of the coastal and sub-coastal speargrass areas through the use of Townsville lucerne (*Stylosanthes humilis*). At Gladstone, liveweight gain per acre of beef cattle on speargrass pasture has been raised from 23 to 100 lb per acre by the introduction of Townsville lucerne, and to 205 lb by the additional use of fertilizers (Division of Tropical Pastures, C.S.I.R.O. Annual Report, 1962–63). Cattle can be marketed one to two years earlier with direct gain to the grazier. Townsville lucerne is regarded by some workers as the 'potential subterranean clover' of the north and this would seem a not unreasonable assessment. In the south-east of Queensland the selection of suitable species has advanced greatly in the past decade (Bryan, 1963) through the work of the C.S.I.R.O. and the Queensland Department of Primary Industry. In some districts progress is now dependent only on adequate supplies of reasonably priced seed and on the fuller integration of new techniques into farming and pastoral practice. The vast area suitable for pasture development in north-east Australia may well exceed 100 million acres. Work at Katherine in the Northern Territory, an area characterized by its very short summer-rainfall season, is similarly showing great promise through the use of Townsville lucerne as a means of securing increased carrying capacity and greater liveweight gains.

We can confidently expect pasture development to extend within regions and properties where it is already practised and also into new regions where procedures are only now becoming defined.

Another factor is emerging which may well prove to be of major importance to stock numbers. It has been realized both in Australia (Arnold and McManus, 1960; Drake and Elliott, 1963) and elsewhere (McMeekan, 1956) that higher rates of stocking could be adopted to economic advantage on sown pastures in better rainfall areas. Even though rates have been 'stepped up' on improved pastures compared with natural pastures, there has been undue conservatism, based on traditional rates and husbandry practices of the past, and on fears of calamitous losses during drought. But it is clear that higher rates could be adopted in many areas without undue hazard. The potential increase is often considerable. Whereas the mean increase due to pasture development has been only 1·6 sheep equivalents per acre, current work suggests that the additional numbers might well be twice as great. These gains are of particular importance because they offer increased production on properties where the main capital investment has already been made. In a survey of 31 properties in the Western District of Victoria, Carney (1962) showed that higher stocking rates were associated with greater yield of wool per acre, no reduction in mean fleece weight and greater return to capital. 'It would appear that stocking rates are largely determined by the "degree of risk" which property owners are prepared to take, combined with skill to manage stock during uncertain seasons . . . but in many cases graziers preferred to remain understocked to avoid any worries about feed shortages.' White (1963) remarks that in Western Australia the demonstration of the potential for increased meat and wool production through higher stocking rates is the most important advance in that State since the advent of pasture improvement itself.

Can we expect the increase in sheep numbers (Figure 3) of 3·3% per annum in the period 1947 to 1962 to continue? It will be noted that the rate in the latter years is a good deal slower, but the provisional figure for sheep numbers in 1964 (165 million) brings the value close again to the fitted line of the graph. If we take account also of the probable impact of higher rates of stocking, there seems no technical reason (subject always to economic circumstance and especially to wool prices) why a rate of increase of this order should not be maintained. If the more conservative figure of 3% annual increase is adopted then the Australian flock will attain 265 million by 1980. Fleece weight may not sustain its increase of the past 15 years (0·7% per annum) because of the depressing effect of higher stocking rates. Turner (1963) indicates that gains of 2% per annum in fleece weight are possible within a flock by the selection of individuals on fleece weight but the likely influence of this practice on a national scale in the next two decades must be regarded as very slight. If we assume an increase for the next 16 years of 0·3% per annum, then the rate of increase in wool production would be 3·3% per annum.

The prediction of cattle numbers involves additional uncertainties. The future of beef production will depend heavily on the rate at which pasture development proceeds in Queensland. Past experience in Australia indicates a long lag between the earliest steps in pasture development and the general adoption of the practice over a region. While beef production in the southern States will share with sheep numbers in the upward trend, the impact of pasture development on cattle numbers and the output of beef in the summer rainfall areas will be less immediate. On the other hand, so active and productive is the pasture research program in Queensland and so keen the interest among producers that the great lag in pasture development in the south may be markedly curtailed in the north. Much will depend on seed supplies and the activity of extension services.

A factor of considerable importance in northern areas is the introduction of Zebu cattle and the development of various new breeds from crosses with British breeds (Francis, 1964). These have opened new prospects for beef production in tropical areas because of their adaptation to the climate and their resistance to tick infestation. C.S.I.R.O. studies (J. Kennedy, private communication) at Rockhampton (latitude 23° S.) have given liveweights of 778 lb for Zebu cross animals (Afrikander or Brahman crossed with British breeds) at 24 months compared with 620 lb for pure British breed cattle.

There has been a modest increase in the production of milk per cow in Australia (379 to 428 gallons per head from 1930 to 1960 or 0·4% per annum). Many dairy districts are backward in their application of existing knowledge, and predictions are so hedged in by problems of marginal production that they must rest more heavily on changes in the economic structure of the industry than on technical factors.

TABLE 4

A forecast of Australian wheat production to 1980 (millions of bushels)

Period	Yield per Acre (bush.)	Actual Annual Production	Estimated Annual Production from:		
			14 Million Ac.	16 Million Ac.	20 Million Ac.
1940–50 (actual)	12·8	146	—	—	—
1959–60 (actual)	17·1	173	—	—	—
1960–70 (estimated)	20·0	—	280	320	400
1970–80 (estimated)	22·0	—	308	352	440

(The mean acreage from 1961–2 to 1963–4 was 15·9 million acres.

If we turn to cereals, the outlook rests more firmly on established trends. It has been suggested earlier that a great part of the 33% increase in yields from 1940–50 (12·8 bushels) to 1950–60 (17·1 bushels) has been due to the use of pasture leys in the rotation. It is considered not unreasonable to apply the form of the curve recorded from 1900 to 1930, under the influence of superphosphate, fallowing and the Farrer varieties, to the extrapolation of the new curve commencing in 1950, though this new curve is of greater height. This procedure gives an estimated yield for 1960–70 of 20 bushels and for 1970–80 of 22 bushels per acre (Table 4).

No prediction of wheat acreage is attempted because the area sown to this crop is susceptible to marked and rapid change according to the economic outlook both for wheat and wool. Nevertheless, the influence of improved fertility on the intensity with which cropping will be undertaken must be borne in mind as a factor tending to increase the mean annual acreage. Another effect of increased yields is a greater margin of profit which has converted many marginal enterprises to sound farming practice; this again has a tendency to stimulate acreage increase. A wheat crop of 20 million acres is considered attainable if economic conditions are favourable.

A factor which could well carry the yield in the nineteen seventies above the 22 bushels per acre here predicted is the advent of new varieties. Although new varieties have been a contributory factor to gains in yield in the past 20 years, their potential contribution from 1970 onwards is likely to be far greater. Two points are involved. First, the breeding of new varieties is now more specifically oriented towards the improved fertility levels induced by pasture leys, so that a new relationship is established between fertility and genotype. Secondly, Australian cereal breeders are currently using a far wider range of parental material in their breeding programs than was the case in earlier years, and combined with new approaches within the programs themselves, there is promise of accelerated yield increment later in the present decade. For these reasons the forecasts in Table 4 may be conservative.

In most countries other than Australia and New Zealand there is a trend towards the use of fertilizers instead of pasture legumes as the source of nitrogen both for crop and pasture production, and it may well be asked whether we in Australia are failing to join the main stream of progress. There are, however, a number of factors which indicate legumes as our principal source of nitrogen for many years to come. First, this is a continent of poor soils and there is need not only for a great input of nitrogen but also of organic matter, with all its effects on fertility. Pasture legumes are the cheap and effective means of promoting this change. Secondly, fertilizer nitrogen is expensive in Australia relative to its price in other countries or to the value of products sold from the farm. Admittedly these relationships may change, but the changes would have to be of very considerable magnitude. Thirdly, there is little real evidence, though much propaganda, to support the contention that grass plus a successful legume, will give any less animal production than grass plus nitrogen (Donald, 1960). And finally, as far as cereal production is concerned, there is the paramount factor that in Australia cereals are combined with sheep raising, so that a leguminous ley in the rotation, though involving the loss of cropping years, is of value not only in fertility lift but in providing fodder supplies for stock.

Despite these comments, the importance of cheap fertilizer nitrogen to our rural economy should not be under-estimated. Not only is it of critical significance to sugar cane and the horticultural crops, but it has a growing role for a variety of special purposes in cereal and fodder production. Fertilizer nitrogen is of value in cereal areas where successful legumes for leys are not available, after leys in which legume growth is poor, where the available nitrogen has been leached from the soil by heavy rains, and for a variety of other special uses. Similarly the use of fertilizer nitrogen is likely to extend on pastures for such purposes as the production of a year-round sequence of fodders for city milk supply or the production of winter feed in fat lamb programs. The extension of these uses will depend above all on price relationships.

A factor which is limiting pasture development in many areas (and especially in Queensland) is the availability of ample cheap seed—and since the legumes are the key to progress, of cheap legume seeds. The wider promotion of pasture legume seed production programs, such as that undertaken by the Department of Agriculture in South Australia, could contribute very materially to the advancement of our agriculture. Subsidization of the purchase of seed during the early production years of a new species would also have much to commend it.

This discussion of the future of pasture development has been principally in technical terms. Obviously, however, development is directly subject to economic factors, first to the availability of the considerable capital needed for land preparation, seed and fertilizer, and not uncommonly for associated costs for fencing and watering points, and secondly to satisfactory returns on investment. During the past fifteen years the rural industries have been in sound economic condition and substantial re-investment has been possible. The current outlook is satisfactory and there seems no reason why pasture development should not continue to attract capital investment. While the returns will vary according to a great number of local factors, a survey by Duloy (1962) of the productivity of investment in the grazing industry of New South Wales showed that 'in the high rainfall zone (in contrast to the semi-arid pastoral zone) the main investment opportunity appears to be in additional pasture improvement and fencing'.

Gruen (1962) has examined the economics of pasture improvement in some detail. He concludes that the individual farmer can expect a long-term rate of return on his capital of between 14 and 22% with wool at 5*s*. per lb, and that this will be a better investment than additional land. On the other hand he draws attention to the possible influence of increased Australian wool production on the prices received for the Australian clip and suggests that the satisfactory return to the individual may not accrue to the wool growing community as a whole or to the Australian economy. It is difficult to assess this factor; past predictions of the likely trend in wool prices have for the most part proved of little value. There are problems in forecasting the market prospects for most of the commodities influenced by pasture improvement. They are subject to a global network of factors, many of them unpredictable, but modest optimism seems warranted. Certainly in the case of two of our pasture products (meat and milk products) the expansion of the local market due to population increase will alone absorb our present exports and additionally call for substantial increases in meat production by 1980.

Work on Pastures in Australia

Because of the extent to which the existing knowledge of pasture development still remains to be applied over great areas or numbers of properties, some workers tend to the view that research on pastures is no longer a pressing need. This is a wrong assessment which could seriously affect progress. We can recognize three fields in which a great deal more work is needed, namely in pasture production, in the utilization of the feed produced and in the utilization of the fertility induced by pastures.

In the production sphere, there are considerable gaps in our knowledge of many aspects of pasture nutrition, including the phosphorus and sulphur economy, the equilibrium level of fertility under various systems of land use, the use of trace elements and the role of fertilizer nitrogen *vis-à-vis* legume nitrogen. The introduction, breeding, assessment and seed production of new varieties has yet to provide pasture plants for many situations in which wholly satisfactory species are not yet available, while studies of the better seasonal distribution of feed calls for much increased study. All these aspects relate eventually to the better use of rainfall, a problem which may prove even more acute in northern areas because of the much greater intensity and variability of rainfall.

Our understanding of pasture utilization is meagre indeed. We know that much feed goes to waste and that stocking rates should often be heavier. But we lack a definition of the principles governing effective management, even within restricted environments. Complex plant-animal relationships are involved, yet there are few studies which have not laid prime emphasis on either the animal or the plant, while lacking interpretation of their changing interactions. Far more work is needed. Effective utilization is also likely to involve considerations of animal breeds, notably the further assessment of British versus Zebu-cross animals in a range of sub-tropical and tropical environments. The incidence of disease directly associated with sown pastures, notably the infertility of animals grazing on subterranean clover, continues to offer challenge to those concerned with the effective use of pastures.

There is inadequate appreciation of the need to utilize fertility. Where pastures comprise short leys within cereal rotation, the alternation of fertility lift and fertility exploitation is self-evident, but as emphasized by Pugsley (private communication), fuller definition of the chemical and physical soil changes influencing production is urgently needed. We know all too little of the phenomenon of nitrogen build-up and release and almost nothing of the release of phosphorus. G. H. Burvill (private communication) points out that soil improved by pastures has given cereal yields far greater than was achieved on virgin soils with heavy fertilizer application and asks 'Why?'. Perhaps the most pressing need is the study of the inter-relationship of improved fertility status and limited water supplies in cereal production; new cultural techniques, suitable varieties for these improved fertility levels, or altogether new practices such as treatment of soil or plant to reduce water loss, are possible approaches to this problem.

When we turn to permanent pasture, the exploitation of fertility poses a problem as yet scarcely considered. While heavy dairy production will draw appreciably on incremental soil nitrogen, the production of wool as a principal product exercises but little drainage of the fertility input. In these terms it is inefficient, leading towards a steady equilibrium at high fertility instead of heavy input and heavy exploitation.

This is a brief and incomplete account of pasture problems remaining to be tackled, but it suffices to indicate the great volume of work yet to be undertaken. We may question whether the allocation of research resources takes sufficiently into account the heavy continuing contribution of pasture development towards livestock production and cereal yields. Table 5 shows the allocation of Industry-funds to biological research. Although the full picture would be provided only by a total analysis of all biological research in these spheres, whether by the C.S.I.R.O., Departments of Agriculture or other agencies, the figures suggest that an altogether inadequate proportion of these funds is devoted to pasture production and utilization. The weighted average for the four agencies is only 28% yet the contribution of sown pastures to increased production has been of the order of 50%; it is considered that the contribution in the next 20 years will be even greater.

TABLE 5

The distribution of expenditure of Industry-Funds on biological research

Use of Funds	Wool Research Trust Fund 1963–4	Aust'n Cattle and Beef Research Committee 1964–5	Aust'n Dairy Produce Board 1964–5	Use of Funds	Wheat Industry Research Council 1963–4
For all biological research (£'000)	1570	768	124	For all biological research (£'000)	238
	%	%	%		%
Pasture production and utilization	25	33	39	Soil fertility and pastures	22
Animal production, nutrition and physiology	51	29	29	Tillage and weeds	9
Animal diseases and disorders	16	30	16	Wheat (69%):	
				Quality ..	26
				Breeding ..	9
Pest control ..	8	—	—	Disease ..	12
				Storage ..	8
Property management	—	8	16	Physiology ..	6
				Machinery ..	8

Derived and condensed by the author from data kindly provided by each of the agencies named and, for part of the wool research data, by the C.S.I.R.O. Industry surveys, extension activities, studentships, administration and contingencies are excluded. Each of these agencies also supports research programs in the processing and industrial fields. The above analyses are not formally endorsed by the respective industry agencies.

If we turn to extension work by the Departments of Agriculture (Table 6), the distribution of effort between pastures, field crops and grazing livestock indicates a somewhat more realistic allocation of resources. In all States but Queensland, 35 to 40% of extension work is devoted to pastures. The low figure for Queensland is of course directly related to the early stage of pasture development in that State, but one might reasonably ask whether a more liberal allocation of extension workers to pastures at this stage might contribute to the more rapid attainment of a full pasture program. Even in the other States, despite the percentage distribution of workers, it cannot be assumed that enough is being done, since the total strength of extension services in Australia is seriously below the national need. In passing, I can do no more than commend the work of the private farm management clubs and advisory services, which are an important supplement to the work of the Departments of Agriculture.

TABLE 6

The percentages of extension workers in State Departments of Agriculture engaged in work on pastures, crops and livestock

	N.S.W.	Vic.	Qld.	S.A.	W.A.
Pastures ..	36	40	19	35	38
Field crops ..	29	17	25	26	12
Sheep and cattle	35	43	56	39	50
	100	100	100	100	100

Derived from data kindly supplied by each of the State Departments of Agriculture. Where workers were shown as being engaged in two spheres (e.g. 'pastures and crops'), as was often the case, they were arbitrarily and equally allocated between the two categories. The horticultural industries and livestock industries not based on the grazing of pastures (pigs, poultry) are excluded. Analysis in these terms is not intended to suggest that these three sectors can be regarded as independent extension activities. The Tasmanian Department of Agriculture places particular emphasis on the integration of extension work with the total agricultural activity of each region.

Concluding Comment

The thesis is submitted that in the next twenty years, pasture development has more to offer Australia than any other country. In many countries problems of population pressure, economic resources, religious or sociological factors, the lack of mineral and power resources or of technical knowledge or skills, limit the role of pastures in food production or fertility improvement. In Australia we have vast areas of infertile 'improvable' soils within good rainfall zones, the necessary economic resources, and a considerable experience and growing knowledge of suitable animals, pasture plants, fertilizer practices and establishment techniques. We are in a phase of development in which pastures are enabling dramatic change of our agricultural environment and a transformation of soil fertility and production levels. While our efforts must be distributed across the whole field of agriculture, it is logical and proper that there should be specific concentration of effort on an activity which is proving so rewarding in our production and stability. We have the opportunity to convert the better watered one-third of Australia, with its great areas of poverty stricken soils, into lands of substantial productivity.

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