# CHAPTER 1

## EVOLUTION OF AUSTRALIAN AGRICULTURE: FROM CULTIVATION TO NO-TILL

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On the Australian landscape, two centuries of trial and error followed by extensive research has resulted in evolved agricultural systems more closely attuned, in the 21st century, to the fragility of the natural resource base and the vagaries of the Australian climate. The history of Australian agriculture is a study in farmer-based innovation as well as natural and man-made disasters. Major agricultural policy over that period occurred in response to such disasters rather than as a proactive process. It was the Australian farmer who tested the limits of the system and the nation is better off for knowing those limits so that the mistakes of the past are not repeated.

This chapter provides a brief account of the development of farming from first European settlement. Any student of agriculture should understand this evolution in order to appreciate the principles and practices now in place. The development of machinery occurred largely through the innovativeness of the Australian farmer whilst the farming systems of today have emerged largely through trial, error and necessity.

There is now heightened awareness of the environmental imperatives associated with rural landscapes as well as the economic imperatives for farmers and their communities. Knowledge is never perfect though and the search for improved understanding and better solutions must continue to underpin the ongoing evolution of Australian agriculture. This chapter traces Australian agriculture from European settlement to the chemical-based agriculture of modern times.

## PIONEER TECHNOLOGY

Cultivation in the early days of settlement was done by hand. There were no draught animals or machinery but human labour in the form of convicts was readily available (Jeans, 1977). This situation persisted into the 1820s even though ploughs were substituted for spades, hoes and other crude tools from about 1797. Due to lack of assistance from the British Government, primitive implements were invented and produced in Australia to help in the process of seedbed preparation. For over 100 years, until the 1930s, the horse was the chief source of farm power (Jeans, 1979).

### FROM MOULDBOARD TO DISC

Before land could be cultivated, timber had to be cleared. The remaining stumps and roots created great difficulties for the pioneer settlers (Wheelhouse, 1966). English ploughs, such as the light Rotherham plough, which were brought to New South Wales in the early days of settlement, were discarded and replaced by heavy wooden breaking ploughs (Figure 1.1) for use on virgin country (Jeans, 1977; 1979).

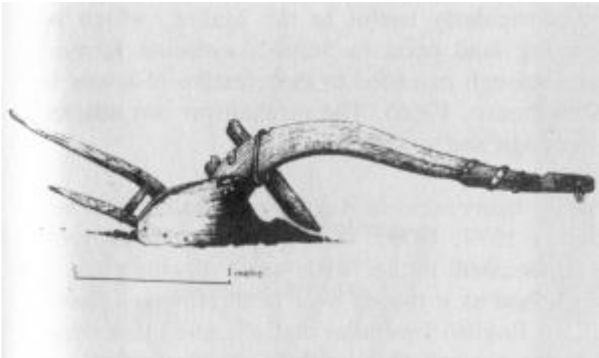


Figure 1.1 Heavy wooden breaking plough used for breaking up virgin country in the early nineteenth century
(Photo courtesy of D.N. Jeans)

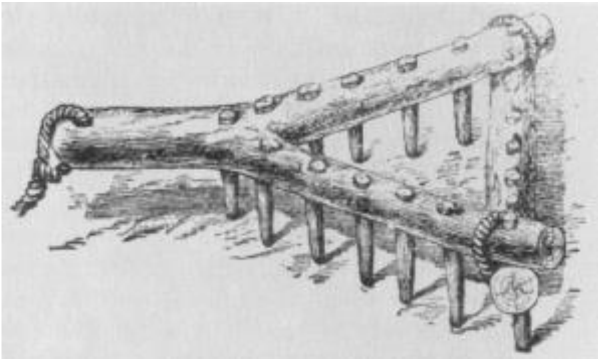


Figure 1.2 Home-made harrow similar to that used for "mullensing" or "Yankee grubbing" in the Mallee in the nineteenth century
(Photo courtesy of D.N. Jeans)

These ploughs were equipped with a sharp coulter and sharp mouldboard edge and were pulled by up to twelve oxen through the root mass to a depth of about 25 cm. It was possible to work up to 1.6 ha of land per week. By the middle of the nineteenth century, locally manufactured light ploughs could be bought for ploughing fallow or stubble. However, because of the inherently low fertility of the soil and the lack of fertilisers, Australian farmers continually had to break new ground, a process requiring a heavy plough. Iron ploughs generally replaced the wooden plough in the 1850s and 1860s (Jeans, 1977).

At about this time, 'mullensing' became a form of land preparation in the light scrub and timbered Mallee regions of South Australia and Victoria. A South Australian farmer named Mullens, after whom the method was named, cut trees down to ground level, sold the best timber and burnt the rest. He then used a V-shaped log with spikes driven into the undersurface: a horse was hitched to the pointed end and the crude cultivator was dragged along the ground; burying seed as it loosened the soil (Wheelhouse, 1966). This unique method of tilling the soil was attractive to other farmers because it was a cheap, simple and quick method of producing a grain crop. The method later became known as 'Yankee' grubbing in other States (Figure 1.2)

In 1876, Richard Bruyer Smith of Kalkabury, South Australia, invented the stump-jump plough and received a payment of £500 from the State Government for his efforts (Callaghan and Millington, 1956). The share and mouldboard were hinged so that they rose on meeting an obstruction in the soil. They returned to work again once the root was passed (Figure 1.3). The stump-jump principle was Australia's major contribution to the development of a plough that enabled scrub and stony lands to be profitably tilled. It was particularly useful in the Mallee, which by 1880 constituted most of the suitable wheat-growing land open to South Australian farmers (Jeans, 1977). The contribution of the stump-jump plough extended to the creation of towns in areas previously opened up by this invention (Wheelhouse, 1966). The mechanism was adapted subsequently to almost all implements involved in tillage and sowing.

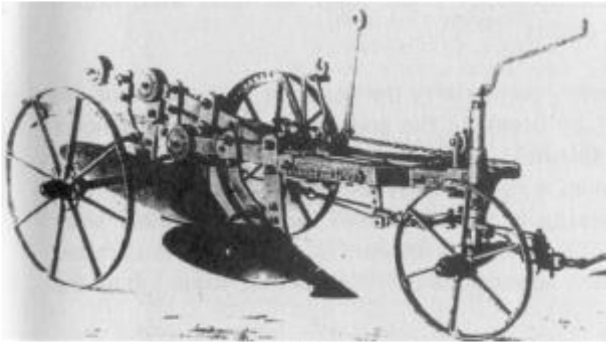


Figure 1.3 Early stump-jump plough invented by R.B. Smith of South Australia in 1876; this implement was especially useful in Mallee country
(Photo courtesy of D.N. Jeans)

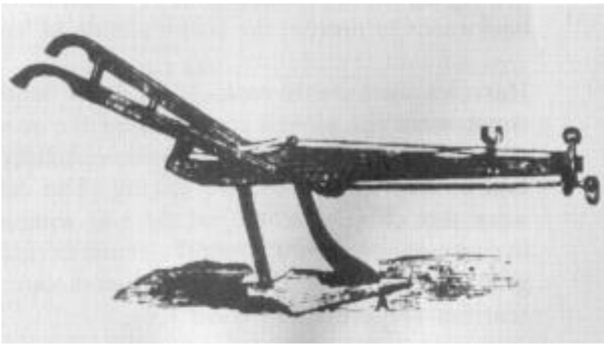


Figure 1.4 Subsoil plough used around the turn of the 20th century
(Photo courtesy of D.N. Jeans)

The English mouldboard plough proved unsuitable for many areas in Australia because the turned sods baked to hard clods in the dry conditions (Jeans, 1977; 1979): in England the winter frosts could be relied on to break them up. A common replacement in the 1890s was a digging plough, which had a high short mouldboard to break up the sod as it turned over in the furrow. Heavy subsoils were broken up by a 'subsoiler' plough, an English invention that ploughed to a depth of 30-40 cm without bringing infertile subsoil to the surface (Figure 1.4). This practice was common in the late 1800s and early 1900s.

The problem of clodding in heavy soils was solved most effectively however, by the American principle of the disc plough. The Americans, motivated by the need to reduce plough draught, replaced the sliding friction of the mouldboard and shares by the rolling action of the discs. A few were imported in 1896 and were manufactured locally from about 1903. James Garde of Victoria adapted a stump-jump mechanism to the disc plough to produce the Sundercut stump-jump disc cultivating plough, which was produced from 1906 (Jeans, 1979).

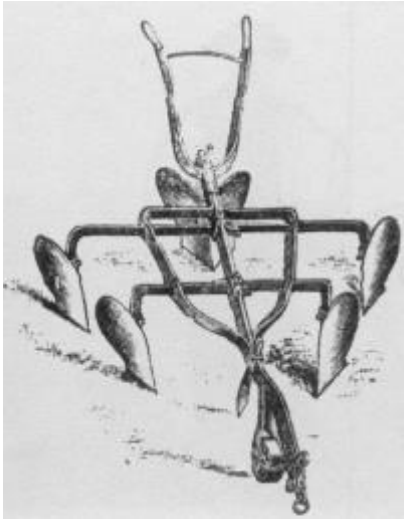
The discs, usually in pairs and set on an angle, turned and pulverised the soil in a way that was suited to dry conditions, particularly on heavy soils. Disc ploughs had been used at Wagga Wagga Experimental Farm since 1898 and, by 1911, the New South Wales Department of Agriculture considered them to be superior to mouldboard ploughs. This was because the disc plough required less draught as well as being faster and better able to break up heavy soils and stubble. The mouldboard plough survived on light soils where the discs pulverised the soils excessively, but between 1900 and the 1970s, however, the disc plough was the main primary tillage implement on Australian farms (Jeans, 1979).

**SECONDARY TILLAGE**

Various forms of harrows were used for the final preparation of seedbeds and to cover broadcast seed. The most primitive forms were spiked logs (as previously described for 'mullensing'), and in some cases tree branches were used to cover the seed. The most common type from the 1870s was the zigzag harrow, which was invented in England in 1839. From 1880, the tines were sloped backwards to prevent the accumulation of weeds (Jeans, 1977).

Harrows were partly replaced by other implements, particularly the scarifier and cultivator, to supplement the plough in preparing the seedbed by breaking the soil down into finer particles (Figure 1.5). The scarifier, a relatively heavy implement with rigid tines, was used to break up fallows and stubbles before sowing. The cultivator, a lighter implement, with spring tines that were less chisel-like, stirred the soil without turning it over. By 1885, these implements were in common use in New South Wales and during 1890 to 1906 were standard implements on Australian grain farms (Jeans, 1977). The skim plough, which appeared after 1900, did the same job as the scarifier (Figure 1.5, Figure 1.6).

The disc principle was adapted to cultivation after 1900. Instead of one or two heavy discs of the plough, the disc cultivator had many lighter discs for scything through surface crusts and breaking up the clods (Figure 1.7).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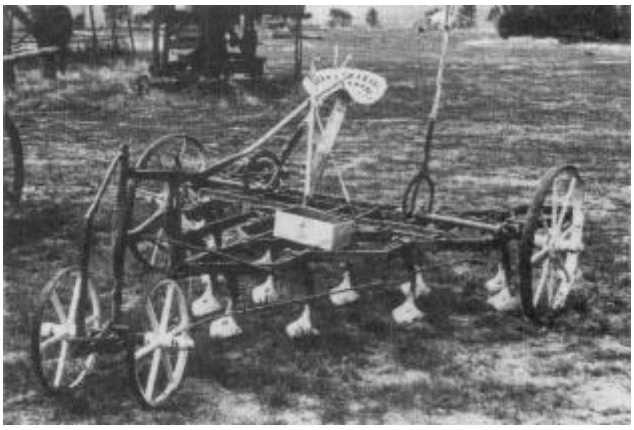
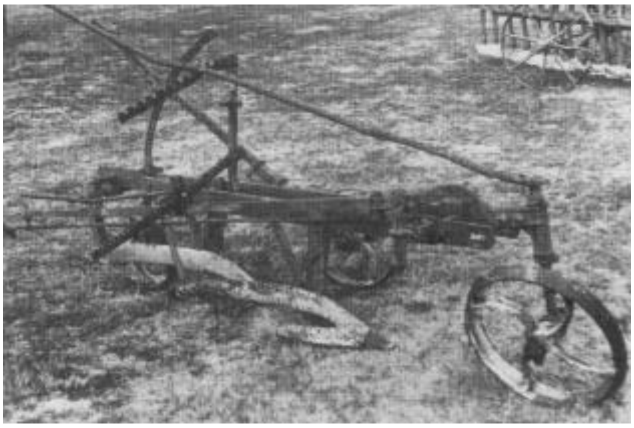

Figure 1.5 A group of secondary tillage implements that completed the mechanisation of the Australian wheat industry in the 1890s:
(a) plough cultivator,
(b) scarifier
(c) skim plough.
(Photos courtesy of D.N. Jeans)


Figure 1.6 Advertisement in *The Scientific Farmer and Agricultural Review*, 1907 for secondary tillage implements and other machinery
(Photo courtesy of D.N. Jeans)

Figure 1.7 Advertisement for tandem disc harrows in the early 1900s
(Photo courtesy of D.N. Jeans)

**SOWING**

Inexplicably, the Australian farmer lagged far behind his European counterpart in sowing technology, though not so far behind the North Americans. Attempts had been made over several thousand years to produce a workable seed drill that would plant the seed reliably in rows. The history of this experimentation traces back to Babylon in 2000 BC and to Italy in 1580. It was, however, Jethro Tull in England who first produced a workable drill in 1701. The drill paved the way for better farming by economising on seed, and sowing in rows, which allowed the crop to be kept clean by inter-row cultivation. A higher germination rate (also improved by the use of a roller, which broke up any remaining clods) and greater tillering were also achieved.

Australian farmers, however, continued to sow seed by broadcasting, the older method of flinging the seed over the land and covering it using a harrow. This was a wasteful procedure in both time and seed. Initially it was done by hand from a bag slung over the shoulder, but later, seed was spread from a hand-held device carried by the sower (Figure 1.8). A revolving mechanism for scattering the seed was activated by means of a bow. These devices remained in use on small properties until well into the twentieth century. In the 1870s a cart implement for broadcasting, the ‘Seedsower’, was imported from America and it was soon manufactured in South Australia for local use (Jeans, 1977). It employed the same method of seed distribution as the hand-held model, with seed being fed from a hopper to a revolving disc, which was powered by a belt-drive from one of the cart wheels. Regular distribution of the seed up to 16 m in width was claimed for this machine, which was widely used.


(a)

(b)

Figure 1.8 Early methods of sowing seed:
(a) hand seed sower showing the bow mechanism for scattering the seed; and
(b) broadcast ‘Seedsower’ using a ground-driven revolving disc for seed distribution. These were in common use prior to the introduction of the combine drill

(Photos courtesy of D.N. Jeans)

In 1782 Englishman James Cook made the first modern drill with a hopper feeding seed down a tube to a ‘boot’. This boot placed the seed in a trench made by a tine (Callaghan and Millington, 1956; Jeans, 1977). Even in England the drill was not common until the early part of the nineteenth century.

As late as 1885 Angus MacKay’s *Elements of Australian Agriculture* made no mention of the drill, and it was absent also from his book *Introduction to Australian Agricultural Practice* in 1890. MacKay was writing chiefly of the less agriculturally advanced State of New South Wales, but there were reports of drills replacing broadcasting in parts of Victoria in the 1870s. It was not until as late as the 1890s that drills began to overtake broadcasting to any significant extent, and not until after 1910 that they were adopted universally, although this varied from State to State. Most grain farms in South Australia had drills by 1910.

The locally manufactured Empire drill of 1895 cost the substantial sum of £35 – farmers objected to paying such a high price! Farming technology then made significant advances, notably in the use of the cultivator. The drill therefore became essential for sowing the crop in rows in order to facilitate inter-row mechanical weed control. The availability of superphosphate also encouraged the rate of adoption of the drill, particularly after 1917 when R.A. Squires of Quirindi, New South Wales, pioneered the ‘combine’ drill, which sowed seed and fertiliser together (Callaghan and Millington, 1956). Cultivating tines were added to the combine to prepare the seedbed and bury the seed. The International Harvester combine drill of 1920 had 15 boots for sowing and 31 tines. In 1912 spring-loaded harrow-teeth were added to the drill, thus anticipating the combine drill and replacing the harrow previously dragged behind the drill machine. For a time a disc drill was also used, but the tine drill has proven to be more versatile in Australian conditions.

It can be seen that the basic technical principles of most of the machinery in use today have been changed only slightly since the 1920s although developments have taken place in engineering design and in modes of operation such as hydraulics and three-point linkage. It is a matter of opinion whether the early designs were the final answer for seedbed preparation and crop sowing or whether the research effort to improve designs has not taken place and the needs of germinating seeds and plant roots are not understood.

## DEVELOPMENT OF FARMING SYSTEMS

### SHIFTING AGRICULTURE

As previously described, the farming ‘system’ of the eighteenth century involved clearing and burning the trees, cropping the soil and then repeating the process on new land. This process is common in primitive agriculture. Cropped land was often left to nature after yields had declined but later returned to cropping after a period of time had allowed for subsequent nutrient mineralisation and organic matter build-up. Unintentionally, this produced a form of crop rotation even in the early days. As early as 1826, James Atkinson in his book *An Account of the State of Agriculture and Grazing in New South Wales* expressed concern at farming practices used at the time:

> ‘If a foreigner who had travelled through England, were afterwards to visit New South Wales, he would scarcely be able to persuade himself that the inhabitants were derived from the same stock; he could hardly believe that the people, who, in the mother country, cultivate their lands with such persevering industry and intelligence, should here become so extremely slothful and negligent...
>
> ...many even neglect this important point (rotations) in good farming, but sow wheat on the same land, year after year, for a succession of seasons.
>
> The consequence of this miserable system is, that the land in a few years gets exhausted, and having very little tillage, is entirely covered with weeds.’

### CROPPING THE MARGINAL LANDS

The cropping frontiers were extended in all States in the second half of the nineteenth century. This expansion was mainly into the drier and therefore higher risk areas particularly to the north in South Australia. Good seasons in 1878 and 1879 provided encouragement and with new land always available there was little incentive for preservation of soil structure.

Yields declined through the 1870s largely through repeated cropping, lack of fertilisers and the burning of residues (Mabbutt, 1978). This decline was accentuated during the drought of 1880-82 and by further droughts during the latter part of the 1800s (Figure 1.9). The only course of action was agricultural retreat, amalgamation of holdings and a return to pastoral activities.

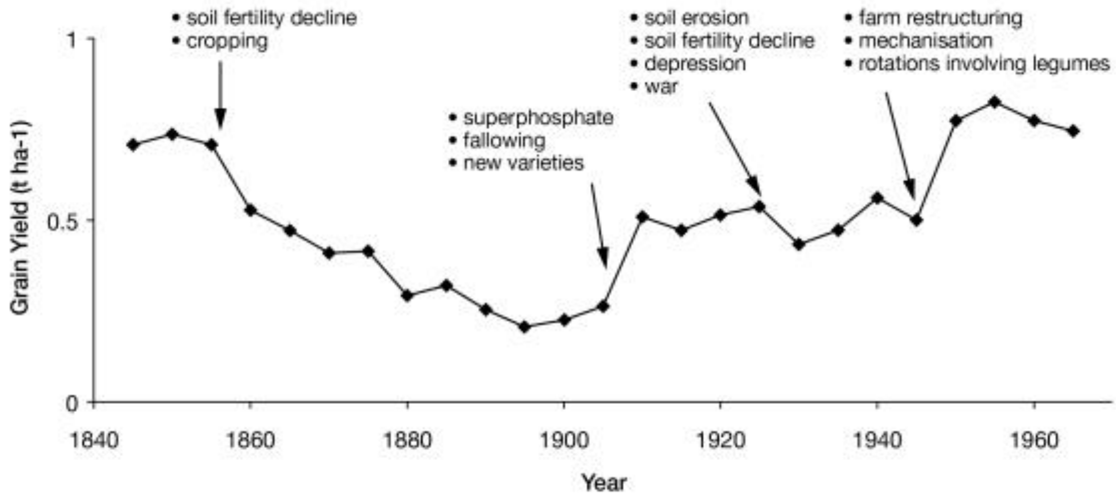


Figure 1.9 Five-year running mean grain yields of wheat in South Australia 1840 - 1970 (adapted from Williams, 1974)

As a result of this decline in productivity of the cropping areas in South Australia, Roseworthy Agricultural College was founded in 1883 with Professor J.D. Custance as Principal and with a charter for agricultural research to improve the productivity of South Australian soils. The early work of Custance (as reported by Reimers, 1983) indicated the value of forage crops in a rotation with wheat for the cereal belt of South Australia although commercial adoption did not take place to any extent at that time. Custance had also demonstrated the value of superphosphate by the 1890s and this subsequently became the normal practice in southern Australia after 1900, reversing the trend of declining wheat yields, at least temporarily. As early as the 1920s there are records of farmers sowing into crop stubbles using disc drills so as to prevent wind blasting of seedlings.

The expansion of cropping in Queensland and northern New South Wales began after the First World War. It spread rapidly westward into grazing lands, and soil erosion soon became a major problem.

**'DRY FARMING'**

Developments in the USA as a result of the Californian goldrush in 1849 and railway expansion during the period 1860 to 1875 enabled the American wheatbelt to be extended over the Great Plains. The dry conditions and the settlers' lack of dry-farming experience meant that success was achieved in wet years but with failures in dry years. By about 1900, dryland farming techniques involving deep ploughing and frequent harrowing to produce a dust mulch had been developed (Callaghan and Millington, 1956).

**Deep ploughing** Ploughing to a depth of 20-25 cm was thought to increase the water-holding capacity of the soil, admit sunlight and air, extend root feeding area, encourage growth of soil bacteria, prevent light soils from blowing away and enable plants to withstand a long period of drought. Later, American reports (Chilcott and Cole, 1918, cited by Callaghan and Millington, 1956) and other work described by Callaghan and Millington showed there to be no benefit in deep cultivation.

The depth of working of soil remained a matter of controversy for many years. Custance at Roseworthy Agricultural College undertook studies in this area in the late 1800s but these were inconclusive (Reimers, 1983). Further work was started in 1910 and following a lack of crop-yield responses over many years it was determined that 10 cm workings gave best yields (Table 1.1). The tendency with the advent of the tractor was towards shallower working. It is significant that the debate on this issue was still active four decades later (McFarlane, 1969).

Table 1.1 Depth of ploughing experiment, 1911-1927 (as modified from Reimers, 1983)

| Ploughing depth (cm) | Average wheat yield (15 seasons) (t $ha^{-1}$) |
|---|---|
| 5 | 0.97 |
| 10 | 1.06 |
| 15 | 1.05 |
| 20 | 1.02 |
| 25 | 1.01 |
| 30 | 0.96 |

**Frequent harrowing** While the surface disturbance was to prevent growth, frequent harrowing was considered to be more important for maintaining a 'dust mulch'. This supposedly prevented water rising from depth through the capillary system in the soil to the surface for evaporation.

Experimental work to test the methods of dryland farming began in about 1907 in South Australia and in March 1911 the First Interstate Dry Farming Conference was held in Adelaide. The Proceedings were reviewed by Callaghan and Millington (1956), and of significance are the reported comments of Mr A.E.V. Richardson

(Assistant Director of Agriculture, South Australia, and later the first Director of the Waite Agricultural Research Institute). He indicated that the following conditions were necessary if maximum moisture was to be stored in the soil:

- a loose broken surface allowed moisture to penetrate readily – hence the need to use the double disc early in the season before the opening winter rains;
- because moisture was held in the soil as a film around each particle, the capacity of soil to hold water was dependent on the minuteness of the subdivision of soil granules. Richardson considered that finely divided soils were not only capable of conserving the maximum moisture but also had greater capillary power;
- moisture must be prevented from evaporating at the surface – a shower of rain readily caused the soil to run together and set, giving a hard surface, which enabled unbroken capillary connection between the moisture-laden subsoil below and the surface. By breaking the continuity of these capillary tubes by means of a cultivator, the soil was effectively mulched and evaporation reduced to a minimum.

It was later shown that where a soil surface was kept free of weeds but undisturbed, moisture losses over summer were lower than on the dust-mulched soils (Call and Sewell, 1917 as cited by Callaghan and Millington, 1956). This indicated that the major loss of water from soils was through plants. Mulching, therefore, produced its beneficial effect largely through the control of weeds. The experiments of Veihmeyer in California showed no significant difference in water content of bare soils in tubs stirred to various depths compared with undisturbed tubs after 2 years (Leeper, 1964). Further, Veihmeyer found that a tub lost twice as much water in 3 weeks through the growth of a single plant as it did in 2 years through exposure to the sun.

## Dry farming in southern Australia

Although the reasons for the success of dry farming were not generally understood, its development in America attracted Australian attention as a means of extending the limits of successful wheat-growing lands into the marginal 250-500 mm rainfall zone of South Australia and Victoria – Mallee country. This was accentuated by the Soldier Settlement Scheme after the First World War, in which new farmers were settled on land in higher-risk areas with rainfall as low as 200 mm. Confidence in the success of the scheme was high also because of the availability of new drought-resistant wheat cultivars and relatively cheap superphosphate.

The application of the American dry-farming techniques to the 'marginal' country was interpreted as being a long fallow, with ploughing in January or February and maintaining a weed-free mulch until sowing time in the autumn of the following year, a period of 15 months. A rapid expansion of dry farming with long fallow took place in the Australian Mallee in all four wheat-producing States but particularly in South Australia and Western Australia, where large areas of such country were available.

Fallowing enabled the farmer to sow his crops each year under good seedbed conditions and offered the advantage of spreading the workload of tillage over many months. When horses were the source of power for tillage this distribution of work over the year was essential because of the time involved with each operation. With the introduction of tractor power less time was needed for tillage operations and the process of tillage became more intensive (Figure 1.10).


Figure 1.10 Sign of the times – an advertisement for the Hart-Parr 30 tractor in the *Farmers and Settlers Bulletin* around 1920
(Photo courtesy of D.N. Jeans)

The fallowing of the light Mallee soils was particularly disastrous. Here the soils were kept clean of weeds and were thus left exposed to the drying westerly winds. Frequent tillage using harrows and disc ploughs produced a fine tilth while at the same time supposedly allowing the soil to breathe and rainfall to enter the soil while reducing soil evaporation losses to a minimum. Rollers were used for compacting the soil. Occasional deep ploughing was used to allow moisture into the subsoil. Fire removed stubble and other surface residues, and protective vegetation on ridges was cleared. The ultimate effect on the soil was structural breakdown, fertility decline and accelerated erosion.

Wheat yields under repeated cropping declined in South Australia after 1910 (Figure 1.9). By the end of the 1920s falling wheat prices and the increased incidence of drought had resulted in serious economic hardship. A greater area was sown more frequently and soil exhaustion and degradation were accelerated. Farmers could not afford the necessary superphosphate and yields dropped still further.

In official advice to farmers in the 1920s, emphasis was placed on the need for more fallowing to conserve moisture and increase the availability of nitrogen (Mabbutt, 1978). The potential role of legumes in this process had yet to be realised or accepted by farmers. The proportion of wheat grown on fallow in the Murray Mallee increased from one-third in 1930 to three-quarters by 1934: the result was catastrophic soil erosion. At its worst the erosion repeatedly blocked roads, railways and stock water channels. Fences were inundated and croplands were buried beneath sand sheets.

By the mid 1930s it was realised that wheat farming in the Mallee was not a paying proposition and instead there was a need for sheep production. This realisation resulted in the amalgamation of holdings and the transfer of families away from the area. While many farmers moved voluntarily from 1937 onwards, the change from commercial wheat farming to a livestock-based industry was mainly after the Second World War and followed the repurchase and redistribution of land by the State. Freehold tenure was replaced by 'perpetual leases' and wheat farming was reduced to part of a rotation with pastures (Mabbutt, 1978).

The work of Hore (1940) at Walpeup identified the value of surface cover in reducing drift in the light Mallee soils. The three measures subsequently adopted (Callaghan and Millington, 1956) were:

- the retention of stubbles, requiring the subsequent crop seed to be broadcast and covered using disc harrows or sown using a seedbox mounted on a twin-disc plough (a sunderseeder);
- the use of cover crops during the fallow period to protect the soil over the summer, which usually reduced yields in the following crops but the reduction in wind erosion provided compensation;
- the planting of cereal rye (*Secale cereale*) in autumn for stabilisation of wind-blown areas (Herriot, 1947), with in some cases pasture species sown into the stubble the following autumn – in the South Australian Mallee the use of rye stubbles on sandhills increased from 900 ha prior to 1935 to over 25 000 ha in 1952 (Callaghan and Millington, 1956).

The concept of a long fallow of about 15 months was not supported by experimental results, as normal fallows of 8-11 months produced yields equal to those of a long fallow (Callaghan and Millington, 1956). The costs in terms of loss of winter grazing and soil loss were also significant. It was also shown that much of the benefit of fallowing was from nitrogen mineralisation (Teakle and Burvill, 1930a, 1930b; Sims, 1948).

## Dry farming in northern New South Wales and Queensland

In the summer-rainfall areas of northern New South Wales and Queensland, a summer fallow has been shown to be necessary for successful winter crop production (Waring *et al.*, 1958; Fawcett and Carter, 1973). As the fallow period coincides with high-intensity summer storms, which cause high levels of soil erosion, the retention of stubble on the fallow has become a major factor in the control of this erosion. By the early 1950s, farmers in the summer-rainfall areas were being encouraged to retain stubbles on the soil surface under the guise of 'conservation farming' (McFarlane, 1952; Anon., 1962). Chisel ploughs were recommended for use in the main tillage operation but disc cultivators, such as the sundercut, were used to incorporate the stubble partially into the soil. Under most seasonal conditions, in the summer-rainfall areas, stubble has normally decomposed before sowing.

The stubble-retention technique in Queensland was developed in the early 1970s when specialised machinery, including blade ploughs, rod weeders and presswheel planters, were imported mainly from the United States. Machinery evaluation committees, which included farmers, were formed and this machinery was subsequently adopted for use in Queensland and northern New South Wales. Financial support was given to the scheme by the Australian Government.

**EVOLUTION OF LEY-FARMING**

The importance of bare fallowing, particularly the long fallow, has declined since the 1920s and pasture-crop rotations have become more common. The pasture phase became known as the ley. Apart from the effect on erosion, the most important developments are described below.

**Sheep feed supply** The reduced value of wheat grain and the improved outlook for sheep in the late 1920s led to fallowing being delayed as long as possible to maximise the feed supply for the sheep.

**Increased speed of operations** The development of tractors from about 1924 onwards allowed the seedbed preparation and sowing operations to be completed in a much shorter time. Pneumatic tyres, which were developed in the 1930s, further increased the working speed from about 7 to 10 kilometres per hour.

It should be emphasised, however, that while the need for spreading the workload over time had been alleviated, the increased speed of operation and subsequent development of larger machinery enabled land to be tilled more intensively. Excessive tillage resulted in a continuation and worsening of the problem of unnecessary soil degradation.

Herriot (1954) indicated that the aim of tillage should be to reach the ideal tilth by sowing time with the least number of workings by the least number of machines. He described the principle of 'defensive tillage operations' as those operations required to overcome the problems caused by previous excessive tillage. Examples cited then included tillage to roughen up the surface of a sandy fallow that was already overworked and the tillage necessary to break up a surface crust.

**Pasture legumes** Use of superphosphate and the introduction of annual legumes overcame the need for mineralisation of soil phosphorus and nitrogen. Legumes improved the quality of grazing and in many cases were grazed until the autumn rains. Their ingress had occurred naturally with the use of superphosphate, and medics and clovers became dominant in leys. The adoption of medics was slow on South Australian farms because of the vegetable fault in wool associated with spines on the burrs; some landholders who were unaware of the benefits of medics considered them to be weeds (Reimers, 1983). In the late 1930s, the release of the short-spined barrel medic (*Medicago truncatula*) cultivar, Hannaford, addressed this problem.

The discovery of the potential of subterranean clover (*Trifolium subterraneum*) by A.W. Howard in 1889 was put to good use in Western Australia particularly. The cultivar Mount Barker became an outstanding plant for south-western Western Australia in 1914, and in 1927 the cultivar Dwalganup was established for the drier areas. The sandplain lupin (*Lupinus cosentinii*) was also widely grown from the 1920s as a self-regenerating forage crop, but it took until about 1947 before its role as a pioneer legume for increasing the fertility of the sandplain country was realised (Underwood and Gladstones, 1979). In the eastern States subterranean clover pastures assumed importance in the 1930s. In the higher rainfall areas of Victoria, fallowing was shown to be unnecessary after a subterranean clover pasture phase (Morrow and Hayman, 1940). The impact of pasture legumes on crop yields for South Australia can be seen in Figure 1.9 and for Western Australia in Table 1.2.

Table 1.2 Selected statistics for Western Australia 1890-1970 (adapted from Burvill, 1979)

| | | Area | | | |
|---|---|---|---|---|---|
| Year | Wheat (million ha) | Bare fallow (‘000 ha) | Sown pasture (‘000 ha) | Superphosphate used on crops and pastures (‘000 t) | Wheat yields (t $ha^{-1}$) |
| 1890 | 0.01 | n.a. | n.a. | nil | 0.93 |
| 1900 | 0.03 | 18 | 1 | 12 | 0.70 |
| 1910 | 0.24 | 120 | 3 | 33 | 0.67 |
| 1920 | 0.52 | 309 | 7 | 67 | 0.63 |
| 1930 | 1.60 | 1143 | 137 | 240 | 0.91 |
| 1940 | 1.06 | 925 | 483 | 260 | 0.54 |
| 1950 | 1.29 | 905 | 1454 | 366 | 1.05 |
| 1960 | 1.63 | 756 | 3113 | 612 | 1.07 |
| 1970 | 2.36 | 593 | 6988 | 1162 | 1.25 |

n.a. = not applicable

**Effects of skeleton weed** The establishment of skelelton weed (*Chondrilla juncea*) as a major weed of cultivation in south-eastern Australia encouraged landholders to use a pasture phase as their only means of controlling the weed. Introduced around 1917, skeleton weed substantially reduced yields of wheat as a result of severe competition for nitrogen and moisture. Active weed growth in the fallow also prevented the accumulation of nitrates in the topsoil because of the weed’s almost continuous nitrogen demand (Cuthbertson, 1967). The tough latex-exuding stems created difficulties during crop harvest, causing wear and tear on machines and blockages of machinery when harvesting a severe infestation. Cultivation was the only weed-control option available to farmers at the time but cultivation of skeleton weed actually encouraged its spread by regeneration from root fragments.

Many wheatgrowers went out of business in the mid-1930s as a result of the total crop losses due to skeleton weed. This coincided with a period of acute national economic depression and the entire wheat industry was in jeopardy. A prize of £5000 was offered for the best means of controlling the infestations, although no payment was ever made (McVean, 1965). It should be noted, however, that skeleton weed probably did the farming industry a favour by hastening the demise of wheat production in many districts in Australia where it was not only a precarious business but was also rapidly exhausting the slender reserves of soil fertility. Also, it probably advanced by many years the movement towards a mixed farming system with the incorporation of a leguminous ley in the wheat-fallow rotation once it had been demonstrated that pasture species, particularly lucerne, could control the weed by competition (Moore and Robertson, 1964; Wells, 1970). These far-reaching results from the introduction of skeleton weed provided the opportunity to emphasise the need for restricting the practice of fallowing to provide more feed for grazing livestock.

**Effects of market forces** Following the Second World War, market forces encouraged a trend away from commercial wheat production to a livestock-based industry particularly in southern Australia. Other factors that reinforced these trends were favourable livestock and wool prices; the availability of annual legumes, notably barrel medic in the marginal areas; and the increased use of superphosphate assisted by the superphosphate subsidy.

It is hardly surprising that crop responses to long fallowing in southern Australia have been relatively small and unpredictable, because the early reasons for fallowing now have little relevance because of technological change. The availability of tractor power and large machinery has alleviated the problem of time needed to cultivate the land. Herbicides have potentially replaced cultivation as the main weed-control weapon, and the legume pasture phase, together with grain legume crops and the availability of nitrogen fertilisers, has overcome the need for soil nitrogen mineralisation during the fallow period. Its main role today, therefore, is for moisture conservation. The work of French (1963) provided the first rational basis for fallowing for soil moisture conservation in southern Australia, and its history is reviewed in detail by Sims (1977).

## EVOLUTION OF CHEMICAL FARMING

The advent of the phenoxy herbicides MCPA and 2,4-D in 1947 provided for the first time a safe and economic method of controlling broadleaf weeds selectively in cereal crops (Amor and de Jong, 1984). At the time, weeds such as wild mustard (*Sisymbrium* spp.), wild turnip (*Brassica tournefortii*), skeleton weed, hoary cress (*Cardaria draba*) and saffron thistle (*Carthamus lanatus*) had assumed economically significant proportions. The use of these herbicides resulted in a change of weed spectrum in crops to grasses, such as wild oats (*Avena fatua*) and annual ryegrass (*Lolium rigidum*), and the more resistant broadleaf weeds. It is of historical significance that it was this development that marked the establishment of the Australian herbicide industry.

From the mid-1960s herbicide development was prolific and, from a tillage viewpoint, provided an effective means to reduce the amount of cultivation needed for weed control. Earlier sowings with higher yields were also possible because it was no longer necessary to use repeated cultivations to control late germinations of weeds. The more recent development of ‘knockdown’ herbicides has largely eliminated the need for cultivation in seedbed preparation.

Earlier attempts in the 1950s to establish crops and pastures without mechanical weed control involved the use of arsenical compounds and later 2,2-DPA and amitrole. The major constraint in the application of these compounds was that the residual activity resulted in unacceptable delays in sowing in order to avoid crop damage. The need for a suitable, non-residual herbicide was, at the time, widely recognised.

With the discovery in the late 1950s by ICI in England of the fast-acting, non-residual bipyridyl chemicals, diquat and paraquat, it was recognised that these compounds had great potential to advance the concept of crop establishment without ploughing (Hood *et al*., 1963; Boon, 1969; Allen, 1981). Work in Australia at the time was restricted to weed control by animals in pasture sod-seeding and by water in rice establishment (Hood, 1961; Boerema and McDonald, 1967) and the development of aerial techniques for pasture establishment (Campbell, 1966, 1968; Dowling *et al*., 1971; Campbell and Swain, 1973), prompted initially by the need to control infestations of serrated tussock (*Nasella trichotoma*) on the Central and Southern Tablelands of New South Wales, on non-arable lands.

The first investigations into minimum tillage and direct drilling began in England in 1961 at the ICI Research Station, Jealott’s Hill, using an Australian Jefferies ‘Grasslands’ sodseeder. In Australia, pilot trials in 1963/64 involved the use of paraquat for the establishment of *Phalaris tuberosa* (= *P. aquatica*) and ryegrass (Robinson and Fletcher, 1965). Potential uses considered for the bipyridyls at the time included control of ryegrass and wild oats on fallows, barley grass and capeweed (*Arctotheca calendula*) control in pastures, potato haulm desiccation, lucerne (*Medicago sativa*) and clover desiccation for seed production and firebreaks.

Pasture establishment investigations continued at ICI Merrindale Research Station and at Wagga Wagga until 1967. Research into cereal establishment started in 1961 in Wagga Wagga, New South Wales (Kohn *et al*., 1966), in Western Australia in 1966 (Greenwood *et al*., 1970) and at Rutherglen Research Station, Victoria (Reeves and Smith, 1973). Other workers, notably Hutchings (Anon., 1976a) at Canberra over the period 1969-73 and McNeill (Anon., 1975; Anon., 1976b; McNeill, 1978) during 1969-76 in southern New South Wales, made substantial contributions to the understanding of the techniques. ICI established the Bipyridyl Research Team in 1966 to develop a reliable direct-drilling system for cereals and pastures, embarking on a program of more than 30 trials in each State annually for the period 1966 to 1970, including a number of long-term investigations.

Sowing was carried out using the standard combine drill. This implement was used because the cultivation provided at sowing, while giving a more acceptable seedbed from the farmer's viewpoint, also increased the weed kill so that minimum herbicide rates could be used. This became known as the 'double knock' effect and was important for the control of annual grasses and subterranean clover (Stonebridge *et al*., 1973). In addition, the combine drill was already available on most farms.

Reduced early crop vigour and rough seedbeds were anticipated as problems but this was not evident in trial yields except where the triple-disc seed drill was used (McNeill, 1975). No additional fertiliser, even nitrogen, was required (Barrett *et al*., 1972; Rowell *et al*., 1977), nor was an increase in seed rates. The herbicide Spray.Seed (a mixture of paraquat and diquat) was released in Western Australia in 1971 and in the eastern States in 1972. By this time numerous investigations over a number of seasons had indicated that direct drilling was a feasible crop-establishment technique, so it was actively promoted to Western Australian farmers. In hindsight, it is apparent that the whole-farm implications of direct drilling were not fully appreciated at the time. More recent experience has shown that direct drilling requires a farming system approach involving livestock and pasture management and is not solely a method of crop establishment (Pratley and Cornish, 1985).

## Agronomic factors affecting adoption of direct drilling

Several problems, both agronomic and sociological, were experienced in the early days of direct drilling. Some of the agronomic difficulties are described below.

**Insect infestations** Webworm (*Sclerobia tritalis*) and red-legged earthmite (*Halotydeus destructor*) in Western Australia, and red-legged earthmite and to a lesser extent pasture grub (*Rhopaea* sp.) in the east, thrived in a direct-drilling situation because they were not deprived of their food source as they had been by a fallow. Control was achieved by including the appropriate insecticide with the herbicide at spraying time. In South Australia the more complex problem of cereal curculio weevil (*Desiantha caudata*) was alleviated by the removal of barley grass from the pasture the year before cereal cropping.

**In-crop infestations of annual grass weeds** In the early 1970s no selective post-emergence herbicides were available for the control of annual ryegrass in-crop, and the wild oat herbicide, Carbyne, was very exacting in its application requirements so it had little acceptance by farmers. A management approach was clearly required. Pearce (1973) had shown that most annual ryegrass germinated from seed set in the previous year, so prevention of ryegrass seed-set the previous spring would alleviate the problem in the next crop. Mechanical topping and haymaking had been used for ryegrass control for some time but it was found that paraquat could prevent viable seed-set when applied to grasses at flowering. This technique, called 'spray-topping', worked well in Western Australia, but results in the eastern States were less dramatic because the flowering of ryegrass appeared to be more extended, and rainfall after spraying encouraged seedheads to emerge and set viable seed.

An alternative management approach was a single cultivation with a scarifier about 4 to 6 weeks before the anticipated date of sowing. This stimulated the germination of annual ryegrass and wild oats, which would then be killed by Spray.Seed prior to sowing. But the approach seemed to be unacceptable to farmers because it was not completely effective.

Lack of a commitment by farmers to a management approach resulted in direct drilling being recommended only in areas where ryegrass was not a problem. The release in 1977 of the post-emergent herbicide diclofop methyl (Hoegrass®) for control of annual ryegrass and wild oats had a major impact on the adoption of direct drilling.

**Availability of pre-emergent herbicides for annual ryegrass and wild-oat control** The availability in the late 1960s of triallate for wild-oat control and in the early 1970s of trifluralin for annual ryegrass control gave farmers selective chemical control of these weeds for the first time and can be considered as a major breakthrough. Both chemicals require a well-prepared fine seedbed into which they are incorporated and are thus in direct conflict with the practice of direct drilling and minimal soil disturbance. These chemicals, rather than replacing cultivation for weed control, actually led to increased cultivation and the rate of soil structure degradation was enhanced. The beneficial effects were that farmers were able to control major cereal weeds very effectively and at relatively low cost, at least in the short term. It should also be acknowledged that the advent of trifluralin in particular resulted in the introduction on to many farms of boom sprays, which hitherto had been a rare piece of farm equipment. The acknowledgement by farmers of the place of chemicals in farming had occurred.

**Inadequate vegetation control** Under circumstances where farmers were unable to control the growth of vegetation by grazing prior to spraying, poor kill of weeds resulted because of the contact nature of the bipyridyls. Established plant of Paterson's curse (*Echium plantagineum*) and capeweed, for example, and perennials were impediments to the successful adoption of the direct-drilling technique. The release by Monsanto of glyphosate in 1980 was a significant breakthrough in this regard because it is translocated in plants. Glyphosate increased the flexibility and therefore the attractiveness to farmers, of direct drilling.

In the early stages of its use glyphosate was seen by farmers as a replacement for controlled grazing. If satisfactory seedbeds were to be obtained it soon became apparent that, for bipyridyls and glyphosate, grazing management was essential as also was the need for the sowing operation to wait for 'root release' after spraying.

In the summer-rainfall areas of New South Wales and Queensland, where a summer fallow remained an essential component of winter cereal production, the adoption of direct drilling was hampered by the lack of a residual herbicide for weed control during the fallow. There was also the belief that the need to fallow did not fit the direct-drill concept. However, stubble retention in tilled seedbeds grew in popularity and this was an important step towards conservation farming in summer-rainfall areas.

### Social influences on adoption of direct drilling

The attitudes of farmers and experiences in the early days of the program played a significant part in the resistance to direct drilling as a farming technique. Some causes of this resistance are discussed below.

**Peer-group pressure** Although promotion of the technique started in 1970, many farmers had been direct drilling for several years prior to that time. As early as 1966 barley had been successfully direct drilled at Temora, New South Wales, and by 1968 some farmers were direct drilling up to half their crop while seriously considering extending the technique to the whole farm. The social pressures imposed on these farmers, however, were enormous because their peers refused to believe that the technique would work. This antagonism was particularly strong in Western Australia where, after 1974, a massive reversion took place (Table 1.3). The seasonal conditions of 1974 proved to be too wet for conventional methods of crop establishment and many farmers tried direct drilling as a last resort. The results were very poor in many cases, thereby confirming farmers' worst suspicions that the technique did not work (Rowell, 1978).

Table 1.3 Estimated area of cereal crops established by direct drilling and minimum tillage in winter rainfall areas of southern Australia, 1971-1983

| Year | Area ('000 ha) | | | | |
|---|---|---|---|---|---|
| | WA | SA | Vic | NSW* | Total |
| 1971 | 21 | - | - | - | 21 |
| 1972 | 24 | - | - | - | 24 |
| 1973 | 57 | - | - | - | 57 |
| 1974 | 140 | 2 | - | - | 142 |
| 1975 | 46 | 1 | - | - | 47 |
| 1976 | 45 | 2 | <1 | - | 47 |
| 1977 | 51 | 5 | <1 | <1 | 57 |
| 1978 | 80 | n.a. | n.a. | 4 | 84 |
| 1979 | 160 | 55 | 25 | 20 | 260 |
| 1980 | 250 | 88 | 24 | 50 | 412 |
| 1981 | 1000 | 125 | 125 | 100 | 1350 |
| 1982 | 1680 | 125 | 86 | 280 | 2171 |
| 1983 | 2340 | 168 | 171 | 400 | 3079 |

n.a. = not available

*tabulated figures in NSW relate only to southern NSW with winter-dominant rainfall

To counteract the lack of technical support and to provide moral support to Western Australian farmers trying the technique for the first time, ICI encouraged selected farmers to act as 'direct drilling farmer advisers'. These were farmers who had volunteered their time to make paddock inspections and to give advice to other farmers.

**Farmer experience** It is widely assumed that the greater rate of adoption (Table 1.3) of direct drilling in Western Australia was due largely to soil type – the western sandy soils being more suitable than the heavier eastern soils. Although this was a factor, it should be noted that the traditional practice in Western Australia was already a form of minimum cultivation – an initial ploughing, a subsequent cultivation, followed by sowing. The transition to direct drilling therefore was not as dramatic a break from tradition as in the eastern States where fallowing had been an integral part of crop establishment.

In the east it was considered that fallowing had served farmers well, having stood the test of time. The cost of time, fuel, lost grazing, damage to soil structure, and the loss of yield due to occasional late sowings were never taken seriously. There was no perceived need for change so the new technique was seen as a threat rather than a genuine attempt at improvement. In this negative climate dialogue was extremely difficult and progress was slow.

In Western Australia, there was strong motivation for a more flexible system that allowed extra grazing, required less time for cultivation and sowing, and provided positive weed control. A system that would allow the crop to be sown on time without the bogging of tractors and implements was seen as a great advance in the west. Once the 'autumn break' arrived farmers traditionally worked against the clock to prepare ground and sow before the soils became too wet. Direct drilling was seen as an answer to this problem.

The advent of the fuel crisis in the mid-1970s, rising costs of farm machinery and labour, the consequences of excessive cultivation through the use of soil-incorporated herbicides, and the seasonal conditions favouring minimum cultivation have all contributed to a substantial increase in the areas direct drilled from the late 1970s.

**Extension** The lessons from 1974 in Western Australia were that the level of technical support was insufficient, and that the technique had been over-simplified. The need for continued technical advice led to the formation in 1979 of the ICI Spray.Seed Project Team. At a very early stage it was apparent that the support of the State Departments of Agriculture was essential if direct drilling was to be adopted on a large scale. Initially, with the exception of a few individuals, the attitude of the Departments reflected the general farmer view. It was mainly pressure from innovative farmers that resulted in a reappraisal of the concept. The change of attitude by Departments and their agronomists was a significant element in the direct-drilling adoption process.

By the end of the 1970s, ‘direct-drilling project teams’, comprising representatives from Departments of Agriculture, the chemical industry and farmers, were operating in New South Wales, South Australia and Western Australia. Their role was to provide comparative demonstrations of direct drilling and conventional cultivation on commercial farms. These comparisons provided a focal point for discussion and, most importantly, gave extension officers experience, which developed their confidence in the technique.

## CONCLUSIONS

The evolution of Australian farming systems from the humble beginnings of first settlement has largely been influenced by reaction to soil degradation and to economic survival rather than a deliberate attempt to devise farming techniques for Australian conditions. Much of the development has taken place by adoption and ready acceptance of European and American procedures and in ignorance of the fickleness of the Australian climate and the poor quality of Australian soils.

Australians have made a major contribution to the development of farm machinery. However, this contribution has not generally been made by scientists or engineers but by farmers who have tried to make their practical tasks easier. Very little development has taken place in response to the requirements of plants and soils. The fact that most of the tillage equipment in use in the 1970s and 1980s was available in a more basic form in the 1920s begs the question whether these implements were the ultimate in meeting farming requirements or whether plant and soil requirements were not understood.

Changes to the farming system have mainly been the result of farmers’ needs. Ley-farming in southern and Western Australia resulted from the impact of skeleton weed devastation and the relative prices for livestock and wheat – a forced change some 20-40 years after the basic resources of pasture legumes and superphosphate were available. Fallowing in southern Australia was thought to be necessary, often for the wrong reasons, and it was questioned only when catastrophic erosion occurred. Direct drilling and other forms of conservation farming have been adopted largely because of the impact of labour, machinery and fuel costs or for expediency (Pratley and Cornish, 1985). There is little evidence that farmers were committed to direct drilling for its beneficial effects on the soil. In summer rainfall areas there has been greater consciousness of the need for soil protection, and stubble retention has been adopted to control wind and water erosion.

It is always timely to take stock of the land resource and plan the management strategy deliberately to protect the resource and maintain its productivity. In the 1980s, for the first time in Australian agricultural history, scientists, governments and farmers have been united in their recognition of the need for careful appraisal and planning. Conservation farming, including direct drilling, was a deliberate step towards this end.

## PRINCIPLES

- Individual ecosystems have their own unique responses to change. Superimposing European and North American techniques on Australian landscapes was inappropriate.
- Practitioners (i.e. farmers) are often the best placed to develop the innovations. Early innovations have stood the test of time.
- Agricultural practices need to be appropriate to the resilience of the soil base in conjunction with the vagaries of the climate.
- Monoculture is an unstable state. The ecosystem responds through weeds and disease.
- Weeds reflect the practices used in crop production.
- The introduction of new techniques or practices can have both biological and sociological consequences, both beneficial and negative. It often represents a change of the system itself.
- Adoption of new technology and changes in practices will take place only when the benefits are apparent to the adopters.
- The past provides lessons for the future. Such lessons can only be learnt by study of that past.

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