Chapter 7

Important plant and soil research and development issues

Over the decades the focus of plant research has shifted, depending on industry needs and the opportunities provided by new knowledge. In the early years agriculture was relatively simple, with the basic activities and principles of crop production following those established over the millennia. However, there was an urgent need to understand the unusual soils in Western Australia and to develop crop plants which could mature and produce seed in climatic conditions different to those encountered in the United Kingdom.

Against this background this chapter summarises some of the main advances the Department of Agriculture was associated with. It does not claim to be complete, nor does it deal with the myriad small projects dealing with on-farm problems which were part of the department’s everyday work. The subjects dealt with are generally but not necessarily in order of their importance.

The introduction of the first generation of machines for cultivation, sowing and harvesting of crops brought major changes to the farming industries. Further major changes followed with the introduction of tractors, motorised transport, more sophisticated machinery, better roads and railways and the capacity to handle materials in bulk, which became the basis of modern agriculture.

Improved tractor tyres and the associated increased power and the development of synthetic chemicals for the control of pests, diseases and weeds in the second half of the 20th century provided further opportunities and challenges for research workers.

Finally in the late 20th century broadscale chemical herbicides eliminated the need for cultivation for weed control. This, coupled with the availability of new machines and equipment, provided the basis for new cropping systems. This required new and modified crops and introduced an entirely new framework for production, with new challenges and opportunities.

A wide range of issues

The range of issues covered by the Department of Agriculture is partly reflected in the following extracts of items listed for reporting against objectives, developed by the central agencies in 1990:

Under the objective of the development of new industries issues were, the development of emu farming as a commercial entity, the establishment of kangaroo meat as a food for human consumption, and the segregation of wheat grain suitable for noodle production.

Under the objective of developing new technology, highlights were the release of lupin varieties resistant to Phomopsis, the introduction of field peas into the cereal farming system, the development of a chickpea industry on the Ord, the start of a major research program into the management and production of Western Australian wildflowers, the identification of the basis for the spread of cucumber mosaic virus in lupins, the integrated management needed to combat herbicide-resistant weeds, examination of reduced phosphorus in pig diets as a method of reducing phosphorus leaching to the groundwater, development of...
of cattle raising through the demonstration of productive potential through changes in the sex and age structure of the herd, provision of advice to pastoralists in the Murchison land conservation area, provision of advice to producers on sandy soil to achieve better water and fertiliser utilisation, management in the Peel Estate and the Peel-Harvey area, identification of the sources of phosphorus which leach into Albany harbour, provision of advice to market gardeners on the use of water and fertiliser to limit leaching and consequent groundwater contamination.

In soil conservation, the protection of small areas of remnant vegetation, the development and support of the land conservation district committees, promotion of the landcare concept at school level, educating children in rural and remote schools on the why and how of restoring degraded areas, the use of space technology to identify issues such as waterlogging and salinity in agricultural areas, and the use of Caesium 137 as a tool for tracking the degree of water erosion taking place in an area

**Plant breeding**

Plant breeding has always been a major function of the department and one of its great success stories. Before 1940, breeding to develop cereals adapted to the climate and soils was the major scientific activity in the plant field. It was initiated in the earliest days of the Bureau/Department of Agriculture with wheat crossbreds tested at Hamel in 1898. However, it only really gathered pace after the arrival of GL Sutton as Commissioner for the Wheatbelt in 1911 who brought a considerable amount of crossbred material with him.

By 1935 there was growing concern about the bread-making quality of WA flour. The Wheat Quality Laboratory was developed in the department to monitor this characteristic. The laboratory tested the flour quality of all advanced crossbred wheats from the breeding program in the 1960s, 1970s and 1980s. The role of this laboratory increased
as the different requirements of expanding markets were identified and the breeding program was directed to match those requirements.

By 1957/58 the focus of the breeding at Merredin was on wheat and six-row barley; at Wongan Hills it was on oats and two-row barley; and at Avondale on linseed in a hope of reviving that industry. Merredin was also working on the pasture legume, barrel medic, selecting the most promising types and bulking them up. By 1970/71 plant breeding was centred at the Wongan Hills Research Station. Merredin and Mt Barker Research Stations remained as testing sub-centres for evaluating introductions and later generation crossbred material.

In the early 1980s the aims of the breeding programs were reviewed. It was agreed that they should continue to concentrate on disease resistance as well as yield improvement. There was a continued challenge to maintain resistance to the evolving threat of new stem rust strains in wheat. Oat breeders were also seeking field tolerance of stem rust. Lupin breeders were making headway in their search for varieties with better seed retention, higher yield and resistance to infection by the *Phomopsis* fungus.

However, breeding was to become more complex. Breeders needed to consider the tolerance of new varieties to herbicides. Market demand for wheat with particular qualities increased the complexity of the task. Then the new farming system which developed in the late 1970s and early 1980s needed different wheat varieties. Until this change the challenge was to have early maturing varieties to match the short growing season where fallow was omitted and weed control was achieved through cultivation after the opening rains. When chemical weed control permitted earlier sowing and gave a longer growing season, later maturing varieties were needed. The development of climate change produced further complications, with increased risk of frost damage to flowering crops and more uncertain rainfall.

The subterranean clover breeding program, which was started by the University of WA in the early 1950s, was carried out cooperatively by the department and the university from 1967, with the breeding at the department. It became the basis for the national subterranean clover improvement program.

In 1993 a Cooperative Research Centre (CRC) was developed called the Centre for Legumes in Mediterranean Agriculture (CLIMA). This was a cooperative arrangement between the Commonwealth, the Department of Agriculture, the University of WA, CSIRO and industry. However, despite CLIMA's success it was not given further funding after 1998.

Lupin breeding, which had also been started at the university in the 1950s, became a cooperative program with the department in 1967 and was located at the department. It largely remained with the department but with close cooperation with CLIMA.

After the CLIMA bid for further funding failed, the partners (including the department) were successful in obtaining funding to $4 million. This allowed work to continue until 2007. The organisation is now a centre within and funded by the university.

The variety of soils and range of climates in WA required the widespread testing of potential new crop varieties before release. Initially the testing was done on the three experimental farms and then on the seven farms established up to the 1930s. Eight stations were available by the 1950s. While this was generally adequate before the extensive development of light land, it was not sufficient by the 1960s.

In 1965/66 the program was substantially increased to cater for the greater range of variation in climate and diversity of soil types being cropped. A network of sites, largely on farmers' properties, was developed to cater for this variation. The size of this program was reflected in 1983 when 200 crop varieties were tested in a total of 540 experiments on research stations and farmers' properties. More than 100 of the varieties were in the final stage of testing.
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In the early 1970s the management of plant breeding was computerised and mechanised so that far greater quantities of crossbred material could be managed and much of the tedium removed. Field observations were recorded on data loggers for immediate and error-free transfer to computer storage, and seed packets and plot labels were printed automatically. Further development of computer-based equipment and new storage and handling facilities (opened 2007) revolutionised the management. This has allowed much more rapid advances across a wider range of species.

In brief, the plant breeding program has been a great success story. A high percentage of the State’s cereal crops are sown to WA-bred varieties. The department’s cereal breeding has become the centre for the national wheat and barley breeding program. In the joint program the narrow-leaved lupin has been developed into an integral part of the new cropping system and the pasture legume program has become a centrepiece in the national legume breeding program. The rapeseed program was a world leader through the 1980s and still enjoys international status but is now primarily with the University of WA. The program has been broadened to cover pulses other than lupins. The following account of the Department of Agriculture’s plant breeding record is not intended to be exhaustive but is indicative of its extent and quality.

Wheat

In the very early days the material brought from England would have been selected on the basis of some plants performing better than others. Certainly there is a record of crossbreds being at Hamel in 1898.

The plant material Sutton brought with him and used in the early wheat breeding program was the foundation of the ‘modern’ breeding effort of the time. It benefited from Farrer’s work in New South Wales. Sutton recognised that it was unlikely that one variety of wheat would suit the whole wheatbelt and considered that a number would be required. Appreciating that it was desirable for breeding to be done near or in the conditions under which a new variety would be used, all variety trials and crossbreeding were transferred to the Chapman and Merredin Experiment Farms. In 1918, Nabawa, was one of eight cereal varieties listed as released.

In 1930 two new wheat varieties were released at the Merredin field day. One was Bencubbin, described as a mid-season variety which had resistance to flag smut. It became one of the most popular varieties planted in Australia, but finally succumbed to rust in 1948.

While flag smut was controlled by breeding there was continued concern with ball smut. The department successfully treated seed with mercury compounds and this treatment became widely used in the wheat industry.
Contractors travelled through the wheatbelt grading and treating seed (known as pickling). The graders were manufactured by the Hannaford Company and were a feature of the wheatbelt through summer and early autumn. They were replaced by more sophisticated centralised treatment and grading facilities after the early 1970s.

**Wheat variety trial at Wongan Hills Research Station in the 1960s.**

A rust garden established at the Merredin Experiment Farm created a humid environment which favoured the development of rust. Following a serious outbreak of stem rust in 1934 it was decided to test all varieties in this facility every spring. The genetic base was periodically increased by introductions, particularly from Sydney University. Although interstate and international varieties were also introduced, in 1939 61 per cent of wheat was sown to WA-bred varieties. Bencubbin was sown on 37 per cent of the area, and was also the leading variety in New South Wales.

During the 1940s and 1950s a number of varieties were released but did not become dominant. Kondut, Wongoondy, Dowerin, Darkan and Moora all appear in the records. Varieties introduced from the eastern states were also planted widely. Gabo, Insignia and Halberd were some of these and later the NSW-bred variety Gamenya became important after a new strain of rust eliminated Gabo.

The main aims of wheat breeding were the development of both yield and rust resistance. In 1964 some 13 400 crossbreds were planted in test rows at Avondale, Esperance Downs, Merredin and Wongan Hills Research Stations. In addition, 180 fixed varieties were planted at Wongan Hills and 260 planted at Avondale. About 5400 crossbreds were planted at Esperance for testing for rust resistance under field conditions.

The genetic base was widened further by the introduction of semi-dwarf varieties from Mexico, as well as the variety Chile, which was crossed with commercial varieties to raise flour quality. Rust-resistant lines were again introduced from Sydney University and introductions from overseas brought into the system. These included material for male sterile and fertility restorer lines of winter wheat from America.

In 1968/69 the wheat program was redirected to look for resistance to species of *Septoria*, which had been recognised as causing a significant yield loss. During 1970/71, 7500 wheats were screened for resistance to *Septoria nodorum* and *Septoria tritici* and sources of resistance to *S. tritici* were located among the early maturing varieties.

The release of varieties for particular markets and/or areas with specific qualities also started. In 1969/70 the variety Bokal was named and seed was released for sowing in 1970. Bokal was selected for higher rainfall areas. It also yielded at least as well as Insignia throughout the wheatbelt. It had a bread-making quality similar to Gamenya, which was the standard at the time, and it was better than Darkan.

In 1974 the department released Madden, which was resistant to all known races of rust. Although it yielded slightly less than Gamenya in trials, it outperformed the current rust resistant variety Eagle by 15 to 25 per cent and had better grain quality. In 1978 a new wheat variety, Tincurrin, suited to the soft wheat markets of South-East Asia, was released as suitable for the south coast.
In 1979 Miling was released. It was an early mid-season hard wheat of short to medium height, with some resistance to leaf blotch septoria, resistance to flag smut but susceptible to rust. It was expected to be used substantially on the West Midlands sandplain and the areas to the east. It had outyielded Gamenya and had a better baking quality.

By 1980, breeding was further focused on developing resistance to *Septoria tritici*. While this had started some years before, by 1980 there appeared to be lines with resistance which needed further testing before release.

Five new wheats were released in 1982. This was a reflection of the increased capacity established some years earlier.

In 1985 further varieties were released. One was Cranbrook, released as an Australian Standard White variety. It was resistant to both stem and stripe rust and bred particularly for the south coastal areas.

In 1986 the variety Kulin was released and performed very well. It was suitable for the Australian Standard White category. Kulin was short-strawed, high yielding, stem rust and flag smut resistant and partly resistant to stripe rust. It was suitable for the central lower rainfall areas and south central medium rainfall areas. Field experience in 1986 showed Kulin to be 5 to 7 per cent higher yielding than the top yielding variety Aroona.

In 1990 two further wheat varieties were released. In addition a screening technique for selecting wheats for noodle quality enabled their segregation from the general wheat deliveries.

Varieties of wheat and barley tolerant to a herbicide for brome grass control were identified. With further development it was considered that control of this weed in cereals might be possible. However, it seemed likely that brome grass could be controlled more easily through herbicides in the legume phase of the rotation.

Cadoux was released in 1992 as a high yielding wheat suitable for white salt noodle production. It was developed in close consultation with Japanese flour mills. In 1998 its continued high performance was noted.

In 1993 two new wheat varieties were released. Amery was a high yielding, early maturing, hard grained, Australian Standard White variety for general use in the medium and lower rainfall areas. It would replace Kulin and Bodallin which had been downgraded to general purpose for 1995. Another variety, Stretton, was released as insurance against future introductions of stripe rust to which it was resistant. It was also high yielding and suitable for the 325 to 450 mm rainfall area.

Extensive sowings of Arrino and Caliningi were reported in 1998. These were released in 1997 for the salted noodle trade. Two new wheats were released, Camm for the Australian Premium White segregation, and Ajana for the Australian Standard White segregation. In 1998 two varieties, Westonia and Brookton, suitable for the Australian Premium White segregation, were released, together with Arrino and Caliningi, suitable for the White Salted Noodle market, and Nyabing, suitable for blending with noodles. In 2000, 45 per cent of WA wheat plantings were of the 12 varieties released after 1996 and almost 67 per cent of the plantings were of WA-bred varieties.

During the next seven years a further 10 new wheat varieties were released:

- **Dataline** - a soft wheat with good resistance to stem and leaf rust and slightly later maturity than the currently-grown soft wheats
- **Tammin** - a very high yielding wheat with potential for white salt noodles
- **Cascade** - a good quality hard grain ASW wheat with excellent flour yield and dough properties, and good disease resistance
- **Kalannie** - a very short season variety with excellent quality for the Australian Hard category
• Carnamah - a mid-season variety adapted to the high and medium rainfall areas, with resistance to the three rusts, *Septoria nodorum* and yellow leaf spot – Australian Hard quality

• Cunderdin – an early mid-season variety widely adapted across the State – Australian Premium White

• Perenjori – a mid-season variety adapted to medium and lower rainfall areas – Australian Premium White

• Binnu – a variety with wide adaptation to much of the central and northern wheatbelt, with improved yield, improved disease resistance and excellent quality for noodle manufacture

• Magenta and Yandanooka were two other new wheat varieties.

In 2007 the department combined with the Grains Research Development Corporation to form a semi-commercial breeding company named InterGrain. This was half-owned by each of the partners. Its focus is the breeding of wheat and barley. It took over the Department of Agriculture's cereal breeding program and is the home of the National Cereal Breeding Programs. It has a small independent board chaired by a prominent farmer. It rents space and facilities at Wongan Hills Research Station. In 2010 it was expected to take over the department’s wheat breeding staff. This arrangement will allow the company to earn royalties from successful varieties such as Wyalkatchem. There are now only two other major wheat breeding institutions in Australia—one in South Australia and one in Queensland.

**Oats**

In 1918 the production of two earlier maturing oat varieties, Burt's Early and Lachlan, was reported. There were no further reports of new oats until 1953/54, when two new varieties, Ballidu and Dale, were performing well and there was a demand for pedigreed seed of these varieties. The aim of the oats program then was to produce varieties with a high yield, high bushel weight and processing quality suitable for export. In 1954/55 a new variety was released called Avon. Avon became the dominant variety in the medium rainfall areas for the next decade. In 1956 a sister line of Avon was released under the name of Kent. It was also successful.

In the 1960s the genetic base for oat breeding was widened with the introduction of advanced crosses from New South Wales and varieties from the United States of America and Cyprus. The overseas introductions were grown under quarantine. In 1965 Irwin was released to farmers, followed by West in 1975. This had outyielded the recommended varieties over the previous five years by at least 8 per cent. The cross which led to this new variety was made in 1965, reflecting the long lead time involved.

In 1978 the variety, Moore, was released for areas receiving more than 450 mm of rainfall. Mortlock was released in the early 1980s; it was well accepted and performed well. In 1985 Winjardie was released for the West Midlands, and Murray for the medium and lower rainfall regions. Both were expected to outperform Mortlock in their specific areas.

In 1992 Yilgarn was released. This was an early maturing, tall oat suitable for both grain and hay production for the export market. In 1998 a feed oat, Needilup, was released. In 1999 two more varieties were released. These were Hotham, a high yielding feed variety and Vasse, a hay variety for the high rainfall areas.

Three further oat varieties were released up to 2008:

• Pallinup – a high yielding oat with potentially high quality for milling

• Coomallo – an excellent milling quality oat with a good yield potential in medium rainfall areas

• Toodyay – which had improved milling quality and higher yield potential than Coomallo across the State.
The national oat breeding program is now located in South Australia and oat breeding was reduced in WA by the end of 2008.

Two-row barley
The initial aim of the two-row barley program was to find a barley which would outperform Prior, which was used almost exclusively in the malting industry. In 1965/66 a crossbred named Dampier was released and accepted by the malting industry. In 1982 Stirling was released, initially as a feed barley while its malting characteristics were assessed by industry. Stirling proved to be very acceptable for malting and rapidly became the major variety planted in WA. By 1988, Stirling occupied some 75 per cent of the area planted to two-row barley.

In 1998 two new two-row barley varieties, Fitzgerald and Gairdner, were released as feed barleys pending assessment for malting. Gairdner and Unicorn malting barley were adopted by the malting and farming industries. The success of the program was reflected in the availability of two more two-row varieties in 2008. These were Baudin and Hamlin which were high yielding and had very acceptable malting quality. Powdery mildew remained a problem for the industry.

Barley breeding made major advances in the early to mid-1990s and the areas planted expanded more than even canola up to 2008. This related largely to finding cultivars which suited brewers in Australia and overseas, resulting in prices which made it competitive with wheat.

The double haploid technology and marker assisted selection which were introduced into the barley program were also taken up by the wheat breeders. They markedly increased the capacity of the programs. Barley breeding has followed wheat into InterGrain.

Six-row barley
In the 1960s the six-row barley genetic base was increased by the introduction of material from South Australia, Israel, the United States, Cyprus and Japan. At that time the program was at an early stage. A new six-row barley variety, O’Connor, was well accepted by farmers and continued to perform well. A new feed barley, Forrest, had been released for the 1981 season, initially for southern high and medium rainfall areas. In 1987/88 the variety Moondyne was released. This had a late spring maturity and was developed for the long season conditions of the south coast. The Moondyne and O’Connor varieties occupied about 10 per cent of plantings in WA. In 1994 Mundah, in 1996 Molloy, and in 1998 Doolup feed barleys were released. Doolup was particularly suited to the medium and high rainfall areas where high levels of boron were a problem.

Linseed
Rust resistance and higher oil yield were the aims of the linseed program which was in place from the late 1940s to mid-1960s. In 1964 a high yielding selection of linseed from an existing variety, Kameniza, which was satisfactory in other respects, was named Gibson and released; it became the leading commercial variety in the State. At the end of 1965 the program was terminated because of limited demand.

Seed of Gibson was distributed to farmers for planting of restricted acreages. Testing of available varieties continued after the breeding program ended. This testing program showed that two un-named crossbreds, A7 and A21, performed very well.

Flax
The collapse of Belgium during World War II resulted in a sharp increase in the price of flax and the establishment of a small industry in the Boyup Brook district. A breeding program was established to meet the needs of that area and particularly to achieve rust resistance. In 1942/43 selections were made of plants which appeared rust resistant in the field. In 1945/46 a rust-resistant flax variety
named WADA was ready for release and two other crossbred flax varieties were showing promise at Avondale. Another variety, Boyup, was released at that time. In 1948/49 a rust strain attacked WADA. By 1955 both the new varieties had become susceptible to the Ottawa 770B strain of rust and breeding work focused on potentially resistant selections. However, the industry failed due to economic circumstances. In the early 1960s there was some interest in the production of high quality fibre in WA. While the trial work was successful, the industry did not develop and the flax breeding program was closed in 1964.

**Lupins**

Lupins had been used in Western Australia as dry stockfeed (largely the sandplain lupin) and as a green manure crop in orchards and vineyards (mainly the narrow-leafed or New Zealand blue lupin). The development of the narrow-leafed lupin (*Lupinus angustifolius*) as a crop started at the University of WA in the 1950s. It was transferred to the Department of Agriculture in the mid-1960s but remained as a joint enterprise. Over the next 30 years the lupin was developed into an important crop plant through astute plant breeding, led by Dr JS Gladstones. It provided the essential legume component to the ‘new agriculture’ system. The conversion of this lupin to a crop plant in such a short time is a credit to the breeders involved.

After CLIMA was established in 1993 the program’s informal cooperation with the partners became more formalised. In 1948 a toxicity problem was first described among sheep grazed on the dry stubble and unharvested seed of lupins. This problem, named lupinosis, caused serious stock losses. It was finally identified as being due to a toxin produced by the fungus *Phomopsis*. Although extensive work was done on the problem the major advances resulted from the breeding of varieties of lupin resistant to infection by the fungus. Details of these investigations are in Chapter 6.

The initial releases of potential crop plants from the breeding program were the varieties Uniwhite and Uniharvest. They had limitations as crop plants. The third variety Unicrop was released in 1973. Standard yield trials up to 1975 demonstrated that it was superior to Uniwhite and Uniharvest. But this was only beginning and yield increases continued to be achieved.

In the 1979 season Illyarrie was released. It was produced in collaboration with the USDA at Tifton in Georgia. It had a similar maturity to Unicrop and the greater vegetative vigour and the green colour of Marri. It was resistant to the disease grey leaf spot and had a better yield than other varieties. Yandee was released for commercial sowing in 1980. It appeared to be higher yielding in central and southern districts in statewide trials in 1979. Danja, released in 1986, outyielded Yandee by 14 per cent. The progress in developing a crop plant resulted in the yield being doubled between 1960 and 1985, with further increases in the pipeline.

Lupin breeding. Glasshouse testing of early generations.

In 1987/88 the first variety with resistance to *Phomopsis*, Gungurru, was released. It also had a higher protein and lower alkaloid content than previous lupin varieties. In 1989 another variety, Yorrel, was released. Both the new varieties were phomopsis-resistant. In addition to providing extended periods of grazing compared with what could be achieved on the stubbles of the old varieties, these new varieties gave higher seed yields.
in many parts of the State. In 1992 Merit was released. It was slightly higher yielding, more uniform and more resistant to *Phomopsis*.

The first lupin variety with significant resistance to brown leaf spot was named Myalli and released to seed producers in 1995. It was adapted to the northern and lower rainfall regions and because of its consistent low alkaloid content was expected to replace Yorrel as the favoured variety for human consumption. A variety named Coromup was released later, with higher protein than the other available varieties and was targeted at the dehulling and protein market.

An outbreak of anthracnose in the northern agricultural areas caused great concern in the industry. Material was identified in New Zealand (where the disease was endemic) which had anthracnose resistance and this material was introduced into the breeding program. Potentially resistant varieties were tested in New Zealand. A new breed line with excellent anthracnose resistance was selected for rapid seed increase and early release to growers. The first release of resistant material was named Kalja which was also higher yielding than Gungurru. This was followed by the release of another high yielding anthracnose-resistant narrow-leafed lupin in August 1998. It was named Taljil.

CLIMA became the world’s leading centre for molecular biology of legumes. A partnership was entered into with CLIMA to genetically modify the narrow-leafed lupin to transfer pesticide resistance into the breeding lines. This project was successful but due to political interference was not commercialised. In collaboration with CLIMA and others it was also proposed to use gene transfer to introduce resistance to bean yellow mosaic virus and possibly other problems into the program. Partnerships were also entered into with other organisations to achieve access to specific skills or materials.

In 1998 the release of two new narrow-leafed lupin varieties was reported. They were Belara, which had high *Phomopsis* resistance and Tallarack which was the first restricted branching lupin.

There had also been interest within the program in other lupin species as crop plants. Work had started on the development of crop varieties of the sandplain lupin (*Lupinus cosentinii*) which was suitable for deep sandy soil. The aim was to breed a line combining sweetness, earlier flowering, white flowers and seeds and non-shattering pods. One such line was bulked up for field testing and possible release in 1977. A combined genetic source of both soft-seededness (to ensure reliable germination) and sweetness was still being sought.

Meantime, work on devising a method of seed scarification had given promising early results. In 1979 a soft-seeded characteristic of a selection from the sweet white-seeded non-shattering breeding line, CBE 49 was identified. Evaluation of its hard-seeded parent CBE 49 was continuing. CBE 49 was subsequently registered as Eregulla for possible use in continuous cropping in the northern sandplain. In field tests Eregulla, with its very low level of alkaloid, became very susceptible to aphids and had to be changed if it was to be a successful commercial crop plant. However, the suggestion of having a small addition of alkaloid to achieve aphid resistance was rejected by the breeder and the program was dropped. No further reference to work on this lupin was found.

There was also interest in the European yellow lupin (*Lupinus luteus*). The varieties available were later maturing and suited to the higher rainfall areas. An early variety was produced in 1998 and named Wodgil because it had been shown to grow on the wodgil soils of the eastern wheatbelt. Despite the suitability for heavier soil types the yellow lupin failed, largely through aphid problems associated with its low alkaloid content. This problem remained to be solved.

Another species of particular interest for loams and heavier soils was an earlier flowering Mediterranean white lupin. In 1980
two earlier flowering Russian cultivars of *Lupinus albus*, which outyielded the then ‘standard’ lupin in nearly all districts were identified as potential crop plants. Seed was increased with a view to possible release if the yield trend was continued. Another cultivar of *Lupinus albus*, named Hamburg, was included in general testing in 1980. Kiev Mutant, a Russian variety of the Mediterranean white lupin, was released in 1982. Three lines of albus lupins were tested in variety trials across the State in 1990. Overall, the material seemed very promising but it turned out to have 0.1 per cent alkaloid content, which was well above the standard of 0.02 per cent and the material was put aside for possible future development.

In 1990 a research program was also started to develop an entirely new lupin for heavier soils and possibly in cold climates. A lupin collected from the highlands of southern Morocco in 1973 was considered to be the best candidate and the world’s first fully domesticated *Lupinus atlanticus* line was sown for testing in the field. Work was also proceeding on the development of both an agronomically suitable variety of the high protein yellow lupin grown in Europe and a low alkaloid, high oil variety of the Pearl lupin native to South Africa. Key traits important for the domestication of both species were being identified before incorporation into the breeding program. However, this work was not persisted with largely through lack of resources. Further work may be undertaken at a future stage but this was not part of the 2008 program.

By 2008 the focus had reverted to the narrow-leafed lupin. A high yielding variety, called Mandelup, with improved content of the sulphur-containing amino acid lysine and resistance to the pesticide Gard, was available. The field pea was still considered the only viable legume for heavy soils at 2008.

**Rapeseed**

Rapeseed (*Brassica napus*) was first grown as a broadscale crop in WA in 1970 but in 1971 crops sown on the south coast were seriously affected by the rootrot disease, blackleg. The rapeseed also had problems of the oil containing a significant amount of erucic acid and the meal remaining after the oil was pressed out of the seed contained toxic glucosinolates. The erucic acid limited the oil’s use in human food and the glucosinolates limited the use of the meal for stockfeed.

Initially the breeding program aimed at developing resistance to the blackleg fungus. As it developed, its objectives were increased to include lines containing higher oil levels, low erucic acid and low levels of toxic glucosinolates.

By 1977 material was available which had a low erucic acid content and good resistance to blackleg. These crossbreds were regarded as having early enough maturity to be suitable for a considerable part of the south coast. The program was continued, aiming to develop earlier maturity and greater resistance. A low content of glucosinolates was also introduced to improve the quality of seed meal. A parallel breeding program was being carried out with turnip rape. The aim was to produce varieties with sufficient early maturity to extend rapeseed growing into the wheatbelt proper by crossing with very early varieties obtained from India. Oilseed rape is closely related to turnip rape (*Brassica rapa*). Being part of the Brassica family it was also related to the weeds wild mustard and radish.

In 1978 a new rapeseed variety which was low in erucic acid and resistant to blackleg was released. It was named Westway and produced from a cross between a French and Canadian variety. It was also earlier maturing and suitable for later planting or lower rainfall conditions.

In 1980 two new rapeseed varieties, Wesbell and Wesroona, were released and were expected to increase sowings. In 1987/88 a gene for complete blackleg resistance was imported from the wild mustard plant (*Brassica juncea*). This was combined with the field resistance already present and the
crossbreds inherited a high level of black leg resistance in the field. Progress was also made in developing improved oil qualities and improved resistance to shattering. The advances in blackleg resistance, together with the development of shattering-resistant types of rapeseed, further highlighted the success of the program. It was recognised as leading the world in several lines of breeding and had attracted much overseas interest with the genetic material in great demand from breeding programs around the world. Unfortunately in those years there was little interest in the crop in WA. As a result, the breeder took up a position at Cornell University in the USA and took the breeding material with him. Cornell had close working arrangements with Canada and the breeding material became a key part of the modern rapeseed – canola.

In 1992 an early maturing canola variety, Narandra, was released, giving the growers in the medium rainfall area a new cropping option. From 1992 to 1999 the area of rapeseed (canola) sown in WA increased from 11,000 to 800,000 ha. The release was well timed to take advantage of the expanding WA oilseeds industry.

In 1998 it was reported that 'Specialty Oil' lines of canola with a high oleic and low linoleic acid were under development. Successful production of a variety was expected to increase the market share for canola. This program was carried out in collaboration with the Georgia and Cornell Universities and was reported as being close to releasing some material.

Today, the canola breeding program is at the University of WA and privately funded by the Canola Breeders of WA.

An interesting side to canola is that availability of honey bees for pollination has a marked impact on yield.

**Pulses**

As exports of pulses increased, a breeding program developed. In 1998 two WA-bred chickpea varieties were developed. They were named Sona and Heera, both of which were of high quality and yield. The Cassab and Cumra varieties of red lentils were also released in that year along with two field peas, King for the northern medium rainfall areas and Magnet, which was the first semi-leafless variety.

Molecular markers were introduced to the program through CLIMA. Achievements from the program were:

- release of the first chickpea variety in a joint program with New Zealand’s Crop and Food Research Institute
- release in 2000 of two field pea varieties, Cooke and Helena, which were expected to increase production
- identification of material resistant to black spot of field peas for introduction into the field pea breeding program which was continuing in cooperation with CLIMA and international organisations.

The program resulted in an increased focus on the need for lime in some soils which had become increasingly acid, particularly for growing some pulses and oilseeds.

In later years the field pea variety Kaspar, which was bred in Victoria, became available. It had reduced leaves and increased tendrils such that it stood up to be harvested. It became very popular and the area sown in WA increased.

The area of locally-bred material fell. The chickpea work continued in close cooperation with Indian researchers who carried out the original crosses and took the crossbred through the early generations. At F4 or F5, 400 to 500 selected crosses were made available and selections were made from these.

An organisation called Pulse Breeding Australia has been formed within the Grains Research and Development Corporation and decided that the national programs for pulses, in which they included lupins, would be located at different centres. As indicated above, the national field pea program was located in Horsham, the national chickpea program was in Tamworth, the national faba...
bean breeding program in Adelaide and the national lupin breeding program remains in Perth.

Work was continuing in the department in collaboration with CLIMA aiming to enhance the field pea germ plasm to produce black spot resistant genetic material. If successful, it was to be made available to Horsham.

**Pasture legume breeding**

Western Australian soils are inherently infertile and deficient in nitrogen and it was important to obtain suitable legumes as the basis of a sustainable agriculture. In the 1920s it was found that a mid-season flowering subterranean clover, later called Mt Barker, was a suitable legume for the higher rainfall South West. Other naturally-occurring strains were tested through the 1930s and 1940s and an early flowering variety named Dwalganup, after the farm on which it was found, was commercialised. It was used widely through the Great Southern and inner wheatbelt areas. None of the other known strains were commercialised at that time.

A breeding program was started by the University of WA in the early 1950s to find a clover for the eastern wheatbelt. This became a joint project with the Department of Agriculture in 1967. Early maturity was the initial focus and a naturally occurring variety, earlier than Dwalganup, was named Geraldton and released to farmers. It became the basic subterranean clover for the wheatbelt.

The demonstration that varieties of subterranean clover varied in their isoflavone content shifted the focus to developing a suite of subterranean clovers with low isoflavone content. This work was simplified by the development of a simple field test for isoflavone levels in the early 1960s.

During 1967 three low isoflavone subclover varieties were released to farmers. Two of these, Daliak and Seaton Park, had been selected from naturally occurring populations, and Uniwager had been produced from the breeding program. While Daliak and Seaton Park were reasonably successful, Uniwager never became a significant commercial variety.

In 1977 Nungarin subterranean clover was released for sowing in the wheatbelt. Nungarin had a low isoflavone content, was earlier maturing than Geraldton, and had a high level of hard-seededness. For these reasons it was believed to be suitable for the eastern wheatbelt and was planted widely before the focus shifted to continuous cropping.

Subterranean clover and the annual medics continued to be the two main pasture legume species in the program through to the late 1980s, when the program was reviewed.

In 1978 another new subterranean clover, Esperance, which was resistant to clover scorch disease, was released. It was suited to the southern agricultural areas.

Subterranean clover strain evaluation plots. The focus of the subclover program was the breeding of a range of cultivars of varying maturity, with high productivity, reasonable hard seed level and low isoflavone content. Seed of four new varieties was built up after they had performed well in trials. These offered a broad range of maturities, low oestrogen levels, and clover scorch tolerance. Another 120 lines were under test. In 1985 the four new cultivars named Dalkeith, Green Range, Karridale and Junee were released.

There was also interest in other species for situations where subterranean clover was not suitable. Seed was increased of 22 lines
of a serradella (*Ornithopus compressus*) selected for improved performance on deep sandy soils. Cultivars of early maturing yellow serradella were tested for the low rainfall districts. A new variety, Madeira, was released to seed producers in 1988. This program was particularly focused on early maturity and hard seed for deeper sandy soils.

The medics were initially seen as being suited to and largely restricted to the heavier more alkaline soils of the wheatbelt. The isolation of Rhizobia for medics suited to slightly acid soils extended the range of soils on which medics could be grown. Varieties of *Medicago polymorpha* had shown promise of having a big impact on pasture improvement on some hardsetting soils. Some early maturing medics appeared to have some potential for the rangeland. As part of the program, medics collected originally in North Africa and the Middle East were tested in the Goldfields, Murchison and Gascoyne regions.

A new variety of medic named Santiago was released in 1988. This was collected in Chile in 1962 and had been extensively tested in lower rainfall areas. Zodiac, the first cultivar of *Medicago murex*, was released in 1988. It was a mid-season variety suitable for areas receiving more than 450 mm of rainfall. Being deep-rooted, it remained green for two or three weeks longer than other species of similar maturity.

In collaboration with the University of WA and CSIRO several lines of work which gave promise of producing useful pasture legumes were undertaken. These included the introduction of the Mediterranean collection which contained a large number of subterranean clovers of all three subspecies. One subspecies, *Yanninicum*, was of particular interest because it was the same subspecies to which Yarloop belonged. A replacement for Yarloop was needed and found in that family.

The relative productivity of the newly recommended low oestrogen strains of subclover under grazing was examined.

These strains were established in the wheatbelt and higher rainfall areas, including Mt Barker and Lancelin. This was in keeping with the policy of testing pasture plants under grazing. Grazing trials with two medics and the subclover variety Dalkeith showed that the medics produced more wool over the summer and autumn than the subclover.

In 1990 the plant breeding program reported the registration of two further subterranean clover varieties for release. In 1992/93 the creation of CLIMA improved the research support for the legume breeding program and progressively widened its genetic base.

From the early 1990s to the end of this review there was a virtual explosion in the range of pasture species tested, released and adopted to varying degrees by the farming community. These developments were reviewed in 2007 in a publication under the names of 27 authors. Fifty-eight new annual and short-lived perennial pasture legumes were listed as having adaptation to both the existing and new farming systems.

While the yellow-flowered serradella (*Ornithopus compressus*) had been used for deep sandy soils for some years, its use had been restricted by high seed costs associated in part with its hard-seededness. The release of Cadiz French serradella (*Ornithopus sativus*) created new interest with easier harvesting and lower hard-seededness. Sowings of up to 100 000 ha were reported as possible in 1998, with a prediction that 500 000 ha could be sown by the year 2000. The seed had originally been collected in the wild in South Africa in 1989. It had the potential to significantly increase sheep production in areas where deep sandy soils were common. Unfortunately it had little hard seed and was susceptible to false breaks. New cultivars have overcome this problem. Two varieties of yellow-flowered serradella, Santorini and Charano, with better seed characteristics, were released during the period.

Three new subclover cultivars from Sardinia were released in 1993—Denmark, Goulburn and Leura. Goulburn was expected to have a role in WA.
The first cultivar of *Medicago sphaerocarpus* (sphere medic) was released to seed producers in 1993, with subsequent distribution to farmers in 1994. It provided a pasture legume option for moderately acidic loams and sandy loams in the medium rainfall wheatbelt where cropping was frequent.

Resistance to attack from redlegged earth mite was given high priority in the development of commercial cultivars of subclover. While there has been little tolerance of the pest in commercial varieties, an early-maturing introduction from Spain showed good tolerance and was immediately introduced into the crossbreeding programs.

Overall, the success of the widening of the pasture legume base in the state was the result of work across southern Australia at a number of institutions, with the department playing a prominent part. The work was based on identification of the need for species with deeper root systems, resistance to false breaks, a range of hard-seededness, tolerance of pests and diseases, acid-tolerant root symbiosis and ease of harvesting to provide low seed costs. Mixtures of these legumes have provided for more robust pastures suited to different farming systems and the varied year-on-year conditions of farming. The size of the overall program was shown in a review prepared for the journal *Field Crop Research* in 2007.

**Fertilisers and plant nutrition**

**Superphosphate**

*The early days*

The most significant change in the development of agriculture in Western Australia occurred with the increased use of soluble phosphorus fertilisers which began in 1904/05. The increase followed experiments and farmer experience that showed that land which had previously been considered useless could be highly productive with the use of a fertiliser containing soluble phosphate which was readily available to plants. Superphosphate provided both available phosphate and sulphur, which was later shown also to be important.

In 1904/05, 2850 tons of artificial fertilisers were imported, with a value of a little less than £50 000 ($100 000). In the following year, 18 560 tons were imported. The quantity of fertiliser imported continued to increase and reached 30 000 tons by 1910.

The Victorian company Cumming Smith started manufacture of superphosphate in WA in 1911. Superphosphate was first manufactured in Victoria in 1876. The reason why it was not imported earlier is not clear. Certainly there was reference to it in the early issues of the *Journal of Agriculture* in 1894. Perhaps it was seen as being too expensive or the rates used in these early years may not have been adequate. Alternatively, this may reflect the lack of professionals in the bureau/department in the early days.

Nevertheless, the clearing and farming of soils previously seen as useless drove a dramatic increase in the cropped area. Since fertiliser responses were less common in the fruit industry the direct relationship does not hold there. The change is shown by Table 4.

A 1925 report refers to impressive results from superphosphate topdressing trials on pasture. There were also experiments reported from the Northcliffe plain and the Cranbrook district. By 1928 the practice of topdressing pastures based on subterranean clover was almost universally adopted for the developing dairy farms in the South West.

In 1922/23 a fertiliser trial on apple trees at Bridgetown showed a response to superphosphate but not to bone dust. This was important, as growers were in the habit of using bone dust, which they believed to be better than superphosphate.
During the 1930s a substantial amount of pasture research involving different species, fodder crops, fertiliser trials and trials with the use of lime was carried out in the South West. These trials established the basic information on which the dairy industry developed and on which subsequent research was carried out. In both the high and medium rainfall areas the fertiliser companies combined with the department to carry out trials aimed at increasing production through topdressing of pastures and fodder crops.

**The wartime shortage**

Throughout the 1940s phosphate fertiliser was in short supply due to enemy action during World War II and the focus was on achieving the best results with minimum applications. The total quantity of fertiliser imported into WA in 1938/39 was 4.5 million tons, including 4.16 million tons of rock phosphate. In 1940/41 the total was 2.53 million tons, of which 2.41 million tons was rock phosphate.

Experiments investigated minimum requirements of super for pastures and cereals in view of the shortage. Long-term experiments at Merredin were the basis for recommending farmers use only 40 pounds of super per acre (45.5 kg/ha) for their cereal crops. This was expected to be reduced to 30 pounds per acre (34 kg/ha) in 1943/44 due to shortage. Work on pasture species and fertiliser requirements was continued through this period.

Experiments were also carried out to test ‘Adams phosphate’ made by treating phosphate rock with 75 per cent of the normal sulphuric acid. This product was developed by AB Adams at Muresk. This became more relevant after the war when a sulphur shortage was feared. Adams was one of the early graduates in agriculture from the University of WA.

**Post-war development issues**

After World War II there was a need for further work on phosphate use, for a number of reasons. First, the explosion in the development of the sandy-surfaced ‘light lands’, some of which had a high level of ironstone gravel requiring heavier rates of superphosphate for successful development. Second, there was a need to revisit established areas to measure the residual value of previous dressings. Finally, and more urgently, there were concerns about the possible shortage of sulphur for superphosphate manufacture.

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Uneven spinner topdressing showing big response to superphosphate.

A possible sulphur shortage
A potential shortage of sulphur based on uncertainty about supplies from the United States was the focus for research in the early 1950s. The experimental work included reassessment of the value of Adams phosphate and assessment of the value of very finely ground rock phosphate. The finely ground rock phosphate did not give very good results with wheat or pasture but seemed to be used better by oats. A major practical problem was that it did not flow freely through the drilling or topdressing equipment, and it was not persevered with. In contrast to its performance on normal soils it was superior to superphosphate on some acid peaty sands because it did not leach to the same degree as the more soluble superphosphate. On many soils, particularly the peaty sands, sulphur was also required. In the mid-1950s a decision was taken to use sulphur extracted from iron pyrites mined in the goldfields and the issue was solved.

In some trials calcined rock phosphate was also tested at the request of the British Phosphate Commission. The material provided was found to be an inferior source of phosphorus for wheat or subterranean clover on phosphate-deficient soils.

The new land areas
Through the 1950s and early 1960s extensive work was carried out on both new land and developed areas. The work concentrated on determining the most economic level for development and assessing the residual value of previous dressings. The outcome in both cases depended on the soils involved, the level of other nutrients, the method of application and the rainfall. An incidental observation of this work was that subclover with good phosphorus nutrition showed less effects of drought in lower rainfall years. In a dry winter some phosphate topdressed onto the surface in these areas probably did not reach the root zone.

In the South West good growth of subterranean clover planted on the virgin gravelly-surfaced soils of the forest country was only achieved where superphosphate was topdressed at high rates. On some gravelly-surfaced soils, particularly where Karri forest had grown, higher phosphate dressings were required, even where the land had been farmed for some time. In trial work maximum yields of subclover pasture were only obtained with dressings of up to 4 cwt of superphosphate per acre (509 kg/ha) on recently cleared ironstone gravelly-surfaced soil which had not been previously topdressed. Where finely ground rock phosphate was used 16 cwt per acre (2036 kg/ha) was required to give equal growth.

In the 1960s, experiments with pastures were carried out on the time and frequency of topdressing superphosphate. It was found that autumn topdressing was the most efficient and that on most previously topdressed land there was very little disadvantage in using twice the normal rate every second year. However, on ironstone gravelly soils at Margaret River and Manjimup the omission of superphosphate in any year greatly reduced pasture growth on established areas over the early years.
Superphosphate was essential for crop production on recently cleared areas even on heavier soil types.

Superphosphate was particularly needed on recently cleared sandplain soils.

**Sulphur deficiency**

Superphosphate supplies both phosphorus and sulphur to the plant. As phosphorus builds up in the soil, sulphur can become the most important nutrient supplied, particularly on sandy soils.

In a series of farm trials during 1965/66 testing the need for phosphorus and sulphur, the development of sulphur deficiency in the absence of superphosphate was identified in a large number of situations. As commercial phosphorus fertilisers which did not contain sulphur became available, this was important. These experiments were carried out in both the low rainfall and high rainfall areas and identified two areas where sulphur deficiency was unexpectedly widespread. These were the Avon and Chapman Valleys.

Using radioactive phosphate, it was possible to demonstrate differences in the phosphate loss from soils. Losses from deep sandy soils were found to be very high whereas the losses from soils with gravel or some clay in the profile were much lower. From soils such as the red brown loamy sand in the Swan Valley the losses were negligible. It was known from other work that there were high phosphate losses from soils such as the Plantagenet peaty sand at Denmark, which had a pH of 5.0 or less.

**Superphosphate on grazed pasture**

A grazing trial on subterranean clover and volunteer grass west of Mt Barker found a complex relationship between the effect of stocking rate and the level of superphosphate applied, on pasture composition. This in turn affected the performance of the grazing animals. The results cast doubt on the interpretation of the results of fertiliser trials on pasture where the productivity of the grazing animal was not measured.

The 1962 trial compared wool production from combinations of stocking rates per hectare (15, 12.5, 10) and superphosphate rates per hectare (127, 254, 380 kg). The highest wool production per head was obtained from treatments which favoured a high clover content in the pasture. A high grass content resulting from insufficient grazing pressure due to either, resulted in both lower wool production and lower body weights through summer. For example a combination of 10 wethers and 380 kg resulted in grass dominant pasture and inferior animal performance in the summer. By comparison, 15 wethers were carried continuously where 380 kg were applied annually, maintaining a better balanced pasture and giving the highest wool production per hectare throughout the trial, which ran until the late 1960s.
Relative importance of phosphorus and sulphur in superphosphate

The advent of low sulphur fertilisers required the relative importance of the two nutrients to be examined. Early experiments with low-sulphur fertilisers showed that sulphur deficiency could occur quite widely.

Trials in the higher rainfall areas to determine the relative importance of the two nutrients found that on the poorest sands and on sand with clay or gravel below 18 inches there was a requirement for higher levels of phosphorus and sulphur regardless of past history. In addition, there were very large responses to spring application of sulphur which could be greater than when superphosphate was applied in the autumn alone. This was doubtless due to the leaching of sulphur out of the root zone by the heavy winter rain.

On grey sands with shallower depths to gravel, and grey and yellow sand over clay, responses to sulphur were obtained, including some responses to spring-applied sulphur. Only on a few better class soils was there no response to spring application of sulphur. Despite this work the researchers were unable to identify exactly where this problem would occur.

In the lower rainfall areas responses to spring application of sulphur were not obtained.

On better class soils responses were obtained in the medium rainfall areas up to 114 kg/ha of superphosphate and in the higher rainfall areas up to the level of about 228 kg/ha of superphosphate, which normally provided the level of both sulphur and phosphate needed.

The relative importance of phosphorus and sulphur on mature pastures was tested under variable stocking rates at Kojonup. It was found that some of the responses were to sulphur rather than phosphorus and that phosphorus responses only occurred at high sulphur levels. At the lower stocking rate there appeared to be some benefit in wool growth from the additional sulphur in added superphosphate. This requirement for wool growth was tested further in a trial at Woogenellup, where there was no apparent increase in wool quantity on the sulphur-treated areas in the 1970 shearing, but the fibre diameter was increased and the crimp was reduced.

Phosphorus leaching and eutrophication

Work in the Harvey, Serpentine and Murray River catchments showed that phosphorus entering the estuaries could be reduced by 30 to 40 per cent through modifying superphosphate applications and replacing ordinary superphosphate with the new ‘coastal’ superphosphate. Coastal super was a granulated mixture of super and phosphate rock. The work on estuarine pollution was continuing in 1985. One finding was that on soils with an acid pH, no iron oxide and no clay, rock phosphate was likely to give a useful growth response.

As a precautionary measure alternative water-soluble phosphate sources were examined against the possibility that the existing supplies of phosphate rock may not continue to be available.

Similar eutrophication problems were encountered in the Albany harbour in later work.

Phosphorus level in seed

In 1988 it was found that the seed of wheat, medic and lupins with high phosphorus content produced plants which grew and yielded much better than those with seed from plants with low phosphorus. Around 1960 Russian and English research had suggested that such a relationship could exist.

Deep placement of superphosphate

In 1988/89 the approach of placing phosphate fertiliser in narrow bands below the seed was shown to be more effective than the conventional banding of seed and fertiliser together. Wheat yield was increased 14 per cent when fertiliser was buried 4 cm below the seed. A lupin crop sown the
following year with no additional fertiliser produced double the yield of a crop sown using conventional seed and fertiliser placed together at planting. The results were probably due to the deeper placed phosphate remaining moist longer and staying available to the roots for a longer continuous period.

The 1992 report refers to new information that phosphorus fertiliser should be placed below and separate from seed in order to improve utilisation. This had given spectacular results with lupins.

**Miscellaneous**

Aluminium toxicity was found on about 10 per cent of the yellow sandplains of the wheatbelt, due to low pH. In association with the University of WA a reliable test was developed for aluminium, which would identify these soils and avoid the losses involved in cropping or attempts at pasture establishment on them.

**Estimating phosphorus needs**

A program to develop soil analysis as a fertiliser guide was started in the mid-1960s. In 1966 the program included 28 field trials planted to wheat, which were soil-sampled. These samples were analysed with a range of methods aimed at estimating the yield potential from the soil analysis. The analytical results were compared with the actual yields. The tentative conclusion reached was that correlations were as good as reported from similar work in the eastern states. However, the confidence limits of prediction based on these data seemed to be too wide to allow practical recommendations for farmers.

District advisers' recommendations based on the strong correlation between the actual requirements and the history of past super applications were strongly correlated with the most profitable rate to use. These recommendations were better than the soil predictions when each was used separately. In brief, an examination of the use of soil analysis to forecast phosphate need showed that while the soil tests were reasonably accurate, they were no better than an examination of the superphosphate history and the advisers' predictions. There were also major problems in sampling due to variation within relatively small areas, which made sampling on a paddock scale very difficult.

In 1970 a survey was carried out of the results of commercial soil testing for phosphorus. The survey showed that 43 per cent of the recommendations would have been higher than would have been made by the department using soil type and fertiliser history, 17 per cent would have been lower and the remainder would have been about the same. As about 10 per cent of farmers were unable to supply any fertiliser history, soil testing would be valuable in these cases. When questioned, a high proportion of the farmers who had had their soils tested commercially had not actually followed the soil testing recommendations.

Efforts to develop more efficient means of recommending fertilisers coincided in 1974/75 with an increase in the price of superphosphate from $15 to more than $50 per tonne. This led to a review of existing technical data on crop and pasture responses to phosphorus in Western Australia and to work to gather new information. The CSIRO and the Department of Agriculture cooperated to develop a model for predicting phosphate responses and economic application rates. By mid-1975 they had produced a computerised program or model which provided for inclusion of the phosphate history of the area, the farmer's individual environmental management and economic situation, as well as his estimate of the likely yield or carrying capacity resulting from the applied fertiliser. On the basis of these inputs the model was able to calculate the optimum superphosphate rate in any situation. It was also possible to calculate the economic consequences of changed fertiliser strategies and economic conditions for farms on a statewide basis. Further research was used to improve the precision and scope of the model, called 'Decide'.
In 1987/88 it was reported that the Decide model had been improved. It was now possible for specific paddock features to be taken into account and allowance made for possible seasonal effects in the choice of a fertiliser strategy.

A strategic fertiliser model to deal with recommendations for nitrogen and phosphorous fertilisers applied to crops and pastures, and a tactical nitrogen application model to deal with use in cereal cropping and take account of the influence of season, soil type and history were also available.

**Phosphorus in orchards and vineyards**

The history of phosphorus applications to fruit trees has been one of varied and unexplained lack of response. The issues seem to be availability of material topdressed on the surface, unknown history of previous fertiliser applications and situations where fertiliser, particularly phosphorus, was not the limiting factor. It is known that early orchardists used rock phosphate in large quantities. In the latter case the limiting factor may have been root pathogens, shortage of moisture, or lack of other nutrients.

In early work on fruit trees and vines, superphosphate gave a response when applied in the planting hole with young apples but there was no response to nitrogen. There had been no response to phosphate and nitrogen dressings to grapevines. This was probably due to historical application of rock phosphate and the natural fertility of many of the soils used in early orchard plantings. Moisture shortage may also have been a limiting factor.

In 1943/44 long-term research was being continued into the effects of nitrogen, phosphorus and potassium dressings on tree growth in the main fruit growing districts, but from 1944/45 the experimental fertiliser trial work was only continued at Kendenup and Bridgetown. The work continued despite barely any growth responses being evident. Observations at Bridgetown indicated that moisture was the limiting factor, particularly on lightly pruned trees.

In 1985/86 fertiliser trials at Margaret River and Frankland River confirmed remarkable yield responses to both superphosphate and nitrogen on vineyards. An extension program was undertaken to encourage vignerons to start fertiliser programs using up to 2.5 tonnes of superphosphate and 300 kilograms of ammonium nitrate per hectare to correct fertiliser deficiency. The increase in yield reflected the inadequate levels of previous application.

**Trace elements**

Next to superphosphate, the identification and treatment of trace element deficiencies has been the most important plant nutrition discovery in the development of WA agriculture. Before the identification of copper and zinc deficiency, agriculture was restricted to less than half the area now farmed.

**Copper deficiency**

The trace element saga was triggered by the discovery of copper deficiency of sheep at Gingin in 1938. This was followed by evidence of plant and animal responses in Margaret River. As a result, numerous experiments using trace elements alone and in combination were established across the agricultural areas, aimed at testing for responses and also developing soil and plant diagnostic information based on both symptoms and chemical analysis. In 1940/41 most of the work was on the South Coast and in the South West. Resources in the department were limited and these were areas where high levels of production were possible.

Responses to copper were initially reported from Albany and from Dandaragan. In all cases these responses allowed the development of soils to proceed where they had previously been regarded as useless. The 1940/41 report lists experiments at Lake Sadie in the south, in the south coastal districts, at Margaret River, Narrogin and Bridgetown.
Gingin and in the wheatbelt on cereals. Trials were also conducted on fruit trees to determine any effect of trace elements across a range of conditions including the so-called pruning dieback.

In 1941/42 more extensive studies of copper nutrition confirmed the effect of copper in overcoming the problem of wither tip in apple trees. This work also showed a very poor uptake of copper from heavy soils at Bridgetown. Addition of eight pounds of copper sulphate per tree showed no increase in the copper content of leaves. The copper was applied in the experiments by spray. It was concluded that all apple growing areas would have some soils which would be copper deficient. Plum trees at Bedfordale showed good responses to copper sprays applied as bluestone (copper sulphate). A response was seen on some sultana vines at Baker's Hill.

An extensive program testing for appropriate rates of fertiliser including trace elements was carried out on a range of species and in a number of locations. The work was partly in response to the shortage of macronutrients and partly an investigation to determine the nature and extent of responses to micronutrients, particularly copper and manganese. This work showed very widespread responses of cereals to copper. There were also responses on grapevines at Gingin. A response to boron was obtained on swedes at Bullsbrook. The observation was made that copper deficiency was more serious in dry years as a result of poorer root growth of copper-deficient plants. The outcome of this work was the very widespread use of super containing copper. In 1942/43 and beyond the work on copper use continued to show responses.

**Copper-zinc interaction**

A 1953 report expressed concern that in some instances zinc addition may reduce the effectiveness of copper dressings on wheat crops and suggested that zinc should not be applied without copper to wheat on light land. It was also suggested that zinc addition may reduce the response to copper in some situations. Some farmers had reported that copper plus zinc super reduced the yield of wheat compared with plain super but these reports could not be confirmed experimentally. The antagonism between copper and zinc observed from time to time was seen with subterranean clover in a trial at Baker's Hill in 1971.

Trace element deficiencies, particularly copper and zinc, were important and extensive in the Esperance district. Esperance Research Station was established in 1949 and the relationship between copper and zinc was investigated. The residual value of both was shown to be high.

A large number of experiments across the State comparing copper/zinc mixtures resulted in different mixtures being recommended to the fertiliser companies in 1967. This was due to the finding that applications of zinc oxide at greater than 1.5 pounds per acre tended in most cases to have a depressing effect on wheat yield. These mixtures contained lower levels of zinc but one mixture did not contain molybdenum and contained a lower level of copper. There were areas which were not fully catered for by these mixtures. By 1970 it had been recognised that molybdenum deficiency extended over a large part of the eastern wheatbelt and other mixtures were needed.

_The residual value of copper dressings_

Experiments on light land at Merredin Research Station and on black calcareous sand at Dongara indicated no reduction in the effectiveness of copper dressings applied three to 10 years earlier. Other work showed that a copper dressing would last for at least a decade.

In later years trials comparing the copper needed for plant growth with the copper needed for the grazing animal were carried out. One trial was at Bramley Research Station and another at a property at North...
Bannister. Past results from Bramley suggested that the level of copper needed to be higher for maximum pasture production than for animal health. However, when animals were put on an area which had received 2.5 pounds of copper sulphate per acre four years previously they failed to recover, indicating that after four years the level of copper in the herbage had declined to a point where it was not sufficient for animal health. Analyses showed that the animals did not achieve a satisfactory level of copper.

The trial at North Bannister was also affected by cobalt deficiency in the sheep. Marked copper deficiency occurred and it was found that 95 per cent of the copper ingested by the animals was excreted in the faeces and that the copper in the faeces could be available to plants. It was therefore likely that copper returned to an area in this form, coupled with the hundred parts per million supplied in the superphosphate, could provide a maintenance dressing. On this trial copper deficiency developed quite markedly on the clover in the pasture and differences were easily discernible between the rates of application.

An opportunity was taken at Esperance Research Station to test the residual value of copper 20 years after application. In the original experiment wheat yields were low and there was a marked response to copper. In 1970 the untreated area was still copper deficient and the original treated plots gave a high yield.

A major trial at Newdegate Research Station on the residual value of copper showed that in the first three years a control area averaged only 23 per cent of that receiving 10 pounds of copper sulphate per acre. Five pounds of copper sulphate per acre gave 65 per cent of the maximum yield. Comparison of the Esperance and Newdegate experiences showed the importance of soil type and possibly that the positioning of the copper application was also important.

Rates of application of copper and zinc
A large number trials looking at rates of application and the interaction between copper and zinc were carried out over the 16 years between 1948 and 1964. In general it was found that copper at the rate of 2.5 pounds per acre of copper sulphate would overcome copper deficiency on sandy soil, 5 pounds per acre on gravelly soil, and on a few sites it was necessary to apply 7.5 pounds per acre. The greatest need for zinc was found on soils at Lancelin, Esperance and Quindanning. On sandy soil at Lancelin maximum yields of wheat and oats were not obtained with less than 12 pounds per acre of bluestone and 4 pounds per acre of zinc oxide. However, somewhat smaller amounts gave near-maximum yields. At Esperance on a sandy soil with ironstone gravel 5 pounds of bluestone and 0.75 pound of zinc oxide was sufficient for wheat and 5 pounds of bluestone and 0.5 pound of zinc oxide gave maximum yield of oats. Rates at other sites of 2.5 pounds of bluestone combined with 1.5 pounds of zinc oxide gave maximum yields.

At Bramley Research Station an important trial using subterranean clover pastures and sheep was extended beyond three years. One dressing of bluestone at 2.5 pounds per acre supplied enough copper for plant growth and animal health for three years on a representative soil. The control (no copper treatment) failed to maintain the clover in the pasture and sheep showed distinct symptoms of copper deficiency.

Research to define more precisely the minimum dressing of trace elements which could be used for the successful growth of cereals and pastures was continued in 1966. In the medium rainfall areas 14 new trials were planted on soils which had either a sandy or gravelly surface or were intermediate between these two conditions. Over all sites the requirements for bluestone were between 2.5 and 5 pounds per acre depending on the location. For zinc the requirement was between nil and 0.75 pound.
per acre. These experiments did not include any assessment of the residual value.

A similar approach to identifying more precisely the trace element requirements of different soil types was taken in the higher rainfall areas. No simple criteria were found for identifying the need for copper or zinc. Soils with apparently similar general appearance and character were found to have quite different trace element requirements. This suggested that the geology of the area may be more important than the soil-forming processes that followed.

The effectiveness of fertiliser copper thoroughly mixed with the soil was shown to decline in glasshouse experiments, in contrast to results from the field.

**Testing for copper status**

Initially with cereals, the copper level in young leaf tissue was used to identify deficiency. In the 1950s Aspergillus niger was shown to be useful as a biological assay tool for copper deficiency. However, in some cases where it had indicated copper deficiency there was no field response to copper application. In 1964/65 soil analysis which used EDTA was developed and gave very good correlations between cereal yield and extractable copper. Later it was decided that, on the limited results available, more reliability could be placed on root copper levels than on plant tissue analysis. A root copper level of 18 to 22 ppm for wheat appeared to be a critical level for maximum yield. Wheat tops would then contain 1.6 to 2.6 ppm. In 1969/70 it was reported that ribonuclease activity was being investigated as a method of identifying zinc deficiency, and nitrate reductase activity in the case of molybdenum. Two other enzymes were of interest for the diagnosis of copper deficiency.

The 1978/79 report detailed a test which enabled the determination of copper status of cereals with far greater certainty than was previously possible. If used correctly this new test for copper could increase the income of farmers through identifying patches of copper-deficient crop scattered within large areas of copper-adequate soil or by identifying marginal deficiency in areas which may never have been treated. It was also found that in particles greater than 3 mm diameter of superphosphate the incorporated copper was ineffective as a copper fertiliser in the year of application.

**Sources of copper**

Sources of copper other than copper sulphate were investigated for possible use in deficient areas. Work in the glasshouse showed that on some soils copper sulphide was inferior to other sources although it was greatly improved if finely ground. The carbonate ores were equal to bluestone as sources of copper.

In 1966/69 investigations into various sources of copper showed that insoluble copper materials were not as suitable as copper sulphate for wheat. The sources of copper other than copper sulphate were comparatively more satisfactory for clover than for wheat. In 1948/49 experiments showed that copper carbonate ores and zinc oxide are as effective as the sulphate salts.

**Zinc as a separate issue**

There was a marked response to applications of zinc on flax in 1946/47. This work was triggered by a large response to superphosphate in the previous year which appeared too great to be due to anything other than a contaminant.

In 1942/43 there was evidence of zinc deficiency on some calcareous soils. The low zinc status of a range of soils had been indicated in widespread sampling of subterranean clover leaves and petioles which was primarily concerned with the level of copper. Leaf samples were also collected from experiments to provide leaf levels as a basis for diagnosis of copper deficiency. The trials, which included zinc and copper applications to wheat, oats and barley, were sown to develop a better idea of the nature
of the response patterns to these elements of the different cereal varieties.

Work on pastures showed that zinc could be important for subterranean clover even where copper was not. Since copper could have an effect on seed production and not any obvious effect on foliage growth, a marginal deficiency was more difficult to identify.

Trials reported in 1953 showed that zinc deficiency was widespread on pasture. This was almost certainly due to the lower zinc content of the superphosphate which was then being largely made from phosphate rock from Christmas Island. By 1954/55 copper fertiliser mixes were being used over a million acres and zinc over three-quarters of a million acres.

There was evidence of a response to zinc on fruit trees when it was applied as a dormant zinc spray. In this work zinc deficiency was controlled with a dormant spray of 2 per cent zinc sulphate. But in 1954 experiments with zinc applied as a spray or soil dressing to fruit trees showing symptoms similar to zinc deficiency, had mixed results.

The experimental results of the early 1950s made it clear that the impurity of zinc in the rock phosphate obtained from Nauru Island had masked zinc deficiency for many years. For a period during and after the war the rock phosphate came only from Christmas Island and this resulted in zinc deficiency across much of the sandy and gravelly soils of WA. In the 1960s the source of rock phosphate was about 50 per cent from Nauru. This rock contained 700 to 800 ppm of zinc while Christmas Island rock contains only 300 to 400 ppm. However the Christmas Island rock contained 120 ppm of copper compared to Nauru rock, which contained only 20 to 40 ppm.

Experiments to identify the true residual value of zinc did not give clear results. This would have been partly because the superphosphate used after the mid-1950s contained at least 400 ppm of zinc.

A synthetic superphosphate which had no trace element contaminant gave yields of about 80 per cent of the maximum at some locations but at Lancelin gave no yield at all and at Esperance produced 15 per cent of the yield obtained with added bluestone and zinc oxide. The experiments also showed that lucerne was more severely affected by copper deficiency than Harbinger medic, Woogenellup subclover or Kondinin rose clover. Serradella showed little or no effect from a shortage of trace elements. There were also variations between the susceptibility of different strains of subclover.

In 1964/65 it was reported that Muscat grapevines sprayed with zinc chelate at Toodyay gave a significant response. Spray applications made in late spring resulted in much better set, heavier yield and improved maturity of fruit. Swabbing pruning cuts with zinc sulphate did not give the same response.

Five long-term experiments to determine the effective life of a zinc application were established. Zinc deficiency had cut wheat yield to less than half on four sites planted with imported di-ammonium phosphate without additional zinc. These results typified crop failures which have resulted from the use of phosphate sources not containing zinc in some form.

Manganese

Extensive work was done on manganese. While it was not as important as copper or zinc, the responses to both soil and spray applications were variable. While soil applications may give higher yields the patchy nature of the problem made them less economic than spray applications to affected plants.

Manganese gave responses on certain marly swamps on the South Coast and on some soils at Kukerin. Manganese deficiency also occurred on some soils in all fruit growing areas.

In 1943/44 an examination of soils where trees responded to manganese showed little evidence of shortage of the mineral. The
conclusion was that the deficiency related more to soil condition and moisture status than to an inherent soil deficiency. Experiments showed that spraying leaves early in the year with trace elements was more successful than soil application. However, the residual value of spray was limited. Also there was a response to manganese placed in holes at depth; this lasted over some years. At Kendenup there was evidence of an effect of manganese on tree health.

Results on fruit trees continued to be variable and intermittent. In 1948/49 further investigations of manganese deficiency suggested there was some residual value of the manganese dressing. Some responses to sprayed nutrients were obtained on citrus where symptoms of manganese or magnesium deficiency were present, coupled with a low level of nutrient in the leaves. No responses were obtained in either case from soil dressings. In this experiment symptoms reappeared after two years, indicating a need to respray the plants.

Manganese deficiency of oats was found on ironstone gravel over clay at Bremer Bay. The spring yield was doubled by a dressing of 40 pounds per acre of manganese sulphate.

Manganese deficiency of cereals was generally likely to occur in patches. Spray applications could be effective, and eliminated the need for soil dressings to a whole paddock, but did not have any residual effect and needed to be applied annually. In 1956 experiments with manganese as a soil dressing showed that the residual effects were low, with no residual effect three or four years later, from dressings of 20 or 40 pounds per acre. Some residual effect was shown with dressings of 60 and 80 pounds per acre but dressings of this order were not economically viable. For this reason spray applications at rates of 2 and 4 pounds per acre were tested on crops. The sprays gave some response but were not as good as soil dressings. Residual effects of some soil applications were seen three years later, indicating variability with soil type.

In 1972 and 1973 the problem of split-seededness in lupin was shown to be due to a manganese deficiency.

**Molybdenum**

In 1945/46 molybdenum deficiency was shown to cause whiptail in cauliflowers. In 1952 molybdenum deficiency of subterranean clover was identified in the Donnybrook area and was thought to be restricted to that district. In 1953 it was demonstrated that molybdenite ore was as effective as sodium molybdate in controlling the deficiency. In 1954 molybdenum deficiency was shown to extend to all the soils developed over granite in the dissected country from Donnybrook to Nannup. Later, molybdenum deficiency was shown to be even more widespread. It was shown to occur through the western districts of the Great Southern in 1961/62. Responses to molybdenum were also obtained on ironstone gravelly soils in the Mt Barker district and were reported on similar soils at Albany and Denmark, and as far eastwards as Esperance.

There was a response on barrel medic and Harbinger medic at Badgingarra Research Station.

The overall position with molybdenum on wheatbelt soils remained undefined in mid-1964. This progressively changed over the remaining years of the 1960s and early 1970s. There was a response to molybdenum in one trial with wheat and one with oats in the north-eastern wheatbelt. This response resulted in molybdenum deficiency in the eastern wheatbelt receiving a lot of attention in 1964 and 1965. Responses were obtained across a very large area of the eastern wheatbelt and in 1964/65 there were 70 trials on molybdenum nutrition of pastures in progress. At Merredin Research Station in 1968/69 a medic pasture responded to 6 ounces of molybdenum oxide per acre.
whereas a dressing of 2 ounces gave no effect.

It was found that where soils had a pH of 6 or higher no molybdenum deficiency occurred but where the pH fell to between 5 and 6 pasture legumes responded to molybdenum. Very large areas were affected.

**Cobalt**

While cobalt was not found to be essential for plants in the field it was essential for animal health on some soils (see Chapter 6). Experiments showed that the residual value of cobalt varied substantially with soil type and application of between 2 and 10 ounces of cobalt sulphate was required to bring the cobalt level of a deficient area up to the level required for animal health.

Soils with a high clay or sesquioxide content, where the pasture was grass dominant and where the growing season was longer, required higher amounts of cobalt and the residual value of the cobalt was lower. This was exacerbated if the cobalt was applied before germination. On most soils the standard application of 6 ounces of cobalt sulphate per acre lasted about three years on moderately deficient sandy soil. On loamy and gravelly soils cobalt was only effective for one year and in some cases might not be sufficient for the whole year. Cobalt oxide was found to be only 10 to 50 per cent as effective as cobalt sulphate in the year of application but showed good residual value in the following year. The problem of cobalt deficiency of sheep and cattle was overcome in later years by inserting a slowly soluble form of cobalt into the rumen.

**Potassium**

A problem of ‘clover stalling’ in pastures of the South West had caused concern from the mid-1930s. Work showed that potassium deficiency was a major cause of this problem. This was demonstrated in 1954 when big responses were obtained to dressings of 200 pounds per acre (227 kg/ha). Subsequent work was directed to finding maintenance amounts.

Some experiments carried out with potassium fertiliser showed that it could be needed on deep sandy soils in lower rainfall areas even through the development years. But it was found to be preferable to use deeper-rooted species in these soils. On potassium deficient sandy soil in higher rainfall areas better responses were obtained to spring applications than autumn topdressing in some trials.

Experimental work on deep waterlogged sands showed a need to tailor application of fertiliser whether it was superphosphate (providing phosphorus and sulphur) or potassium. Later applications in the season were often important for sulphur and for potassium. The residual value of potassium in the years after the initial application was shown to depend on soil type and management.

Unfortunately the potassium resources of most sandy-surfaced soils are limited. As a result continued removal in crop or hay reduces the supply available for future crops or pasture. After between 30 and 50 years of use many of the sandy-surfaced light land soils of the medium rainfall cropping areas are depleted and potassium is now used widely and regularly. Issues of placement to avoid toxicities are important.

**Nitrogen**

Very little nitrogen fertiliser was used in broadscale agriculture before the 1960s. It was used extensively on horticultural crops, mainly on vegetables. Increasing amounts have been used in broadscale cropping since the 1960s. This use was initially associated with cropping of recently cleared land, particularly for second crops on new sandplain. Its use increased in the move to multiple cropping following a period of legume-based pasture and it was shown to be necessary in the practice of continuous cropping without a legume phase.
Wheat on recently cleared sandplain. The plot on the left received 127 kg/ha of sulphate of ammonia. Both plots had the same basic fertiliser.

Nitrogen is now used widely to maximise yield in the minimum tillage cropping system, where higher yields can be obtained. These opportunities result largely from the longer growing season, particularly in the medium and higher rainfall zones with the earlier seeding allowed by the use of herbicides for weed control. Nitrogen use on pastures in the high rainfall areas was also tested in the early years without much impact but is now used as part of an integrated management system on pastures.

Determination of the rates, forms and timing of applications to both crops and pastures has been and continues to be a major research program for the department. A range of experiments on new land in 1954 showed that the average increase in yield from nitrogen addition did not pay for itself. In 1962/63 investigations of the effect of nitrogen application to pasture in the high rainfall dairy areas suggested an ability to increase the carrying capacity of dairy farms. Nitrogen use on pastures in the high rainfall areas was also tested in the early years without much impact but is now used as part of an integrated management system on pastures.

In 1961/62 some 30 trials were carried out from Binnu to Esperance to determine crop responses to nitrogen fertiliser, largely on sandy and gravelly-surfaced soils. In 1962/63 a large number of trials on the value of nitrogen fertilisers on cereals were conducted on both new land and previously developed land. Considerable improvements in grain yield were achieved in many of these trials and recommendations were made. Times of application, the use on successive crops and areas where stubble had been ploughed in or had been burned were investigated. Also experiments were carried out on the use of nitrogen on linseed crops. In 1963 good responses were achieved with quite high rates in the medium rainfall zone on gravelly country. Results on sandy country were less reliable. Surprisingly there was no difference between autumn and spring applications. Both nitrogen and phosphate were shown to be essential and interdependent for new land.

Work on the use of nitrogen fertilisers on cereal grain crops continued in 1964. As before a favourable climate resulted in good responses and profitable results. In continuous cropping trials over six or more years, yields without nitrogen fertiliser were still high for the sixth crop but all yields were needed between closing up a paddock and actual cutting.

It is most valuable in years with a late start, as it increases autumn and winter feed. When there was an early start, pasture levels were usually adequate and nitrogen application was unlikely to give benefits. The eight-week gap between closing a paddock and cutting for hay was confirmed in further trials. Nitrogen application to a paddock to be cut for hay was shown to result in the protein level remaining high for eight to 10 weeks after closing. The need for nitrogen addition to maximise the fodder conserved would again depend on the season. Successful use of the added feed depended on adequate stocking rates. Despite the results of this work it was not used widely in the dairy industry.
improved by nitrogen fertiliser. Anhydrous ammonia gave profitable yield increases when applied at two or four inches deep and about five weeks before seeding or at sowing time. Increased wheat yield was obtained where stubble was burnt. In treatments which did not include stubble burning there was a heavy infestation of Wimmera ryegrass so that the difference in yield was not high. This work was repeated and the results confirmed.

In general the results supported a recommendation for nitrogenous fertilisers for cereal crops to be applied as close as possible to seeding. Applications more than four weeks after germination were less likely to improve yield.

Work with nitrogen fertilisers continued in 1967. Under continuous cropping profitable responses were obtained at all locations except Merredin Research Station.

Investigations were continued into the appropriate time and method of application of urea, the relationship between wheat varieties and responses to nitrogen, the use of nitrogen/phosphorus compound fertilisers and anhydrous ammonia, and rates of nitrogen used. Later, the results had to be reworked as major changes occurred in methods of planting crops.

In 1971, in 35 field trials with nitrogen, a large percentage gave profitable responses. A higher proportion of these were in the lower rainfall areas, which was unusual. As a result of evidence in 1969 that the drilling of the more soluble or compound fertilisers with the seed had reduced germination, a series of experiments showed that under some conditions drilling the highly soluble compound and nitrogen fertilisers with the seed could be a disadvantage.

In 1969/70 the work on nitrogen fertilisers and stocking rates continued at Wokalup Research Station. The addition of nitrogen to irrigated pasture made a substantial difference in carrying capacity. However, the animals lost weight from March to May despite the presence of feed of adequate quality. A similar experience was encountered using weaned calves at a high stocking rate.

**Lime use**

It has been known for many years that when soils with a low initial buffering capacity were sown to improved pastures and topdressed with superphosphate the pH would fall over time. The concern with this gradual acidification of cropping and pasture areas resulted in a strong recommendation for liming of some soils. In 1997/98 it was reported that almost 400 000 tonnes had been used and was expected to reach an annual use of between one and two million tonnes.

**Pastures**

**Pasture legumes**

**Subterranean clover**

The introduction of subterranean clover as a pasture legume was a major development in agriculture in Western Australia. It appears that subterranean clover had been identified in Western Australia in the early 1900s but was thought to be of little use. In 1907 some seed was obtained and plots planted at the Hamel State Farm. It grew very well and attracted some attention but does not seem to have been used at that time. The mid-season variety which would have been planted at Hamel was heavily promoted by its ‘discoverer’, AW Howard of Mt Barker, South Australia.

In 1922 a graduate agricultural adviser was located in the southern areas. His 1923 report refers to paspalum and Rhodes grass as promising pasture plants for the establishment of permanent pasture. In other experimental plots pastures were based on paspalum and white clover. It seems that the focus was on perennial pasture plants in the European tradition. In 1924, 27 other farm experiments or demonstration plots were established in the South West but they surprisingly do not appear to include
subterranean clover. Yet presumably by that time it was being used in the group settlements.

According to AB Adams, writing in the Journal of Agriculture in 1924, an early maturing variety was identified at Wilga in the early 1900s but was not developed. Some seed was reported to have been brought to Katanning from South Australia as early as 1902. It would have almost certainly been of the mid-season (Mt Barker) variety and would not have been suitable. Separately in 1908, a farmer named Martin obtained some seed from South Australia. He planted it at Mt Barker in 1910 but it was 1912 before it was noticed. Subsequently it was spread over the whole property by livestock. This variety became the basis of the pastures of the higher rainfall areas of WA but would not have been very successful outside the 700 mm rainfall belt.

Adams recommended that the seed should be sown at shallow depths or topdressed before the first rains ‘on the burn’ without any cultivation. He recommended that it be topdressed with 106 to 176 pounds per acre (120 to 200 kilograms per hectare) of superphosphate followed by 106 pounds (120 kg) each year. Sowing on the burn became very popular in the Group Settlement Scheme, where subterranean clover became the basis of pasture development, but the fertiliser rates were low for new land. Nevertheless, these were sound recommendations.

It is likely that the rate of superphosphate used was generally low. In a 1925 report there is reference to impressive results from superphosphate topdressing trials. There were also experiments reported from the Northcliffe plain and the Cranbrook district. By 1928 the practice of topdressing pastures based on subterranean clover would have been universally adopted for the developing dairy farms in the South West.

During the 1930s, following the collapse of the export wheat price, there was increased interest in sheep management on cereal farms in order to improve income. This focused farmers’ minds on pastures and, aided by demonstrations of topdressed sown pastures by the department in association with the fertiliser companies, there was an increased interest in pasture. This extended to the medium rainfall areas. Unfortunately the variety of subterranean clover planted outside the higher rainfall areas was Dwalganup.

The availability of tractors, which permitted much faster working of land, made it possible to take advantage of the fertility build-up under the legume-based pasture through the use of an alternative farming system for cereal production. Initially the State’s wheat industry was based on a system of crop-fallow. While horses were the main source of traction it was necessary to crop onto well prepared fallow to achieve the combination of good weed control and early sowing. There had been a progressive change in the rotation from fallow/crop to a fallow/native pasture/crop rotation with the crop planted on a ‘late’ fallow. Tractors allowed crops to be sown where the pasture was ploughed and weed control achieved after the first rain immediately before the crop was planted. This possibility was seen by department researchers, TC Dunne and FL Shier, whose paper *An Alternative Rotation for The Wheat Belt* in 1934 became the basis for the development of the ley farming system which was the basic crop rotation for the 1950s through to the early 1980s.

The crop/sown pasture/crop rotation of the ley farming system provided an opportunity to increase farm productivity, provided the resources were available to achieve weed control before planting the crop. With a pasture legume, fertility was increased for the cropping phase as well as improved pasture for the stocking phase.

Subterranean clover was equally important in the dairy areas. It was obvious from records that available feed was a major factor in the variations in year-to-year production of the dairy herd on established farms.
In the medium rainfall cropping areas pasture improvement became important. In the 1953/54 report the statement was made that “the most outstanding development of recent years has been the establishment of subterranean clover on Chapman, Wongan Hills and Avondale Research Stations”. Interestingly, it was reported that subterranean clover had re-established itself at Avondale and Chapman but not at Wongan Hills. This situation changed over the years.

In 1956 barrel medic and subterranean clover were planted at Wongan Hills Research Station. Barrel medic did not do well there but did on heavier soils of the eastern wheatbelt and was planted extensively on Merredin and Salmon Gums Research Stations.

The large amount of work on the breeding, nutrition, establishment and varietal comparisons on subterranean clover, which has been a foundation stone of Western Australian agriculture is dealt with elsewhere in this book.

After 1990 there was a major change in the available pasture legumes, which changed the pasture landscape in Western Australia.

**Legume establishment**

A major service provided by the department in the pre-World War II years was the provision of Rhizobial cultures, with instructions on their use, to farmers planting legumes, mainly subterranean clover.

During the development period of 1948 to 1968 substantial areas of sandy soils were sown directly to pasture, particularly in the southern higher rainfall agricultural areas.

While legume establishment had not been a problem on older developed soils, a problem of mortality of 40 to 60 per cent or even 100 per cent of young clover plants was observed on areas of recently cleared and ploughed sandplain which had been sown to subterranean clover pasture. The problem became known as ‘clover mortality’. It normally occurred where the native scrub was burnt and the land ploughed and seeded in the same year. It was worse if some vegetation was ploughed in. It did not normally occur on land which had been left fallow for a year or had been cropped following clearing. As a result there was a general recommendation that subterranean clover only be planted on recently cleared land which had been fallowed or cropped before planting clover.

The start of detailed experimental work to determine the cause of this seedling mortality was delayed due to other important issues occupying the time of the limited number of pathologists available. Their work showed a favourable response to fumigation, which suggested that the cause was an antagonist produced in the soil organic matter following clearing. This proved to be the case.

In 1957 studies of the establishment of subclover and barrel medic on new land, *Rhizobium* strains and protection of inoculum at planting were investigated. As a result of this work lime pelleting of inoculated seed was recommended for all legume plantings instead of inoculated bare seed.

In 1953/54 extensive trials on acid peaty sands demonstrated the necessity of lime together with adequate dressings of superphosphate and trace elements on these soils. However, most WA soils are less acid and the addition of lime to new areas to adjust the pH was not necessary. Lime was also known to accentuate zinc and some other trace element deficiencies through raising the soil pH and reducing the trace element availability. On the other hand it increased the availability of molybdenum.

Variation in the effectiveness of different *Rhizobia* was shown in a clover establishment trial on sandy soils at Badgingarra Research Station. The best second year establishment of one variety was produced by a strain of *Rhizobium* which was relatively inferior in the first year. This suggested that some strains have better survival over the summer, and that on some sandy soil other strains did not survive the
hot dry summer conditions. Selection of Rhizobia capable of surviving through to the second year of development, and the use of alternative deep-rooted pioneer plants proved necessary on these soils.

Due to the evidence of differences in strains of *Rhizobium* for various annual legumes and for lucerne, specific strains better suited for particular pasture legumes were identified. These strains were included in the commercial inoculum and would have had a large unmeasured impact on productivity. This work on testing and improving the legume Rhizobia has continued. A large number of strains have been collected in the field and tested for effectiveness on subterranean clover, lucerne and barrel medic over the years. Field work has shown that there is delayed nodulation on a large number of established clover pastures.

Further work on nodulation was reported in 1971. In that year strains of inoculum available commercially were compared and the new strains. The methods used in commercial pelleting were also examined and found to be deficient. Examination of nodulation in the field showed that some subterranean clover cultivars had greater problems in nodulation in the first year than others.

Some experiments were also carried out on inoculation of lupins. It was found that on new land nodulation was only effective where there was an extremely high rate of inoculum on the seed. On old clover land however lupins appeared to be healthy and well nodulated.

During the 1980s two medic *Rhizobium* strains which were more acid-tolerant were identified. This allowed medic to be established on more acid soils than previously and extended their range significantly.

In 1992/93 an acid-tolerant strain of medic *Rhizobium* superior for lucerne and disc medic was isolated from a Greek island and was adopted Australia-wide.

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**Land development**

The building blocks of agricultural development had been produced but the challenge was to produce viable systems of farming from these building blocks. For a particular area the issues were to determine the right cereal/pasture combination and the right species, cultivars and fertiliser treatments to maximise production.

**Examining pasture species**

In the mid-1960s a number of grass and legume species were tested on the wheatbelt research stations and on farmers' properties over a wide range of environments. The environments included deeper sands, the drier parts of the wheatbelt and some saline areas. Some 60 legume species trials were established. The range of species included subterranean clover, barrel medic, rose clover, cupped clover and serradella. The grasses included soft brome (*Bromus mollis*), which was being tested in collaboration with CSIRO over a range of situations, and bluebush and saltbush on salt-affected soils at Salmon Gums. The use of deep-rooted species such as blue lupins, lucerne or serradella proved reasonably satisfactory on deep white siliceous sands of the western sandplain with serradella achieving better production than other legumes.

A range of grass species was tested in the higher rainfall areas, mainly under grazing. At Bramley Research Station promising strains of soft brome did not withstand heavy continuous grazing under conditions where Wimmera ryegrass performed satisfactorily. In a trial during the 1960s at Bramley lucerne and kikuyu grass were the only perennials which contributed to grazing. Kikuyu in particular was later used in a number of areas in the South Coast and South West. At Esperance Research Station lucerne, which had been continuously grazed for four years, was also almost eaten out at a stocking rate of three wethers per acre. The rotationally-grazed lucerne, at the same overall stocking
rate, remained as a vigorous dense stand after four years, producing about 18 pounds (8 kg) of wool per head in 1964.

Perennial grasses were tested at Kendenup, Mt Barker and Forrest Hill in trials established in 1965. They were tested under continuous grazing to determine whether they could stand a low input grazing management regime. It was concluded in 1969 that under continuous grazing, these perennial species made little contribution to pasture productivity.

Experiments were carried out on methods of establishing legumes in the wheatbelt. The relative merits of spacing and under-sowing a cereal crop were investigated. This work showed that under-sowing with even a light rate of clover seed could result in substantial losses of yield, probably due to competition for moisture.

Nine trials comparing the production and persistence of a range of legumes were sown in 1966. These legumes established under intermittent stocking but were tested under the heavy continuous stocking which subclover withstood. On the deeper sandy soil in the West Midlands which had gravel or clay within 15 to 30 inches, Pitman’s serradella grew better than other species.

A grazing trial was established on heavy land to compare Cyprus barrel medic, Geraldton subclover and Kondinin rose clover. These species were compared separately, with a mixture of all of the species and with a volunteer pasture consisting mainly of barley grass and woolly clover. The trial was subject to continuous grazing at two rates of stocking – 1.5 and 2 sheep per acre.

In a higher rainfall trial the fertiliser and establishment needs for lucerne were investigated at Lancelin. It was also compared with other species. A further species trial under grazing was established on light yellow sand west of Moora. The trial included lucerne under a range of management techniques. In the grazing trial at Lancelin, rose clover became sparse and serradella proved susceptible to insect damage, leaving the subterranean clover and medic providing the best pasture contribution in the second and third years. Lucerne was also satisfactory under rotational grazing of one week in every four.

A grazing trial at North Bannister showed that following a dry season when seed was low in the late maturing cultivars, there was a drop in body weight compared with the early or mid-season cultivars. Extensive pasture production trials were carried out at Denmark Research Station through the 1960s related to plant introduction, fertiliser sources and rates and use on specific soils, lucerne management and carrying capacities.

Phased pasture species

One approach to obtaining a dense legume-dominant pasture sward in the year between crops was to rely on a high degree of hard seed in the selected legume. This process was shown to work with hard-seeded species such as serradella and biserrula which could be sown with a crop at high seeding rate, having seed which did not germinate until the season broke in the following year. The alternative approach was to take the emphasis off pasture regeneration (selecting for hard seed etc) and use cultivars with a high level of seed production and ease of harvesting so that growers could produce their own cheap seed and sow pastures at high seeding rates in the inter-crop years.

Testing new areas

In 1959 an area was established at Forrestania some 40 miles (60 km) east of Hyden to determine the suitability for agriculture of yellow loamy sandy soils similar to those at Wongan Hills. The experiments were successful but it was decided not to develop that area. There was adequate rain during the trial period and growth of crops and pastures was good. Molybdenum was essential for legume growth.

A further area was selected in April 1965 half-way between Lake King and Salmon.
Gums, south of the Johnson Lakes, with an estimated average rainfall of 12 inches. No rainfall records were available and rain gauges were put in strategic locations. Sites were selected for two experimental areas near the 90-mile tank.

The experimental program gave quite good yields even though conditions were relatively dry. The yield on fallowed land was much better than on non-fallowed areas, apparently due to increased moisture. This raised the question of whether fallowing should be part of the normal cropping practice in the outer wheatbelt where moisture can be very important in dry years. Subsequently a decision was taken not to proceed with any development to the east of the rabbit-proof fence at the level of Lake King or Salmon Gums.

Both the Forrestania and the 90-mile tank areas were within the area originally considered for the 3500 farms scheme of the late 1920s. At that time the sand and gravelly-surfaced soils were not considered, as the trace element needs had not been understood.

In 1966/67 the demonstration of suitable pasture species, fertiliser and lime requirements for two of the main sandy soils of the Scott River area increased the possibility for pasture development in this high rainfall area. The development of the sandy soil west of Harvey was also proceeding rapidly following demonstration of successful pasture growth under grazing on the winter-wet Joel sands. The Scott River Plain has been developed largely as pasture for dairying. In 2009 it was reported that two major dairies of over 1000 cows each were planned. However, with its underground water it has the potential for more intensive forms of production.

Fertility build-up under legumes
In 1947/48 research included studies of the effect on crop yields and soil properties of legume pasture and the capacity of the legume to recover when mature subclover pastures were cropped. In the early 1950s crops grown on old clover pasture were compared with crops grown on areas not previously under legumes. As expected, there was a marked improvement in both yield and flour quality of the grain.

After 14 years of a rotation experiment at Wongan Hills Research Station it was concluded that crop yields rose rapidly after a short period of clover pasture but did not reflect the accumulated nitrogen level of an area which had been under clover pasture for seven years. The explanation appeared to be rapid mobilisation of nitrogen in the early years and a slower mobilisation of nitrogen from the more complex soil organic matter existing in later years.

In other trials the crop yield after two years of clover pasture increased about 10 bushels per acre (680 kg/ha) over virgin land but only increased by a further 4 bushels per acre (270 kg/ha) after seven years under clover. The soil nitrogen and soil carbon build-up and overall fertility increase was examined. It was found that soil carbon increase under clover pasture was confined to the top 2 inches (5 cm). At Wongan Hills a nitrogen build-up under dense clover of 30 to 40 pounds per acre (35 to 45 kg/ha) each year was measured.

An experiment to determine the effect of harvesting clover seed on the fertility of clover pasture showed that the soil carbon and nitrogen were substantially reduced. Yield was reduced by almost 4 bushels per acre (270 kg/ha) in the most severely treated experimental area.

In 1983, 1984 and 1985 there was increased focus on tillage research and development. Alternative methods of planting to achieve a one-pass sowing with minimum soil disturbance were studied and there was increased work on crop rotations. This is dealt with later.

Alternative crops
At Mt Barker Research Station a sunflower trial using two seeding rates, three row spacings and three planting times produced
low and uneconomic yields. The experiment was part of attention given to alternative crops which included a detailed economic examination of oilseed crops and grain legumes including linseed, rapeseed, safflower, sunflower, lupins and peas. Numerous trials investigated aspects of lupin production across the wheatbelt. The results indicated that the low alkaloid lupins available at that time were generally disappointing. Experience showed that these early cultivars did not indicate the potential for this developing crop.

**Weeds and diseases**

*Weed control*

Weed control remains a fundamental part of crop production and the work of the weed science and control group was fundamental to the earlier ley farming system and the basis of the 'new agriculture' which developed in the 1970s and early 1980s. The group carried out extensive experiments and demonstrations of the effectiveness of the wide range of herbicides on a wide range of weeds. Work was also needed on the tolerance of important crop and pasture species and cultivars to the range of herbicides potentially in use. Part of the work focused on hard-seededness in legumes. This work also included management techniques for weed control where herbicides were not available. For example, the weed radish, which was difficult to control in the lupin phase of a rotation, could be relatively easily controlled in the cereal phase. However, this was not always successful and in 1986/87 it was found that a second application of simazine had potential for substantially better control. With satisfactory radish control it was estimated that lupins could be grown on an additional half million hectares. The threat of skeleton weed to the grain growing areas was examined. A study found that it was liable to be a problem across most of the wheatbelt but the area from the south-eastern wheatbelt to Esperance appeared to be at particular risk. Based on this work the statewide program for skeleton weed eradication was continued.

The possibility of herbicide used in drilling programs affecting later crops and pastures was examined without evidence of residue carry-over being found. Nevertheless monitoring of the effect of herbicide residues continued.

Over time some important weeds, including radish, became resistant to an important herbicide in the cropping system and management solutions or alternative herbicides had to be used or developed. This became a cooperative program with the University of WA.

*Flue gas toxicity*

In 1971 it was reported that investigations had shown that the flue gas emissions from a brickworks were damaging vines. The likely cause was fluoride in the emissions. The same report suggested that vegetation damage on the areas surrounding the Alcoa refinery was due to sulphur dioxide from fuel oil. Toxicity was also suspected as the cause of damage to vegetation near phosphate works at Picton Junction and Esperance. At Esperance damage to the Norfolk Island pines and Moreton Bay fig trees suggested that the dust from loading operations of shippers was contributing. Chloride and/or nickel toxicity was suspected and investigated.

*Plant diseases*

Every year the Plant Pathology Branch examined a wide range of diseases. For example in 1965/66, 20 different diseases were examined and work was done on them. Some of the more common and important ones are listed below.

*Lupinosis*

This major problem caused many animal deaths and limited the use of lupin stubbles which were a valuable summer feed. It was diagnosed early as caused by a fungal toxin
but little progress could be made in developing a control measure until the fungus was identified. The Plant Pathology Group showed that the fungal spores infested lupins much earlier than previously thought. They also showed that fungicide sprays were ineffective in controlling the disease. Lupinosis is discussed in detail elsewhere.

Cucumber mosaic virus
By 1988/89 cucumber mosaic had been identified as a serious problem of lupins. It was shown that lupin plants grown from seed infected with the virus died during any long dry period. Other work showed that it was spread by particular aphids. Control was proposed through the monitoring of aphid population and strategic spraying.

Nematodes
Attempts were made from 1945/46 to obtain responses to fertiliser on grapevines which were not thriving in the Swan Valley. The responses were variable and unconvincing. Over the years attempts to revitalise vines with nutrients largely failed.
In the early 1950s, the possibility of root knot eelworm being a factor in grapevine decline in the valley was investigated. In 1954/55 experimental work on eelworm was stepped up as new techniques and fumigants became available. Increased yields following fumigation reached 28 per cent on sandy soils. Studies of the resistance of rootstocks to eelworm resulted in a number from the United States being tested in the Swan Valley in 1971, with good results.
The 1973/74 report referred to an apple replant problem. This was shown to be caused by two disorders. One was an infestation by nematodes and the other was a complex of diseases, the cause of which had not been identified. Soil-inhabiting micro-organisms were suspected to be the main cause of the problem as outstanding control results had been obtained with soil fumigation. Experimental work showed that by the second year replant apple trees showed a marked growth response to fumigation before planting.
Studies of citrus decline in the 1950s also showed that an eelworm could be involved, together with a Phytophthora rootrot. In general, there was a realisation that eelworm was more important than had previously been thought. Extensive work including testing rootstocks for susceptibility and testing pesticides and fumigants on eelworm problem areas was undertaken with both vines and apples.
The general interest in eelworm focused attention on whether the nematodes were involved in orchards where dieback was a problem. At Manjimup an area of poorly performing orchard was removed and the soil fumigated. The area was then replanted. Apple nematode control by fumigation was shown to maintain healthy tree growth for some time but in the fifth year at one site growth had stopped and nematode numbers were increasing. In other cases fumigation did not show a response after two or three years. The question was whether the increase in the yield was more than offsetting the cost of fumigation. Further work was being carried out on eelworm-resistant rootstocks for vines.
In 1966/67 a major part of the investigation work related to eelworm of cereals, apples, citrus and grapes. In grapevines an infection by citrus eelworm was found for the first time. All rootstocks were found to be susceptible. With apples a large experiment was started at Donnybrook.
Cereal eelworm was found on some older properties in the Geraldton-Dongara district.

Virus diseases
Considerable work was undertaken on virus diseases. Granny Smith and Jonathon apples and the Pomme de Neige were freed of the apple mosaic virus. In 1961/62 studies of the impact of viruses on tree growth were started. Virus indexing of plums for the line pattern disease had also started, as well as a study on the effect on growth in the commercial plum varieties of this disease.
Virus indexing of the grape varieties had also started. Clover stunt virus was identified at Esperance. In 1961/62 the yellow dwarf virus was discovered in WA for the first time. Tests at Avondale and Esperance found no evidence of yield losses from yellow dwarf virus infection on cereals. This situation changed later.

Jarrah dieback
The 1964/65 report described a joint study in the Forest Research Institute led by a Department of Agriculture pathologist and involving the Forestry and Timber Bureau and Department of National Development, was successful in identifying the causal organism of Jarrah dieback. *Phytophthora cinnamomi* was the causative agent. This finding enabled the development of control approaches.

Wheat stem rust
Stem rust was periodically a serious problem in the wheat industry. Two epidemics mentioned in 1934 and 1943, reflected favourable climatic conditions for the development of the fungus. The overall policy was to control it by breeding resistant varieties. There was no other general problem before the early 1960s, then in late 1962 there was evidence of a new race in Esperance.

In 1963 rust was widespread in the wheatbelt due to a general incidence of the new races 21-2 and 21-12. Only the New South Wales-bred cultivars Gamena and Mengavi and the WA-bred Moora remained resistant. In 1964 three new strains of stem rust were found. All three were capable of attacking Gamena, Festival and Dowerin. One of the strains could also attack Mengavi. This meant there were strains of rust capable of attacking all current varieties. An Australia-wide survey of rust strains showed that six of 56 submissions from Esperance were a new strain designated as 21-2,3,4,7. This was known to break down Gamena and Mengavi. In 1968/69 a survey of the whole State showed that the situation appeared to have stabilised with 21/1,2 and 21/2 being the common strains present. Gamena was resistant to both. A garden to identify varieties of rust was established at Denmark Research Station. Loose smut of wheat and barley is seed-borne and not controlled by usual fungicidal seed dressing. Overseas work suggested that a systemic fungicide, Vitavax, may control the problem and an experimental program was started to examine this possibility.

Root rots
Root rots were a serious problem of cereals in clover ley cropping. No treatment apart from a cleaning crop had been successful in overcoming them. With the rotation experiment at Esperance, wheat sown after pasture, barley or wheat was severely affected by take-all whereas wheat after linseed, oats or vetches was relatively free from this disease. Experiments at Esperance Research Station showed that barley grass and rip-gut brome grasses were extremely important carry over species of take-all in WA. Silver grass and blando brome grass, although susceptible, do not carry take-all so effectively. Wimmera ryegrass and perennial veldt grass were not obviously affected by the disease.

In 1977 it was reported that that some nitrogen fertilisers reduced the incidence of root rot on wheat. Sulphate of ammonia and Agras18:18 were the fertilisers involved.

Septoria
The 1968/69 survey of the incidence of *Septoria tritici* across the wheatbelt found it to be present in 95 per cent of the 200 wheat crops examined. There was a higher incidence in the southern wheatbelt, particularly in the higher rainfall regions. Examination of 28 isolates showed no significant difference in their parthenogenesis. Testing of 400 wheat varieties in the glasshouse identified some which could be of use in differentiating...
strains in future isolate testing. In a 1968 study *Septoria* was found to be present in almost all crops sampled but did not generally cause yield losses of more than 10 per cent in areas which received less than 16 inches of rain. In 1969, which was the driest year in the wheatbelt since 1914, there was some infection with *Septoria* but no crops were seen where it would have had any impact on yield.

*Seed emergence of wheat*

An examination of the fungicidal seed dust used for disease control showed that there was either no effect on the emergence of wheat, or emergence was assisted by the presence of the fungicides. However, it was shown that emergence could be reduced by the presence of large amounts of stubble incorporated in the soil. In this case the fungicide could have a protective effect.

*Powdery mildew*

In an outbreak of powdery mildew on barley it was shown that this was unlikely to cause any significant commercial problems. This was the case with a large number of other diseases of less importance dealt with by the plant pathologists during most years.

*Subterranean clover damping off*

Work at Donnybrook in 1952/53 and 1953/54 demonstrated that heavy grass residues reduced the subterranean clover content of the pasture in the following year. In the mid-1960s researchers identified two organisms capable of causing damping off of subterranean clover when it emerged under heavy trash cover. They were identified as two species of *Fusarium*.

*Subterranean clover scorch*

Clover scorch reached serious proportions on subterranean clover pastures in south coastal and south-west districts. In 1973 it was reported for the first time in the Dandaragan district. While promising results have been obtained with a systemic fungicide to prevent the disease build-up, it was uncertain whether this would be economically feasible. Breeding for resistance held the solution, provided by the later release of the Esperance cultivar of subclover.

*Subterranean clover root rot*

The 1973/74 report dealt with large areas of subterranean clover pasture in the south coastal and lower South West districts which were affected by a root rot disease which was particularly widespread in the Walpole, Denmark and Manjimup districts. A number of *Pythium* and *Fusarium* fungi were isolated and tested for their capacity to cause the disease.

*Pesticide residues in pasture*

Analysis of pastures and fodder crops in the South West showed a marked interaction between soil type and the level of organo-chloride residue in the plant. A peaty soil with a high organic content gave a low level, whereas the reverse was true on a red silty loam. The work involved the collection of 300 soil samples and 700 samples from crops and pastures.

*Vegetables*

Routine work of the pathologists included examination of a range of disease control measures using old and new fungicides across the large number of diseases. Pedigree seed of the rust-resistant Westralia bean was produced to meet national demand. In 1967 advice was received that the Queensland Department of Agriculture had shown that the Westralia bean was resistant to all six known rust races in Australia.

Bacterial wilt, pink rot and rhizoctonia of potatoes were among many diseases investigated, plus powdery mildew of capsicums, bean rust, diseases of root crops and the freezer pea industry.

Continued effort was made to ensure the potato cyst nematode did not establish in Western Australia. Discovery that it survived...
on the sour thistle, a plant not of the Solonaceae family which had been thought to be the only plant family affected, was a concern. This increased the difficulty of controlling the nematode. While outbreaks were eradicated from WA, national agreements required the department to contribute to its eradication in Victoria.

Powdery mildew of potatoes
Powdery mildew had reduced marketable potatoes in winter and spring crops in the Spearwood district for many years. It was reported in 1973 from all of potato growing areas. Serious losses in some plantings occurred in the Manjimup and Pemberton districts. Experiments indicated that a range of fungicides could control the disease but conflicting results were obtained with trials.

Agronomy and soil studies

Soil structure
Over the years there has been concern about the loss of soil structure in most cultivated soils. Some soils which had poor structure under natural conditions were difficult to manage. Experimental work had shown that cultivation reduced soil structure and periods under pasture resulted in full or partial recovery. The loss of structure was much more significant on clay and clay loam soils where it was likely to reduce water penetration, make root penetration difficult, and could affect germination. It also increased the difficulty of cultivation and reduced the period when soils could be worked. Soils with naturally poor structure experience all these problems.

Gypsum was regarded as a valuable soil ameliorant capable of improving the structure and general characteristics of these soils. As a result, extensive experimental work was carried out to test the effect of gypsum. Some examples of this work follow:

- At Merredin Research Station 12 experiments were carried out to study the effect of sulphur and gypsum on soil structure. No positive results were reported.
- Studies of the effect of different cultivation methods (mouldboard, disc or scarifier) showed no difference in effect on yield or soil structure, between cultivation methods. This cast doubt on the claim that deep ploughing aided water penetration and organic matter build-up to depth. Experiments with speeds of cultivation at Merredin and Salmon Gums showed no difference. Similar results were obtained at Wongan Hills where, in clover/wheat rotation experiments, a speed of cultivation trial gave inconclusive results.
- In 1961/62 at Merredin Research Station and Corrigin, soil structure was again studied, including a comparison of the relative impact of soil amendments versus continuous subclover pasture. This included a study of soil moisture penetration and utilisation under different vegetation cover.
- Gypsum was studied as a possible soil amendment for soils which had been difficult to cultivate and showed poor emergence if there was heavy rainfall post-seeding. The rates of gypsum were 2 and 4 tons per acre. These experiments showed some minor differences in two locations but generally no major effect on yield. Samples however showed that the water stability of the soil had been increased. Trials of gypsum as a soil amendment showed significant yield increase in one experiment. While on other sites the value of the incorporation was hard to identify, there was a general improvement in the soil structure of the treated areas, which could be described as being ‘softer’ than the untreated areas.
- In Carnarvon gypsum studies on irrigated soils showed no effect of gypsum dressings in the first year.
- Other work showed that sheep grazing very wet areas of pasture reduced the soil structure through a trampling effect.
In an experiment at Merredin Research Station the soils protected from grazing in winter for two seasons had a greater water-stable aggregate than soil which had been grazed for that period. In another structure experiment, soils in an area which had been under a long-term clover wheat rotation, were sampled on four occasions. The samples were collected once before any cultivation, once during fallow, and on two successive years of wheat crop. It was found that over the four years total nitrogen was lowered by cropping and cultivation, as were the water-stable aggregate and bulk density. Organic carbon values showed no consistent trend.

At Merredin Research Station the stable soil aggregate after four years of pasture was higher under Wimmera ryegrass than under medic or volunteer pastures. This work also confirmed the effect of compaction during winter stock grazing in reducing the level of stable aggregate.

A study of the effect of pasture and cropping on the water-stable aggregates showed that under pasture the water-stable aggregates increased but cropping quickly destroyed this improvement.

A similar result was obtained from an experiment at Wongan Hills. In 1969/70 studies of soil structure under two long-term pasture/wheat rotation experiments showed that the water-stable aggregates were maintained or built up under pasture but were destroyed by cultivation and cropping. On the other hand, the decline in the water stable aggregate after the two years of crop was reversed after the first year of subclover pasture.

The advent of chemical weed control and virtual elimination of ploughing and cultivation revolutionised the impact of cropping on soil structure and protected the build-up of fertility in the soil following periods of pasture. In one experiment comparing different planting methods on a clay loam at Merredin Research Station, it was observed that the ‘no till’ treatment had returned to a natural ‘soft’ state to walk on after only a few years. This further demonstrated the detrimental impact of cultivation on soil structure.

**Value of cultivation**

Experiments investigating cultivation practices in crop planting showed that weed control was the main concern. Repeated ploughing before seeding risked delaying seeding, which was detrimental to yield. Depth of ploughing was only relevant to the extent that it improved weed control.

**Saltland revegetation**

Saltland revegetation studies were carried out over many years. In the early 1960s yield and grazing trials were conducted with bluebush and saltbush and seed viability was investigated. It was found that bluebush and Wimmera ryegrass seeds were able to survive for an extended period under 3 per cent salt water. But the trials showed that the growing plants did not like areas where they were waterlogged in winter. Puccinellia grew in these conditions, as it could grow successfully in extremely salty water.

In 1962/63, demonstration plots showed that revegetation of saline land was feasible and potentially productive. After repeated establishment failures with bluebush it was found that it was necessary to remove the floral parts to expose the seed, which resulted in an increased speed of germination. This was in part due to removal of a physical inhibitor but also to the removal in the seed husk of a water soluble germination inhibitor. It was also found that the salt level could inhibit germination of bluebush.

Surprisingly when the bluebush seed was allowed to stand in a 3 per cent salt solution for three weeks and then the salt solution was removed, the seed germinated more quickly than the untreated seed. Bluebush seed maintained its viability in the solution for at least three weeks. Both bluebush and saltbush have been planted on salty land as
potential feed in the eastern wheatbelt. Given that the statistics available showed that large areas of formerly good soil had become salt-affected, and that this was increasing, a capacity to revegetate with a productive species was important.

Seed of two varieties of samphire was collected from salt-affected areas in both the ripe and unripe condition. When the unripe seed heads were allowed to dry, the seed germinated as well as the ripe seed. It was found that there was a wide temperature range for germination, occurring in both species between 5 and 35°C. The varieties were tested for sensitivity to the concentration of salt present at the time of germination. One variety gave a 50 per cent reduction at a concentration of 0.8 per cent of sodium chloride and the other at 2.0 per cent of sodium chloride. It was concluded that from the point of view of salt tolerance at germination, both varieties were no more tolerant than most common crops. This indicated that the varieties have naturally selected to germinate in periods when the salt concentration was low.

Sheep grazing saltbush. The department demonstrated that saline land could produce very valuable high protein summer feed.

The bluebush and creeping saltbush plantings established at Merredin Research Station grew well and provided good autumn grazing in two years. A number of salt-tolerant species were planted at eight salt-affected sites in the Central Agricultural Region and provided both demonstration and research information. Also experiments were carried out to find a solution for the difficulty experienced in establishing bluebush on some wheatbelt soils.

Over 10 years to the late 1960s more than 70 demonstration plots on management of saltland were established throughout the agricultural areas. They served both as a source of additional knowledge and provided farmers with a demonstration of how saltland could be utilised.

In 1966 the program of saltland trial plots, samphire studies, and puccinellia and bluebush establishment continued. Leaf coatings were also compared as a means of reducing the amount of salt uptake through spray irrigation with saline water. In 1967 the issues examined were puccinellia germination and establishment, plant introduction and testing, the use of tamarisks in saline areas and groundwater studies at East Pithara and Busselton. Renewed interest in tamarisks arose from reports of success in lowering the groundwater in parts of the United States.

In 1969/70 it was reported that the collection of the salt-tolerant plants had been increased by a further 29 accessions so that a total of 478 plants were available and that this work was continuing. By 2000 it was regarded as a mature technology which could be built on from time to time. A major contribution to the use of salt-tolerant plants was the development in cooperation with a farmer of the ‘Mallen’ seeder. This facilitated the planting and establishment of larger areas of saltbush. These in turn provided the resources for carrying capacity experiments and demonstrations. The program was the catalyst for formation of the Productive Use and Rehabilitation of Saline Land (PURSL) program.

Other issues such as the demonstration that citrus grafted onto citronelle rootstock did not take up salt from variable salt levels in irrigation water but did take up salt if grafted...
onto trifoliata rootstock had potential commercial application.

**Water balance studies**

Water balance studies were carried out to evaluate the change in water usage on different soils after clearing. Studies of a saline groundwater table in a salt-affected valley showed that the water was under pressure in underground aquifers and would rise above the surface when the impermeable barrier was penetrated with a drill. This confirmed the view that the source of the water was from higher country where water seeped into the underlying aquifer which progressively filled and produced hydraulic pressure in the lower parts of the aquifer.

In 1967 studies of the watertables in the Busselton area showed that saline water was present in salty valleys at a depth of 6 feet and that it was under pressure. In 1967 the work on watertables in the Harvey area and Elgin, and soils studies in Carnarvon continued. Examination of the Collie irrigation area showed that some 400 to 500 acres were salt-affected due probably to leaching of salt out of the naturally saline soil which was being irrigated.

**Soil conservation**

Land use surveys and mapping were done for two catchments.

A study of water run-off from a 60-acre catchment at Berkshire Valley was initiated. After a number of years it was contoured and the run-off compared with the previous experience. A system of banks was constructed in November 1965. The catchment was cultivated and sown to wheat in 1966 and 1967. It was then sown to Geraldton subclover and left without cropping for another five years. Recordings of rainfall and run-off continued through that time.

This work was expanded to include two further catchments in the eastern wheatbelt. Preliminary information on the run-off from one catchment in 1963 was reported in 1964. In the very wet winter of 1963 the catchment, with an area of 27 300 acres, received 6.9 inches of rain over the measured period, and had a total run-off of 6100 acre-feet. Similar results were obtained from other catchments.

Nitrogen fertilisers were tested to determine their effect on the density of grass on a waterway in a contoured paddock. As with other soil-related activity, cultivation had an overwhelming influence on run-off. With modern farming systems, there will be little or no cultivation and depending on the farmer’s approach and total farming system there may be little or no farm soil exposure. However, with large machinery and up-and-downhill cultivation, contour banks have been largely destroyed.

**Soils Division in 1970/71**

The year 1970/71 is chosen to illustrate a ‘normal’ year in the Soils Division, with the focus on soil conservation, research, pastoral catchment surveys and assessment and irrigation advice and oversight. In later years the division’s role was expanded in helping to supervise and assist community groups involved in the new focus on natural resource management. Fortunately there was reduced focus on soil conservation because of the advent of the minimum tillage farming system.

The erosion problems in the wheatbelt, rangeland vegetation deterioration, advice to private irrigation schemes, extension and advisory services to 1200 properties, water and soil testing were the main issues addressed that year. In the Kimberley, general liaison with the Kimberley Research Station and extension and advisory services on irrigated crops, including advice on irrigation and drainage, were required. In southern areas the issues were irrigated pasture trials, saltland amelioration, trials on trickle irrigation, orchard investigations and demonstrations of drainage and catchment treatment to increase run-off for on-farm water storage.
The Soil Conservation Branch was substantially involved in providing advice on contour surveying, development of soil conservation plans, demonstrating the possibilities for farm water conservation in the northern wheatbelt, providing advice in the non-farm areas in relation to management of coastal lands, recovery of mining sites, roadside erosion and the subdivision of land. Staff were also involved with 12 catchment groups, stabilising coastal sand dunes, saltland management and run-off, and soil loss investigations.

The introduction of minimum cultivation dramatically reduced the need for contour banks. The Soil Conservation Branch was substantially involved in providing advice on contour surveying, development of soil conservation plans, demonstrating the possibilities for farm water conservation in the northern wheatbelt, providing advice in the non-farm areas in relation to management of coastal lands, recovery of mining sites, roadside erosion and the subdivision of land. Staff were also involved with 12 catchment groups, stabilising coastal sand dunes, saltland management and run-off, and soil loss investigations.

The Soil Research Branch was involved in salinity investigations, salt leaching experiments, Carnarvon soil and water issues, plant collection and testing, polythene lining for earth tanks, sealing earth tanks with STPP and Riverseal, soil permeability studies and catchment sealing trials. Soil structure studies were carried out on a continuous wheat crop experiment at Merredin and long-term work aimed at reducing the percolation beyond the root zone was undertaken, particularly in identified intake areas.

In 1977/78 the first mention was made of 'interceptor banks'. These banks were bulldozer-built with a deeper channel than used in the normal contour banks for erosion control. They were similar to the absorption banks built to control water movement where very high water flows were anticipated. It was claimed by the promoters that these banks would cure the salt problem. They needed to be built where the subsoil clay was within 45 cm of the surface, allowing it to be pushed up to line the face of the bank. The procedure was based on the belief that the salt problems were wholly caused by water moving in the top 45 cm of soil from the higher slopes to low-lying land and that interceptor banks would prevent such movement. The approach was given widespread publicity which led to significant criticism of the Department of Agriculture's approach to the management of salt-affected land, which depended largely on revegetation of affected areas.

The department carried out research into interceptor banks to critically examine the proposition. The approach taken was to place test wells on either side of interceptor banks to see if there was any difference in the accumulation of water in the low-lying areas. In practice no effect was seen and in one area north of Dangin, the water was under pressure, causing it to rise from the subsurface aquifers, in one case to 3 metres above the surface. Another well was overflowing at a discharge rate of 11 litres per minute before casing was fitted. The conclusion was that there might be some small impact through a reduction in waterlogging but the interceptor banks were of no value in addressing the main problem.

**Raised beds**

While the use of raised beds is not a major issue for most of Western Australia it is very important in areas prone to waterlogging. The issue is really one of drainage, which has been recognised for many years. Raised beds have helped carry the message about waterlogging and provide a relatively low cost solution. In some cases the beds are very wide and probably are the spacing between micro-drainage lines.

**Minimum tillage**

Minimum tillage was first reported in 1975/76. Initially there was a lack of interest in the technique due to relatively poor weed control.
control. However in the late 1970s selective weed control improved and use of minimum tillage for crop establishment became commercial practice.

In 1979 about 700 farmers were direct drilling in one form or another. This was reflected in the areas sown, which in 1971 had been 10 000 ha, rising to 70 000 ha in 1974 and falling to 25 000 ha or less for 1975, 1976 and 1977, then increasing to 40 000 ha in 1978 and 100 000 ha in 1979.

Earlier interest appears to have been based on availability of commercial numbers of the triple disk drill which was a specialised machine for direct planting without cultivation.

There was initial concern that without cultivation the mineralisation of soil organic matter to release nitrogen would be reduced. It appeared possible that additional nitrogen would be required to optimise yields if direct planting was to achieve its potential. In research carried out it was noted that seed placement in slots had not been covered sufficiently and direct planting with a combine gave a very cloddy seedbed and poor seed placement, which caused poor germination. There was also more webworm and insect damage with zero cultivation and ryegrass densities generally increased proportionally with the amount of soil disturbance. An examination of the impact on nitrogen nutrition in four centres gave mixed results. In two locations only, early season crop growth was poorer on uncultivated treatments and yields on direct-planted treatments were generally lower than on cultivated treatments.

The department’s research effort and involvement with industry grew rapidly in the intervening years, with a working party of 15 scientists brought together from within the department’s resources to bring a coordinated approach to research projects in this field. The experimental program was rationalised and expanded with long-term trials established on most research stations to allow a reliable monitoring of the many facets involved. Soil structure, nutrition, weed control, insect and disease patterns, yields and economics were examined. Parallel paddock-sized plots using different reduced tillage techniques were established on research stations. District office personnel were involved with farmers in paddock-sized demonstrations. There was a particular interest in erosion and stubble management.

Overall, the work demonstrated that provided minimum tillage techniques were properly applied and follow-up post-emergent herbicides used, yields compared favourably with those from conventional systems of cropping.

The final solution was the result of the combined efforts of the department and the farming community. Who did what first is a grey area. In general however, the farming community made a major contribution in the machinery area and the department was more prominent in the biological aspects. The critical tools were the array of selective and general herbicides provided by the chemical industry. Advice on their safe and effective use was part of the department’s contribution. Critical contributions were the provision of the legume in the rotation and the development of wheat and other cereal varieties suitable for the changed conditions, particularly planting times. A rotation using a legume as a break crop was important to maintain disease and pest control.

In 1990 it was reported that record crop yields had been achieved by some South Coast cereal producers following adoption of a new crop management package using a lupin/cereal rotation to reduce the weed and disease burden. Some of the issues involved are listed below:

**Reduced tillage and the management of stubble retention**

Mixed results were obtained on stubble retention. Initially, burning stubble was favoured but a re-examination led to the conclusion that retention was an advantage. It was seen to aid water penetration and protect the soil surface from wind damage.
Row spacing, precision placement
The use of press wheels and knife points to obtain germination on low rainfall areas became part of industry practice. With press wheels germination was possible on 5 to 10 mm of rain provided stored moisture was available. While the development of the knife points was an industry initiative it was based on the department’s demonstration of the value of separation of seed and fertiliser and the advantage of placement of fertiliser deeper under the seed.

GPS guidance systems
Guided steering saved fuel and chemical overlaps, which was an important benefit of the use of GPS. As indicated earlier the use of GPS resulted in a lot of up-and-back working and removal of contour banks. Using GPS guidance in a tramline farming situation could also increase available spraying time as spraying could be done at night. While GPS was available, the technology had to be developed for on-farm use. CSIRO did some early research into use of GPS systems.

Wider planting rows
The issues driving wider rows for planting included reducing early crop water use to save it for grain fill, seeding tractability into dense stubbles, better weed control with herbicides and more efficient use of fertilisers. Hardpan ripping may have also been an issue.

Better decision support systems (DSS)
Decision support systems made a big difference to modern farming and were largely developed by the department. The systems were initially for the use of fertiliser and lime but developed to cover a wide range of issues such as variety choices, water supplies, disease and weed control.

It has been suggested that the introduction of the GST (Goods and Services Tax) resulted in more computers on farms than any other factor influencing farmers to computerise their work. Without farmers being computer-literate decision support systems and GPS could not have been adopted.

In summary …
The advent of minimum tillage, satellite guidance, computers on farms and the associated availability of decision support systems has meant that many of the accepted ‘truths’ of cropping have had to be re-examined. This has required a lot of objective research and investigation by the Department of Agriculture.

Crop physiology
Crop physiology and soil moisture studies were carried out for a short time during the 1960s.

In 1965/66 experiments on the physiology and growth of wheat showed that:
- Adequate nitrogen levels are needed for wheat early in its growth to attain its potential. High nitrogen levels were more likely to occur under those field conditions without nitrogen additions, towards the end of the growing season.
- Soil moisture levels on a loamy sand were higher to a depth of 6 feet under plots with low nitrogen levels, reflecting better vegetative growth on the medium and high nitrogen plots.
- After the end of September soil moisture at depths below 18 inches changed very little, suggesting that plant growth and survival in October depended primarily on additional rainfall. Further studies showed that for the normal time of sowing the critical period for finishing rains was early October at Wongan Hills.
- The number of grains set per head was important. The highest yielding WA variety, Gamenya, set 41 grains per head under standard conditions compared with Pitic, a Mexican variety, which set 93 grains per head.

Studies on crop moisture extraction showed that a crop reduced the moisture in the soil
to a level of 24 inches as early as the third week of September and to 48 inches by the second week of October. In the Wongan Hills loamy sand cereals were capable of influencing soil moisture to a depth of 7 or 8 feet. With clovers this influence was recognisable to 4 feet. Varietal differences in moisture use by wheat caused by maturity differences became evident later in the growing season.

Extensive experiments were carried out to determine the root pattern underneath cereal crops in terms of both varying soil types and varying moisture levels.

In 1966/67 the effect of factors such as light, temperature and length of day on the growth of cereals and the effect of environmental differences on the translucency of wheat grain using different cereal varieties were studied under a controlled environment.

Separately, field work was carried out on the impact of variety and nitrogen in different locations through the wheatbelt, on time of planting in the Esperance district, and on the impact of row spacing and seeding rate on yield at Wongan Hills.

In other physiological work:

- Examination of the interaction between variety, nitrogen and location showed no clear indication that one variety was more efficient than another in making use of nitrogen.
- Study of the relationship between head weight and the overall weight of the above-ground parts of the wheat plant showed that varieties with a higher ratio of head weight to overall weight normally gave higher yields.
- Investigation of the environmental effects influencing grain mottling showed that a number of different climatic variables could influence the condition.

Radioactive isotopes were used to determine the availability of fertiliser from 11 soils in a glasshouse, a problem of root penetration in a field experiment, and the availability of cobalt from soils in the glasshouse.

It was shown that as a result of early rain there was deeper moisture penetration on a deep yellow sand than on a sandy loam or a sand over clay. On a grey clay the water penetration was limited to only 12 inches. In the subsequent dry period the crop on the grey clay failed while that on the deep yellow sand yielded almost 24 bushels an acre, and on sandy loam almost 27 bushels. On sand over clay the yield was 16 bushels.

The impact of nutrition on root growth was studied in various situations under controlled conditions. Root numbers were lowest with low nutrient level but plants without an adequate potassium supply ceased root growth dramatically 10 days after planting. Moderately low levels of phosphate gave best root growth. An examination of the root growth of 30 varieties of wheat selected from a large range showed that there was little difference in the pattern of the time of initiation. There were marked differences between the degree of branching and the length of root per plant. However, it was not possible to establish any relationship between the degree of branching and yield.

In addition to providing overall guidance for agronomists the plant physiology work provided plant breeders with valuable insights for their work.

Tobacco

The tobacco industry operated principally at Manjimup from 1925 to 1962, when the tobacco companies decided that the leaf quality from there was inferior to other sources.

Downy mildew in seedbeds was a serious initial problem and the discovery that benzol would control the problem was an important advance. The experimental program initially compared varieties and fertiliser use and placement but later covered trace element needs, rotations, times of planting, row spacing and inter-row cultivation. Advice was also given on seedbed design and curing barn design, and the department produced high quality seed which was made available to growers. Results indicated that yield could
be increased from closer rows, earlier planting, the correct variety and selected seed. Clear production benefits were shown from irrigation but irrigation increased the chlorine level, which impacted on quality. As quality became an issue the research focused on the influence of chloride content on burn time. Glasshouse trials confirmed the sensitivity of tobacco to chloride but could not identify a solution.

**Horticulture**

**Fruit crops**

Horticultural and viticultural industries were established throughout the Colony in the early days as the technology required was very similar to that used in Europe. When production outstripped consumption in the early 1900s, development of an export industry was necessary and cold storage experiments were carried out. These proved successful and an export industry developed. By 1921, 193 000 cases of fruit were exported out of a production of 793 000 cases. As resources increased in the department, a range of work was carried out.

**Irrigation**

It appeared that under ‘dryland’ cropping, moisture was the limiting factor on growth, particularly on lightly pruned trees. Trial watering with brackish water from the Blackwood River was tested to determine whether salt deposited in the summer was leached out of the root zone in winter. In 1940/41 some work on the relationship between pruning and root growth began at Bridgetown and some work was started with alternative rootstocks. The work on rootstocks could not be done on farmers' properties and had to wait until Stoneville Research Station was commissioned to be addressed seriously.

**Canning and dehydration**

Largely in response to conditions during World War II extensive canning of vegetables and dehydration of potatoes was carried out for the first time in WA during the 1940s. The department was responsible for inspection and provision of technical advice to the processors. In 1943/44 the issue in apple canning factories was achieving satisfactory packs suitable for long storage. Three plants were engaged in canning and four in dehydration at the time. Few problems were experienced with dehydration.

Research was carried out into canning or dehydration of vegetables. Vitamin C levels were of particular interest. Some preliminary work was done with potatoes to determine relative nutritive value of samples from different soil types and districts. Cooking tests showed considerable differences between products from different soil types. In 1944 a rapid drying technique was evolved for apples, with the help of US Army personnel. An investigation of the sugar to acid ratio helped in the selection of fruit for canning and dehydration. In 1945/46 manufacturers were faced with the need to move to packs more suited to the civilian population. New techniques were necessary, and these produced their own set of problems.

**Fruit storage and packing**

Experimental and demonstration work on the problems of fruit storage and packing was done over the years. Broadly this work demonstrated that:

- it was important to pick at the correct time
- with pears, it was particularly important to minimise the time between picking and cool storage
- with oranges, much of the loss of fruit in storage was due to rough handling earlier
- potassium bisulphite was a valuable fungicide in packed fresh grapes.

Two physiological problems arose with apples - superficial scald and bitter pit. Superficial scald was finally overcome by the adoption Australia-wide of diphenylamine-
dipped wraps when packing. This simple statement hides a lot of work using a range of materials over years before the final solution was identified. Correct storage temperature was also important. Later, when apples were shipped in various bulk containers, techniques for diphenylamine treatment had to be developed.

In the case of bitter pit of Granny Smith and Cleopatra apples, work continued over many years. Calcium shortage in the fruit was identified as the problem quite early. However, it was the late 1970s before a solution was found. In 1977/78 it was found that good calcium treatment for bitter pit in Granny Smith apples could be achieved where the calcium chloride was applied under forced infiltration using a vacuum or pressure. Some further protection could be provided by the addition of diphenylamine to the calcium chloride dips. In 1979 it was reported that the adoption of an American technique of using a diphenylamine concentration of 1500 ppm in conjunction with a 3 per cent calcium chloride dip on freshly harvested apples gave complete protection. This resulted in the virtual elimination of the problem from export Granny Smith apples.

Other work on the storage life of a range of apple varieties and pears found that:

- Jonathons could not be stored past June.
- Storage life of the Yate apple was favoured by polythene-lined boxes.
- Pear storage was favoured by sealed polythene boxes, coupled with correct picking time.
- Comice pear life in storage was particularly affected by the time of picking and time between picking and storage.

Management issues were also investigated. Some examples were:

- In 1953/54 chemical treatment of Jonathon apples was tested to accelerate maturity.
- Control of budburst and foliation on Granny Smith apples, with oil sprays, in areas with insufficient cold periods.
- Increased fruit and fruit size were achieved.
- 2,4-D was shown to reduce premature fruit drop in citrus. Effectiveness was not affected by mixing with copper oxychloride it was affected by mixing with Bordeaux mixture.

Grapes

In 1952/53 the use of PCPA (parachlorophenoxyaceticacid) spray was shown to be effective in removing the need for cincturing of dried fruit vines. This work was confirmed and recommended to the industry in 1953/54. Subsequently it became clear that cincturing had reduced the vigour of the vines and sprayed vines gave better growth and yield. This revolutionised the currant industry.

Experiments were carried out with a new dipping material developed by CSIRO for drying sultanas. The chemical PCPA was also used for setting Early Madeleine table grapes and prevention of shattering in Santa Paula grapes. Alternative hormone sprays to set currants continued to be tested. It was shown that gibberellic acid was not as effective as PCPA.

Routine work continued on other issues and included:

- studies of the value of different cover crops in different soil and drainage situations
- setting Ohanez grapes with pollen sprays which showed that pollen spray from a late variety of grape was a superior source
- study of currant grape buds and in 1996/97 the department started to provide quality propagation material true-to-type and of known disease status
- demonstration of the use of deficit irrigation stress of the vine in the vegetative phase with an adequate supply of water in the berry stage
- cold treatment was approved for export of fresh grapes to Japan in 1999/2000
the Mid-West was shown to be suitable for table grape production.

**New apple varieties and trellising**

By 2008 the Department of Agriculture was responsible for the National Apple Breeding Program, which became a major undertaking. The program is centred on the Manjimup Horticultural Research Institute. In 2009, 140 000 seedlings were planted. Of these 17 000 were expected to fruit and require evaluation in 2010, and about 3 per cent were expected to be taken forward for further evaluation. A further selection of this fruit will be made and the third generation put on rootstocks. The process is repeated on an annual basis and is very demanding on time and resources. In 2009 six selections, protected by plant variety rights, were being grown on selected commercial orchards for evaluation.

A 1971 report refers to the testing of two new apple varieties considered to have commercial possibilities at Stoneville Research Station. An early variety called Stark Early Blaze ripened in mid-January and had good market characteristics but did not become a commercial variety. The second variety was called Lady Williams, a development from a seedling at Donnybrook, which was being grown in a small way commercially. This proved to be a valuable variety for storage and late season marketing. Other varieties from New Zealand, Canada and the United States were tested, having been through quarantine after importation. None of these varieties appear to have become commercial in Western Australia.

An experiment on training apple trees to meet the trend for smaller high yielding trees, more densely planted, was started at Manjimup during 1971. Apparently the high capital cost resulted in some growers rejecting trellising. Work on rootstocks for apples and other species was continued from 1971 through the 1990s but would have been terminated with the sale of the Stoneville Research Station.

**Cripps Pink (Pink Lady™) apples bred by the department were adopted worldwide and led to a 30 per cent increase in apple exports.**

It was reported that 20 000 Cripps Pink apple trees had been planted by the industry to June 1990. In 1998/99 there was a 30 per cent increase in apple exports, driven by this new variety. The Cripps Red variety was also distributed about that time. In 2008 a variety Enchanted®, which does not brown after cutting, was released.

**The southern wine grape industry**

Interest in grape growing in southern Western Australia was stimulated by recommendations of Dr Howard Olmo, from the University of California. In his 1955 report he stressed the need for lighter-style table wines in the State. He suggested the region around Frankland and Mt Barker should be examined for this purpose and that the climate south of Bunbury was suitable for viticulture. This resulted in two 2-hectare demonstration vineyards, one planted to Riesling and one to Cabernet grapes, being established by the department at Forest Hill near Mt Barker. The demonstration proved an incentive for a number of farmers in the Mt Barker/Frankland River area to plant vines.

Almost at the same time several growers began planting vines in the Margaret River region. An article in 1965 in the *Journal of the Australian Institute of Agricultural Science* by Dr JS Gladstones of the University of WA, described the potential of the area for viticulture. The first cuttings were
planted at Mt Barker in 1966 and by 1975, 220 ha were under vines in the district. A further 120 ha had been planted in the South West involving 23 growers. Most of this area had been planted in the previous five years. It was expected that a further 100 ha would be planted in 1975. Expansion of this industry in new areas resulted in a heavy demand for advice from the department. It also resulted in a boutique industry which revolutionised the reputation of WA for table wines. Wine growing extended to the Manjimup–Pemberton area following demonstration of its suitability by the department at its Middlesex Research Station through the 1970s and early 1980s. It is now a major industry in these districts.

Wine grapes growing at Margaret River. Fine wine production has become a major industry in the South West.

Vegetables
In an industry with multiple species and often multiple varieties, in sandy or swampy soils in an environment favourable to both insects and pathogens, there is no end to the work for professional advisers and research workers. The introduction of a canning pea industry in 1946/47 merely added to the challenge. While the first trials were at York the longer growing and processing period made Albany more suitable and the industry was established there.

A wide range of research was carried out over the years. The focus was on fertilisers, varieties, disease control, pest control and potential for processing. Potatoes received the greatest attention. Below are some examples of the work on vegetables:

- In 1950/51 the aim was to improve on the Delaware variety; comparisons indicated that Delaware potatoes were better for WA conditions than Kennebec but they later proved to be unsuitable for processing.
- In the early 1950s width of spacing, fertiliser rates, sett spacing and size were conducted on well-drained soil showing the highest rate of fertiliser (30 cwt per acre), the widest sett spacing and the larger setts gave the best yields.
- Potatoes from high quality seed were shown to produce more first grade potatoes. For many years the department provided virus-free seed as a service to growers.
- Fertiliser trials demonstrated the most economical use of fertilisers for potatoes under irrigation.
- Dithane to protect potatoes in storage proved valuable.
- A survey of Geraldton tomatoes showed the main factors influencing quality were fungus (alternaria), cold injury and mechanical injury.
- Variety trials were carried out on onions at Manjimup and at Albany.
- Tomato hybrids resistant to spotted wilt were tested through to 1957/58 and resulted in a hybrid which was largely resistant.
- Trials with brown globe onions showed that they could be kept for six months in cool store with only 4 per cent loss from all causes, provided only sound material was stored in crates instead of bags, to allow better air circulation.
- A sprout-inhibiting agent, maleic hydrazide, was tested for onions in storage but did not seem to have an effect.
- The value of zineb for the control of mildew in onions was tested.
• In the 1950s extensive testing of new fungicides and pesticides was undertaken.
• The rust-resistant bean variety Westralia was developed and released.
• Management techniques were developed for vegetables growing on acid peaty sands.
• In 1971, experiments covering potato fertilisers, production from small potatoes, dormancy, cooking quality and control of potato tuber moth were in progress. Other work covered rockmelons, zucchini, tomatoes and egg plant.

In the north, at Gascoyne Research Station work was proceeding on the nutrition, watering and plant densities for bananas and on conditions for the successful growing of pineapples, as well as a range of work on vegetables and other fruit crops. In 1992 the results of a five-year trial demonstrating improved irrigation scheduling encouraged more than half the Carnarvon growers to adopt the department's recommendation.

In late 1976 a new potato named Cadima was released. It was selected and developed from a seedling bred by the Victorian Department of Agriculture and introduced into WA in 1964. It met all of the culinary requirements for a potato and had similar yield potential and growth period to Delaware, almost the only variety grown in WA at the time. It was also found to have a long rest period and remained sprout-free for up to five months. In storage trials it suffered minimal loss of weight or culinary qualities. The results indicated that it could be suited to a single planting each year. This would contrast sharply with the traditional Delaware cycle based on a succession of plantings from June to January. The variety also had processing potential. Seed supplies were being built up in 1977 but in 1979 it was reported that the Cadima variety broke down in plastic bags after washing and it never became a major variety. This emphasises the difficulty of developing a variety for all purposes.

During 1979 the department released two new potato varieties, Geographe and Bremer, for testing. It was considered likely that Bremer might gain a place as a processing variety while Geographe may be suited as a boiling variety. They are not seen in shops today.

In 1990 it was reported that new technology had been developed for the production of potatoes for the frozen French fry industry.

In 1992 fungicide treatment to control problems in export carrots proved successful.

Wildflowers

In the 1980s the Department of Agriculture started limited work for the floricultural industry then began research into the issues involved in the production of four major groups of native plants. The research program was designed to examine agronomic factors such as nutrition, weed control, soil salinity tolerance, general management and the range of soil and climatic conditions in which the plants would grow successfully. Propagation was also examined, together with the opportunities for extending the period of supply by using a range of climates.

In 1995/96, two new wax flowers had been selected and released, and were marketed as Jurien Brook and Esperance Pearl.

Commercialisation of wildflowers was assisted by departmental research.
In 1998/99 a biotechnology program was established to include studies of the expression and development of floral pigments, development of the floral parts and a transformation technique. A Centre for Australian Plants was also established.

**Alternative fuels**

Following the oil shock in the mid-1970s, the department looked at a range of alternative fuels from agricultural crops which could be used in diesel engines. The successful use of such a fuel would depend on efficiency, cost effectiveness and small-scale extraction systems suitable for operation on the scale of existing country fuel depots. It was also desirable that a by-product be produced; in the case of an oilseed it would be a high quality meal. This work was carried out in cooperation with the Government Chemical Laboratories. Rapeseed (canola) oil was found to be an effective source.

Preliminary work was also successful in generating producer gas from pig manure. The product could be harnessed through a gas producer similar to those used in World War II. Use of the gas in diesel engines in conjunction with diesel fuel was shown to result in an increase in power rather than a decrease as occurs in petrol engines. This producer gas was also suitable for steam boilers. However, the total amount of material available was limited. Considerable research efforts elsewhere on the use of ethanol and methane meant that further direct research by the department in those areas at that time was not justified.

From 2005 on there has been a sharp increase in the price of liquid fuels. This again triggered interest in alternative fuels. Rapeseed varieties which are only suitable for fuel but are higher yielding than other varieties have been introduced from India. It was proposed that a small group of farmers could combine to establish a simple processing plant and grow their own diesel replacement.

**The northern areas**

The northern half of Western Australia was always seen as having vast untapped potential. In the early years of settlement the native grasslands and shrublands had been used for extensive grazing. In the early 1900s one of the earliest professionals appointed to the Department, AJ Despeissis, was commissioned to report on the potential of the north. He produced a positive report and was subsequently (1909) appointed as Commissioner for the North West.

However, apart from desultory experiments little action was taken. In his 1924 report FJS (Frank) Wise, who had been appointed as a tropical adviser, commented on a range of areas, crops and issues surrounding development. While he saw some possibilities, he pointed to the need to consider market access. The possible need to dam rivers to obtain reliable water supplies for irrigation was also suggested. He did not see cotton as a likely dryland crop. He thought that with suitable water supplies and fertiliser the Pindan areas could be used for intensive agriculture. He also commented that the Carlton Plain had considerable potential. However, he was not convinced that banana growing could be a big industry in Carnarvon. In retrospect, this was a perceptive report, except for the comment on bananas.

He resigned at the end of 1925 but was reappointed in September 1929. He then worked in the Carnarvon area until March 1933. He later became a prominent State politician, becoming Minister for Agriculture and later Premier of Western Australia. His final appointment was as Administrator of the Northern Territory. When the Department of Agriculture took over the Kimberley Research Station from CSIRO it was renamed the Frank Wise Research Institute.

Access to markets was a major constraint in early days. It was a serious problem at times for the Kimberley cattle industry until after World War II. It had certainly been a problem for the fledgling horticultural industry on the...
Gascoyne during the war. While a limited irrigated agriculture had developed on the Gascoyne River at Carnarvon, no attempt was made before the war to develop intensive agriculture on the large northern rivers.

Separate from the potential for irrigation there were problems with the management of the fragile native pastures of the Kimberley and the semi-arid shrublands of the Pilbara and southern pastoral areas. These areas were used for pastoral activities without any understanding of their long-term carrying capacity, particularly the impact of drought, which was part of their natural environment.

After the war the department carried out extensive rangeland surveys throughout the pastoral areas, which gave an indication of the true carrying capacity of these native pastures at the time of the survey. In the main these surveys showed that the areas were being overstocked. Over much of the area exclosures were established to monitor future pasture development. Extensive field days were carried out in the surveyed areas to explain the outcome of the surveys and to recommend action which could or should be taken to ensure sustainable land use.

In some cases, such as at the Fitzroy Pastoral Research Station, it was possible to demonstrate the impact of cattle over-grazing the native pastures. It was also possible to illustrate pasture responses both to over-grazing, and grazing restrictions. Later, at regenerated areas of the Ord River catchment it was possible to demonstrate the value of both proper pasture management and changed herd management. Trials of Townsville stylo on cockatoo sands and studies of breed differences in beef cattle were also carried out.

At the Woodstock/Abydos Research Station in the Pilbara, the focus was on sheep and rangeland pasture management and this work is reported in some detail below.

The Ord River Catchment Regeneration Project

The Ord River Catchment Regeneration Project was probably the largest such undertaking in the world. It started in 1960 when the Department of Agriculture was given the task of halting erosion and restoring vegetation on a severely eroded part of the catchment. The area involved approximately a million hectares. The issue was long-standing as it was described in 1944 by a surveyor and reported on by CSIRO and the department in subsequent years.

Some parts of the Ord River catchment were completely denuded.

In 1960 the problem was tackled with a major fencing and pasture regeneration project. The two basic techniques were control of grazing animals and soil disturbance for seeding of pioneer and potentially valuable species. Livestock were not removed in the early years but it became evident that complete removal of grazing animals was essential. More than 1000 km of cattle fencing was erected after 1960.

Some 45 000 head of cattle and 30 000 donkeys were removed over the years after the area was destocked by the previous lessee. Even so, some cattle and donkeys remained.

In many areas degradation was so complete that virtually no seed sources of perennial grasses were left and soil disturbance and reseeding was necessary. This resulted in many thousands of kilometres of
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discontinuous strip contour ploughing and reseeding. The strip ploughing of the broad slopes and undulating plains was aimed at breaking the surface to promote water penetration, slow the rate of run-off and supply a seedbed for introduced and native grasses. Seed from plants established on these sites was washed into the lower gully systems, where new vegetation was also established.

Initial recovery was slow after a series of below-average seasons and inability to exclude stock. However, a series of above-average or average seasons and the exclusion of stock had a snowballing effect as vegetation and seed built up. Recovery of both native grasses and introductions was reported in 1977 as being spectacular in parts of the project.

Unfortunately the renewed vegetation resulted in fires becoming a regular feature. New management methods were needed to deal with this problem. Some fully recovered parts were used for pasture management and breed comparison studies and the area became a centre for cattle and pasture research in the Kimberley. It became the rangeland research area for important cattle management work when the Fitzroy Pastoral Research Station was closed in 1978.

The eastern part was destocked and fenced in the 1960s and 1970s. The west, on the western side of the river, was not so seriously eroded, and was not initially protected by fencing. It was fenced and a major destocking program started in 1984/85. Nearly 12 000 cattle were removed from this area. At Kununurra, the shrub leucaena was tested under irrigation as the basis of an intensive cattle grazing project.

A study reported in 1992/93 showed that 80 per cent of the silt from the Ord catchment came from channels and gullies rather than sheet erosion. The progressive revegetation of these areas was particularly important and was happening as seed washed down from the revegetated areas.

The cattle work on the regenerated area produced results that demonstrated the potential for increased production from better herd management in the area. The main gains, apart from those due to the use of Brahman bulls as opposed to pure British breeds, came from weaning the calves and sending a large part of the annual drop south for development and fattening instead of retaining them on the rangeland until they were three to five years-old. The space vacated would allow many more breeders in a reconstituted herd. This information was packaged into a recommended change in herd management in the Kimberley. It is reported to be slowly being adopted across the industry. The changes were made more possible because of the investment in infrastructure that had occurred during the TB eradication campaign.

**The Ord River development**

Apart from a small site at Carlton Reach on the Ord River where various pasture plants were tested, no experimental work had been done on east Kimberley rivers before the end of World War II. In the dry season of 1942/43 a soil survey was carried out to determine the potential for irrigation of the Ord River basin. This survey showed that there was an extensive area of soil types suitable for some form of agriculture under irrigation.

A Commonwealth/State agreement to develop irrigation on the Ord was signed in 1946. In 1945/46 a comprehensive plan was prepared by CSIRO for investigational work. The development of the necessary infrastructure was a State responsibility and there was to be joint technical oversight of both the research program and of policy development. The State was responsible for providing farm staff while CSIRO was to provide the research staff.

By 1950/51, work started in earnest on the Kimberley Research Station.

Over the next decade many crops were grown, largely successfully. Pasture species were also tested. A diversion dam was built and completed in 1963 and land was prepared for the first farmers to take up blocks. The experimental work provided the
basis for the first commercial cotton crop, which was planted in 1964. The saga of the Ord cannot be dealt with here. It is sufficient to say that the department progressively developed a research capacity aimed at identifying a crop or crops which could provide the basis for a sustainable productive agriculture on the whole of the potential irrigation area. This work built on the foundation laid by the work at the research station, which was substantially planned and carried out by CSIRO.

Due to insects becoming resistant to available insecticides the cotton industry failed. Sugar was the ‘natural’ crop for the area and a successful pilot farm was developed. However, despite a number of attempts a sugar industry could not be developed due to powerful political opposition from Queensland. In the late 1980s the department took over the Kimberley Research Station from CSIRO and it became the Frank Wise Research Institute. A great deal of work was done on alternative crops after the cotton industry failed and for a period a small industry produced sugar for the local market. More recently, genetically modified cotton has been grown successfully and may lead to development of a new cotton industry. In today’s environment of climate change and need for reliable agricultural areas, the potential of the Ord may be more fully realised.

Rangeland research in the Pilbara

In the late 1940s the department decided to investigate ways of improving the carrying capacity of the degraded spinifex-based pastures of the eastern Pilbara. The landscape consisted of broad swales between low hills. The dry tops of the hills carried spinifex and in the undeveloped State the swales had largely carried tussock grasses. These swales had been poorly managed, resulting in the grasses disappearing and the vegetation becoming unpalatable spinifex.

In order to examine ways of reversing this process the State Government purchased two abandoned sheep stations, Abydos and Woodstock. Initial work had to focus on renovating the infrastructure. It was necessary to fence the properties and control wild dogs so that sheep could be run. Improvements were completed and the dog problem largely controlled so that sheep were put on the area around the end of 1950.

In 1951 a graduate officer took up residence on the stations. There was a heavy load of euros in the area and a CSIRO officer was stationed at Woodstock to study this problem. With the problems largely under control, experimental work began and continued through 1954/55 and 1955/56 it was shown that the practice of winter burning and grazing immediately green shoots appeared after summer rain caused the grasses to disappear and spinifex to become dominant. Early summer burning and deferring grazing until the grasses were well established after summer rain allowed the swales to revert to their grass-dominant condition. With this treatment swales could carry one sheep to three acres. The grazed areas also appeared to be superior, possibly due to seed being trampled in by the stock. It was shown that it was important to maintain the spinifex in an actively growing condition. This could be done through continuous grazing or the regular burning of the spinifex at the correct time of the year.

On a private property (Mundabullangana) a problem existed through bad management on coastal country where poverty bush had become dominant. With the same treatment of burning in the early summer and deferred grazing of the grasses, the native grasses would recover. In this case bare areas were seeded with buffalo and Birdwood grasses. About 50 000 acres of poverty bush were transformed into natural pasture through this management approach. This and work at Woodstock-Abydos were the focus of very successful field days.
Chapter 7 – Important plant and soil research

In 1957/58 a study was initiated of the factors involved in the low oestrus levels and low conception rates among ewes in the area. This research showed that it was essential that lambing be timed with the rainy season from January to March. Studies also showed that the fertility of locally-bred rams was better than that of introduced rams and their libido was higher, so they covered the flock earlier. This probably contributed to better lamb survival. Weaned lambs did well on buffel grass, which appeared to benefit from the closer grazing. In 1970, a 76 per cent lambing was obtained from ewes lambing in February. In the very dry summer lamb survival was reduced due to various problems including dingo attack. A range of different climatic conditions called for this work to be revisited but this has not been done.

**Experimental work out of Broome**

In the early 1950s an officer based at Broome began plant introduction work. The 1956 report refers to proposals to investigate producing fodder crops in the Kimberley. This work stimulated interest among pastoralists in pasture improvement and regeneration. By the late 1950s the planting of Birdwood and buffel grasses had been successful on six stations in the west Kimberley as well as in parts of the Pilbara.

In the 1960s establishment of grasses on Pindan country at Derby and at Broome was attempted but met with great difficulty due to competition from wattle germinating and growing rapidly from a massive seedbank. While the grasses grew satisfactorily nitrogen and phosphate fertilisers were needed and wattle had to be controlled. This made them uneconomic. Intensive horticulture could be possible if required in the future.

In the north Kimberley it was shown that fodder crops and tropical legumes could be established in areas receiving more than 35 inches of rain annually. A study of the value of spreading water on a private station ran into difficulty because of the development of the dense stands of trees and shrubbery along the water course, which crowded out the grasses.

At the same time an experiment on rice production at Camballin also ran into serious difficulties because of flooding and heavy grasshopper infestation. Despite these difficulties yields of over 2 tons per acre were obtained. Experimental plantings continued over the next two decades. They all failed due to uncontrolled flooding, with heavy financial losses to investors on some occasions. Any irrigation from the Fitzroy River would have to wait for water control by damming tributaries upstream.

**Southern pastoral areas**

In the southern pastoral areas the department carried out some regeneration work and some demonstrations of the impact of grazing. This involved various types of vegetation and regeneration of denuded areas using discontinuous contour-ploughed furrows to gather seed. This work was not on a station but was a study of deliberate revegetation of areas which had been degraded by mining or the construction of services such as roads and telecommunications.

*Denuded overgrazed pastoral land cross cultivated to encourage seed germination and water penetration.*

Since many of the species had not been grown previously, considerable research was needed to develop the best methods of propagating them in a new environment. A study of regeneration was also set up in the form of exclosures and enclosures across the southern pastoral areas, part of a national program. Change is measured
largely by photographic record but also includes some physical measurements. These assessments are made today under contract by a previous employee of the department.

Insect pests

Insect are a continual problem for agriculture. Biological control of introduced pests was the early focus of the bureau and department. In 1902 entomologist George Compere was given the task of travelling internationally and to other colonies in search of predators of major insect pests present in Western Australia. Mediterranean fruit fly was a major pest as early as 1903 and the search for a predator was a high priority. Over the years the Entomology Branch of the department has been active in achieving control through introduction of parasites. It has used available insecticides as alternatives. The advent of new synthetic insecticides revolutionised insect control initially but was challenged by the gradual development of resistant populations. This resulted in renewed interest in biological control.

Extensive insect control work was done over the years on a wide range of pests of agriculture and horticulture. A few examples are listed below.

Grain storage on farms

Grain is stored in bulk on farms as a reserve stockfeed and seed for the following crop. Insect control was historically achieved by using phosphine gas as a fumigant, and malathion insecticide.

In 1977 it was reported that resistant grain insects were found in 35 of 850 grain samples from farms. In a further survey of farms in the Merredin area, 92 per cent of the rust red flour beetles were resistant to malathion. This compared with 20 per cent found resistant during a 1972 survey. The developing resistance made ‘on-farm’ storage more difficult and focused attention on finding a simple method of achieving airtight conditions, resulting in insect suffocation.

Two methods were examined. The first was to bury the grain using plastic sheeting in carefully excavated pits. The alternative was to line an above-ground bin lined with butyl plastic supported in a weldmesh frame which had proved airtight. The underground storage was tested at both Merredin and Salmon Gums research stations. Most of the grain from the Salmon Gums pit was still satisfactory after more than three years. The butyl-lined bin also proved airtight and appeared suitable for on-farm use. It was a simpler and more flexible method than underground storage. One approach would be to use the butyl-lined weldmesh for an annual reserve and the underground storage for a longer-term drought reserve.

The 1988 report records work on the eradication of resistant grain insects. The Agriculture Protection Board collected samples of grain insects thought to be resistant and tested them in a laboratory. If they proved resistant the location where they were collected was fumigated to eliminate that population. The same approach was taken with Cooperative Bulk Handling. As a result CBH was able to continue to use first-generation insecticides until the time of reporting, with a major saving to the industry.

Armyworm

Armyworm became a problem for cereal cropping once pasture areas were cultivated on the first rains and sown when weed control had been achieved. The insect was controllable with DDT initially and then with other insecticides, but this was costly. Outbreak of armyworm in 1975 and 1976 was the first for nine years. It gave opportunity for investigation of new control techniques and a study of the life cycle of the insect. It was shown that the problem related to the caterpillar stage of three moth species. The study also showed that the caterpillar was often parasitised by a wasp. The incidence of the problem related to the relative numbers and time of hatching of the
caterpillars and the wasp. In 1979 a further parasitic wasp (*Apanteles ruficrus*), which had successfully parasitised cutworms and armyworms in New Zealand, was introduced into Western Australia.

Later the introduction of six parasitic wasps which were predators of 11 species of caterpillars which attacked cereals and a wide range of broad-leafed crops was reported. In 1988 it was reported that two of the six parasites imported from overseas earlier had become well established. The first released was a small wasp imported from Pakistan, which was attacking armyworms and cutworms in early 1988. The second, imported from Greece, was found to be breeding in the native budworm. Monitoring of the effectiveness of these predators was continuing.

**General biological control**

A predatory mite was introduced successfully into the South West in 1976 for control of two-spotted mite.

In 1979 the department undertook a campaign to eradicate the Mediterranean fruit fly from Carnarvon. The campaign involved the use of irradiated male flies, supported by an intensive and area-wide baiting campaign. Mediterranean fruit flies were bred in large numbers and the population was then irradiated to sterilise all males. Sterile males were released every week from August 1980 for six to eight months.

As the female fruit fly only mates once, mating with a sterile male meant no live eggs were produced. After six months the releases ceased and the population was trapped to find the impact of the releases. The population was eliminated but the fruit fly was subsequently re-established by introductions from Perth.

Two predatory mites were introduced by CSIRO for control of redlegged earth mite and lucerne flea in about 1960. Inspections showed that they were well established. Both species were shown to be effective predators but the natural rate of spread was very slow. Secondary releases appear to have failed.

Parkinsonia is a prickly bush found around waterholes in northern Australia. A search was made for predators, and some beetles which appeared to be potential candidates underwent host specificity trials in Queensland. The WA Government contributed to this program. In 1993, two biological agents, a mirid bug and a mimosestese beetle, were released as parasites on parkinsonia in the Kununurra area. The wet season was known to have killed the mirid bugs. Efforts were being made to locate colonies of the mimosestese beetle.

Biological control programs were also aimed at the weeds dock and doublegee. Two clear-winged wasps regarded as having potential to control dock in pastures across southern Australia were imported from France into quarantine glasshouse facilities at the department. No further record of these predators is available. A predator from Morocco, which had been fully tested against becoming a threat to non-targeted plants, was released in June 1981. In 1994 it was reported that 23 populations of a dock control agent were established in WA. New release technology had increased and the potential for future establishment improved.

In 1988/89 biological control of Paterson's curse became possible due to the introduction of small leaf mining moth from France. In 1994 it was reported that a root boring weevil for control of Paterson's curse had become available for national distribution from Victoria in late 1991. After a colony had been established in Perth, 1650 weevils were released at four selected sites.

A parasitic wasp was introduced by the department's entomologists in an attempt to control the blue-green aphid. This insect was first detected in June 1979 and by 1981 was recorded from virtually every pasture growing district from Geraldton to Esperance. It caused serious damage to lucerne, subterranean clovers and annual
medics. The multiplication of the wasp was aided if lucerne was continuously available through the summer. Up to 74 per cent of plants in a Hunter River lucerne paddock had parasitised aphids in 1981. The predator (*Aphidius ervi*) was released in other districts but did not prove as effective on subclover because of the difficulty of surviving the summer; other approaches were being examined.

Work was proceeding on a weevil pest of lucerne which became important to growing areas.

Eradiation programs for Argentine ants, green snails and the European wasp were all in progress or had been carried out. Biological control of the cowpea aphid, which attacked medics, subterranean clover and other legumes was attempted through the introduction of a tiny wasp from India.

Queensland fruit fly was successfully eradicated, using the sterile male technique. This major campaign involved intensive baiting and a coordinated sterile male release program.