Agricultural science and technology - meeting the challenge

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Introduction

In this paper, I will deal mainly with the broadacre, cereal-livestock farming systems which extend from the Darling Downs in southern Queensland through New South Wales, Victoria, South Australia and Western Australia. This farming system produces much of the wealth generated by Australia's primary industries and if we are to remain a major supplier of food in the world, it will be necessary for us, as agricultural scientists, to address the challenges to increase the productivity of this zone without jeopardising the long term sustainability of the soil resource. This is a particularly challenging time for agricultural science throughout the world because of the very rapid pace at which biotechnology is moving into agriculture. However, no matter how clever molecular biologists are at introducing new genes into plants to improve their productivity, digestibility, pest and disease resistance etc. those plants will still need roots and the roots need soil, nutrients and water. For this reason, in this paper, 1 shall cover many areas related to improving plant production well into the next century. The farming systems discussed in this paper are essentially low input systems being conducted often with variable and unpredictable rainfall in soils of low inherent fertility, which restricts our options.

Soil management

Most of the soils in this agricultural zone were originally low in nutrients and extremely fragile so we need to develop systems compatible with these problems. Low nutrient status has been overcome in the past through the use of superphosphate, trace elements (where necessary) and nitrogen fixing legumes. However, with the decline in farm incomes, many farmers have reduced their inputs of fertilisers to dangerously low levels that do not match the nutrients which leave the farm with the produce. As they move from systems with a high proportion of pastures and sheep to more continuous cropping, the problem of nutrient export is exacerbated and needs to be addressed.

The links between plant nutrients and soil-borne root diseases must not be overlooked by agronomists in the future (2). Field trials working in the Victorian Mallee and the Wimmera demonstrated that losses from take-all were reduced by applying superphosphate. Wilhelm *et al.* (25) on Eyre Peninsula, South Australia, found that manganese reduced take-all damage. Losses from Rhizoctonia bare patches can be lowered through the application of nitrogen (12) and zinc (21,22).

Soil structure is a major problem in many soils in the cereal-livestock zone, largely as the result of the exploitive system of fallow-wheat with multiple cultivations each year which was practised for many years prior to the 1950's. The introduction of conservation farming throughout much of the cropping zone, through the use of herbicides rather than the plough, represents a major step forward in improving the sustainability of our farming systems. The acceptance of conservation farming by our cereal growers has not been as widespread as we would like (25), largely because of the more complex management required for conservation farming often calling for new or modified equipment, compared with traditional farming in which plant residues are burnt and farmers rely on cultivation for weed control. One of the challenges for the future is to ensure that the growth of conservation farming continues through research which solves many of the problems currently facing farmers attempting to change to this method of farming, coupled with effective communication and technology transfer systems.

The extensive distribution of sodium-affected soils (causing the problem known as "sodicity") throughout Australia creates a major problem because these soils have the tendency to disperse, set hard, restricting both germination and root growth when the sodicity occurs in the A horizon (13). There are extensive areas throughout southern Australia, where sodic sub-soils occur and cause problems of drainage and waterlogging. Surface sodicity problems can be addressed through the application of gypsum, the retention of organic residues and minimum tillage but sodic sub-soils are difficult to ameliorate.

The development of soil acidity is a natural process in soil, which in Australia has been exacerbated through the use of annual pasture legumes to improve the nitrogen status of the soil (4). The acidity problems can be resolved through liming and, in appropriate areas, by the introduction of deeper rooted, perennial pastures.

Many Australian soils are naturally high in sodium chloride and as a consequence of excessive clearing and the replacement of deep rooted perennial trees and grasses with shallow rooted annual crops, salinity has become a major problem in many areas. This problem requires a catchment or district solution rather than an individual farm solution, so the introduction of the Landcare movement throughout Australia offers a marvellous opportunity for farmers to work together on a catchment basis.

Water use efficiency

A very consistent finding by agronomists throughout the wheat belt in Australia is that wheat crops are not using soil water and rainfall efficiently. In fact, most crops throughout southern Australia use only 30 to 50% of the water which is available for crop growth. Furthermore, it is consistently reported that water use efficiency in wet seasons is even lower and yields fall away. Use of models which calculate the potential grain yields based on 10 to 20 kilograms/hectare/mm of growing season rainfall has alerted agronomists and farmers to this problem. In South Australia, French and Schultz (I) developed a farmer-friendly model based on 110 mm loss through evaporation and 20 kilograms per hectare per millimetre April-October rainfall which has brought about a revolution in farmers' thinking about their crop production. In northern Victoria, van Rees and Somogan (24) have developed the MEYCHECK model for farmers which uses 15 kilograms/hectare/mm growing season rainfall with similar impact on farmers. Although these models are approximations based on experimental work, they provide advisers, agronomists and farmers with a yard stick. One of the challenges facing agronomists for the future is to lift the production of the majority of farmers from 30-40% of potential to 70-80% of that potential. Such an increase would result in a 50% increase in total grain production across the wheat belt which, at current values, would be worth more than $1 billion to the Australian wheat crop each year (16).

Plant management

The management of crop and pasture plants throughout the cereal-livestock zone is absolutely essential if productivity is to be maintained. Until recently, this management has been agronomic e.g. time of sowing, correct varieties, appropriate fertiliser applications, appropriate treatment for foliar diseases etc. However, there are two technologies which we need to address for the future:

Conventional plant breeding

Advances in crop production in the foreseeable future will still depend on conventional plant breeding practices for pasture legumes, grain legumes, alternative crops and cereals. Conventional plant breeding could lead to more nutrient-efficient cultivars as it has been shown that some cultivars, in barley and wheat are more efficient in extracting manganese, zinc and phosphate from soil than other cultivars and such traits can be exploited through conventional breeding methods. This would mean a more efficient use of soil resources. The development of new varieties tolerant to boron toxicity demonstrates how conventional breeding can overcome soil problems. The breeding, screening and selection of cultivars of pasture and grain legumes resistant to pests and diseases will enable us to increase pasture and crop production.

Biotechnology and genetic engineering

Discoveries through biotechnology over the past decade have led to a revolution in our thinking for the future of agriculture throughout the world. Dr Jim Peacock (14), CSIRO Division of Plant Industry believes that the agriculture of the future will be driven by biological research being conducted by genetic engineers. This is one of the fastest growing fields in agricultural research and because it is difficult to keep abreast of developments, it represents major challenge to traditional agronomists (3).

An exciting aspect of these advances due to biotechnology is that it now provides the plant breeder with access to a tremendous gene resource because the molecular biologist can now tap into all living organisms, be they plants, animals or microorganisms. In the development of this technology, it is essential that the plant breeder work closely with the genetic engineer and indicate the precise objectives of the breeding program. With classical breeding, in which a particular trait is sought, the process of crop improvement is slow because the entire genomes of the two parents are combined, even though the breeder may be trying to transfer a trait controlled by a single gene. Consequently it takes repeated back crosses to eliminate the extraneous genes in order to obtain the desired properties in the new variety. Molecular biology now enables researchers to transfer single genes carrying the desired properties into the host plant which will greatly accelerate the development of new varieties. The use of molecular markers to indicate the inheritance of certain traits in breeding programs could speed up the development of varieties resistant to foliar and root diseases (8).

Molecular biologists in CSIRO Division of Plant Industry have transferred genes from the seeds of sunflowers into lucerne and subterranean clover to increase the levels of sulphur-containing amino acids which could increase wool production on sheep. This example indicates how future plant breeders will be able to tailor their plants to the needs of grazing animals or humans.

Another example of the application of biotechnology is the introduction of the BT gene from the bacterium, *Bacillus thuringiensis* into the higher plants. This transfers to plants the ability to produce a bacterial toxin which kills insect pests grazing on those plants. Molecular biology is being used to improve the digestibility of pasture species through targeting the genes responsible for lignin biosynthesis and if this is successful plants with lower lignin content and hence a higher digestibility will be the result (I I). Work is in progress to genetically modify the rumen bacteria through the introduction of genes responsible for cellulose decomposition from anaerobic fungi from the rumen, which increases the digestion of cellulose in the rumen (27).

These are but a few of the many examples where biotechnology is going to revolutionise the properties of plants in the future and agronomists need to be aware of the power of these new techniques.

Herbicides

The introduction of herbicides into agriculture after World War II represented a major revolution in farming. Food production throughout the world depends heavily upon chemical control of weeds. The development of selective herbicides for use in different crops has been responsible for much of the increased food production throughout the world. However, the use of herbicides is not without its problems.

Herbicide residues in crops and soils

On the whole, modem herbicides present few problems in terms of residues in soil or foodstuffs but there are some which are causing concern in certain soils. The sulfonyl ureas are active at extremely low levels (7 to 30 g.(a.i.)/ha) and hydrolise in neutral or acid soils but in alkaline soils they break down extremely slowly and can have serious effects on following crops and pastures, either directly or through increasing the susceptibility of plants to root diseases (17). In the lower rainfall areas of the cereal-livestock zone, residues in high pH soils can cause serious losses in the legume component in pastures; even if 99% of the herbicide has been either degraded or leached down the profile, the residue is sufficient to reduce growth and nodulation of medics with serious consequences for the nitrogen status of the soil.

Herbicide resistance in weeds

The persistent use of some herbicides with single modes of action has led to the selection of weed populations resistant to those particular herbicides (10, 15). The most spectacular example of this is the development of resistance in annual rye grass to a range of herbicides which have been used to selectively control grasses in crops and pastures. Much is now understood about the rate of development of resistance and measures to reduce its impact, but nevertheless this problem represents a major challenge with respect to modern farming systems.

Allelopathy

Allelopathy is due to the non-nutritional chemicals produced by one plant which affect the growth of other species. In this process of allelopathy, some plants release allelochemicals which inhibit the growth of other species. Lovett and Hoult (9) have shown that barley contains chemicals that inhibit growth of other plants. Umbers (pers. comm., 1993), working with Lovett, has shown that the residues of canola and oil seed rape contain glucosinolates which inhibit the germination of grasses, which could explain the anecdotal evidence from farmers that there are seldom serious weed problems following canola. The exploitation of allelopathic effects and the ability to transfer genes responsible for the production of allelochemicals from one plant species to another is likely to be an important method of weed control in the future.

Mycoherbicides

A well known example of using a pathogenic fungus to control a specific weed is the control of skeleton weed by a rust fungus introduced into Australia several years ago by CSIRO Division of Entomology. Because of the desire in many countries to reduce the amount of chemicals, fungicides, insecticides and herbicides in agriculture, there is now a major push to develop mycoherbicides (5). Considering this emphasis on mycoherbicides, I expect that in the future we will see a wider use of them within the normal farming system.

Insect pests

The control of insect pests is usually through the use of chemicals some of which are damaging to the environment. Hence alternative methods of reducing losses from insects are being sought. One example is a program in the CRC for Legumes in Mediterranean Agriculture (CLIMA), in Western Australia to screen subterranean clover for strains resistant to red-legged earth mite. Molecular biology will enable the introduction of genes with specific activity against insects and hence offers considerable promise e.g. introduction of BT gene from *Bacillus thuringiensis* into dicotyledon plants confers resistance to *Heliothus.* Until now, this technique has been developed for high return crops such as cotton but there is no reason why similar strategies could not be used for grain legumes subject to attack by moths of the same family.

Fungal diseases

Extensive breeding programs have been in place for many years to control foliar and root diseases, the control of rust and scald in wheat and barley are well known examples of how the introduction of resistance into crop plants will increase production.

Foliar diseases

There is considerable emphasis in breeding programs on the development of cultivars resistant to fungal foliar diseases but as pressure is placed upon producers to reduce the input of chemicals in their programs, greater emphasis will be placed upon this method of control, either through conventional breeding techniques or through the use of molecular biology.

Roots diseases

In the past, control of root diseases in broadacre farming has essentially been through rotation, although for a time the control of cereal cyst nematode was achieved through the use of chemicals. Wheat, barley and oat varieties resistant to cereal cyst nematode are now available for inclusion in the rotation, thus reducing the need for chemical control. However, as in the case of many of the root diseases which affect the productivity of the pastures and crops, it has been difficult to find resistance to breed into commercial cultivars. Examples are Rhizoctonia bare patch, which affects most crops and pastures, and Take-all disease of wheat and barley.

Take-all is the major root disease of wheat throughout southern Australia costing in the order of $200 million per annum. At present the main control measure is through rotations with non-host plants or the removal of grasses from pasture early in the year prior to sowing wheat. Oats is resistant to the common form of Take-all fungus which attacks wheat and barley, due to a compound in oat roots called "avenicin". There is considerable interest now in determining whether the genes responsible for avenicin production in oats can be transferred to wheat. If this can be done, agronomists and farmers can think differently about grasses in pastures.

Environmental effects of pest and disease control agents

As stated earlier, the control of pest and foliar diseases in many crops is very much dependent upon chemicals. Although many of these chemicals have no detrimental effect on the environment nor on the quality of the food, there is considerable pressure on the community to reduce the use of chemicals. For this reason, I believe that we will see a much greater emphasis in the future being placed upon alternative forms of control such as rotations, breeding, genetic engineering etc. In some European countries e.g. Holland and Denmark, legislation states that the use of chemicals will be reduced by more than 50% before the turn of the century. Thus agronomists will be faced with a tremendous challenge and in this situation, molecular biology will be of great value.

Soil Biology

Nitrogen fixing bacteria

The symbiotic association between the root nodule bacteria *(Rhizobium* spp.) and legumes has been of inestimable value to broadacre farming in Australia. However, we know there is a wide range of effectiveness in different strains of *Rhizobium* and that many of the nodulating rhizobia in the field are of questionable effectiveness.

Nodulation problems occur in acid soils, but the work of Howieson and Ewing (6,7) in Western Australia using acid-tolerant strains of *Rhizobium* isolated from nodulated medic plants growing in acid soils in Sardinia together with the selection of acid tolerant medic cultivars, has made it possible to extend medic pastures in acid soils of the Western Australian wheat belt. This work demonstrates the need to find the strains of *Rhizobium* suited for adverse soil conditions. Scientists at the Rutherglen Research Institute, Victoria, are searching for competitive, effective strains of rhizobia which can be introduced into soils acidified as a result of agricultural practices. Molecular biology can help the research through the incorporation of specific marker genes into the *Rhizobium* so that the introduced strain can be distinguished from background rhizobia through the development of coloured colonies on agar or even through the development of coloured nodules. This type of research is going to be extremely valuable in the future for improving nitrogen fixation in pasture and grain legumes, but seldom do agronomists take on such microbiological challenges.

Mycorrhizal fungi

The roots of most agricultural plants arc infected with mycorrhizal fungi which are capable of transporting nutrients,(e.g. phosphorus) from the soil into the root. The research conducted by Thompson (20), has shown the importance of mycorrhizal fungi for the growth of crops in Darling Downs, he demonstrated that the "long fallow disorder" problem in which poor crop growth following long fallow was due to the decline in mycorrhizal spores in the soil during the fallow period. His research solved the problem by reducing the period of fallow so that the number of mycorrhizal spores did not decline below a critical level. Despite this demonstration of the benefits of mycorrhizal fungi to crops in Queensland, their importance to productivity in crops and pastures in southern Australia is unknown because so little research has been conducted on field aspects of arbuscular mycorrhizas which cannot be grown on laboratory media. These mycorrhizal fungi growing out into soil from the roots of grasses contribute greatly the beneficial effects of grass roots on soil structure (23).

Plant growth promoting rhizobacteria

There is considerable evidence from overseas that a significant proportion of bacteria in the rhizosphere are capable of stimulating plant growth, especially under adverse soil conditions. Work conducted in Australia in the 1960's demonstrated that these beneficial bacteria can be isolated from our soils but the importance of these plant growth promoting rhizobacteria in Australia has yet to be assessed.

Biological control agents

Research has demonstrated that the Take-all disease of wheat can be controlled by introducing biological control bacteria or fungi into the root zone by either seed coating or directly into the furrow. Field responses to the introduction of biological control agents have been variable and unpredictable but as more is understood now about the ecology of the biocontrol agents and the Take-all fungus I expect that future agronomists will be able to use biological control agents to control take-all and other root diseases.

Earthworms

Until recently it was considered that earthworms did not occur in any great abundance in lower rainfall agricultural soils and nor were they considered important in improving soil properties and increasing crop and pasture production. However, recent work in several parts of Australia refutes this perception and has shown that in situations where stubble is retained and minimum tillage or direct drilling practised, the populations of earthworm can reach significantly high levels to improve the soil and increase pasture and crop production. The species of earthworms in our wheat growing soils are mainly "feral" earthworms introduced by accident from Europe. For this reason, it is not known if they are the best earthworms for our environment. This is an area which we will see developing in the future with the possibility of introducing the best types of earthworms to suit soil and the environment. An exciting recent discovery that earthworms can spread the beneficial bacteria *Rhizobium* spp. and biological control bacteria down the roots could have important implications for the introduction of more effective rhizobia into permanent pasture (18, 19).

Biodiversity of microbial populations

Little is known of the impact of different farming systems on the soil biota, apart from those organisms of direct economic importance e.g. root diseases. More research is needed to study this problem and to determine whether it is possible to manage the soil biota to increase productivity and to make farming systems more sustainable.

Perennial Pastures

Throughout the cereal-livestock region of Australia most farmers depend upon pastures consisting of annual clovers, medics and grasses. Whilst these pastures have been productive and profitable, they increase the development of soil acidity and do not lower the water table, which causes salinity problems. There is considerable interest now to develop mixtures of perennial grasses (e.g. phalaris) and legumes (e.g. lucerne) which will reduce the rate of acidification of the soil and also reduce salinity through the lowering of the water table. This is one of the challenges of the future requiring considerable research in different soils and environments.

Agroforestry

Until recently, throughout Australia there was little interest on the use of trees within the farming systems and it was not until problems of salinity became obvious due in part to the removal of trees from the landscape, that community interest developed in planting trees on farms. Trees have the same advantages as perennial pastures in that. being deep rooted, they are capable of lowering the water table and reducing salinity. Some excellent examples of the use of the leguminous shrub Tagasaste can be seen in Western Australia where it is used either to intercept the movement of water down slope and so reduce the problems of salinity at the base of the slope or in flatter areas, such as around Esperance, in large areas to reduce the water table and so reduce salinity. Tagasaste has the advantage that it is a legume and hence, together with *Rhizobium,* builds up soil nitrogen while it is reasonably salt tolerant and the foliage can be used as a high protein fodder for farm animals. In the future we will see extensive plantings of trees, including Tagasaste, throughout the fanning areas of southern Australia. Some of the models developed by Mr Peter Bulman, in South Australia on agro-forestry are exciting because they take into account the agronomic and financial aspects of different types of agro-forestry.

Phase Farming

For many years, the standard system farming in southern Australia was a two year rotation with pasture alternating with cereal, and although this farming system was successful in lifting the fertility, improving structure and the nitrogen content and organic matter levels in soils, it has presented many problems such as root disease carryover and the development of herbicide resistance. An alternative to this system of ley farming is to move into phase farming in which the farmer has two or three years of pasture followed by several years of continuous cropping. The length of pasture can vary from two to three years whilst the length of the cropping phase, based on results from long term rotations in Victoria, South Australia and New South Wales, can be from six to ten years without a significant decline in the physical, chemical or biological properties of soils, providing stubble retention and direct drilling are practised together with adequate fertilisers to compensate for the export of nutrients during the cropping phase. Such a farming system reduces the selection pressure on grassy weeds and so reduces the risk of developing herbicide resistance. It also has the advantage that during the period of continuous cropping, soil compaction from winter grazing of pastures is avoided. The advantages of phase farming with long periods of continuous cropping with adequate rotations have been demonstrated by a number of leading farmers and certainly this is the way for the future.

Remote sensing and aerial photography

As technology improves and farmers develop systems which enable them to maximise efficiency and increase yield, monitoring crops and soil will be become more important than it has in the past. The use of remote sensing and aerial photography to monitor the development of the crop and the development of diseases and weeds in crops will play an important part in future farming. In fact, in the United Kingdom, some of the more advanced farmers have their harvesting equipment connected to a computer which records the yield over the field as the crop is harvested and transmits this to a satellite which links yield to the position of the harvester in the field. When they have finished harvesting a field, the computer plots out the yield over the whole field so the farmer can investigate the causes for yield differences in different parts of the field and determine whether factors such as nutrient level, water-logging and disease were responsible. Management can be adjusted to the productivity of different parts of the field.

Growing products for specific markets

Until recently. grain growers throughout Australia have tended to grow the wheat best suited for the district and left marketing to the marketing authority. With this system, there have been areas which have been designated as suitable for hard wheats, others for soft wheats, others for ASW wheats and so on, but farmers have seldom sought to grow grain for specific markets.

With the deregulation of the wheat market it has now been possible for farmers to contract to specific buyers for their products. For example, the south east of South Australia is suitable for growing soft wheats and growers have formed a consortium to negotiate with biscuit manufacturers to grow quantities of wheat with the particular qualities required for biscuits. In other areas we find farmers have contracted to grow durum wheat for the pasta market and so take advantage of the high fertility of their soils to produce high protein durum wheats. One of the challenges of the future will be to target particular markets and grow the product required by those markets.

Another approach is to research the market needs, to determine whether grain currently imported can be grown in Australia. If so, then the technology should be put into action to determine where the crop can be grown. An example of this is in oil seed crops, which grow well in much of our cereal zone and yet Australia imports $100 million of vegetable oil each year. Here is an opportunity to develop more diversity into the cropping system. But, this will mean that considerably more research and extension into oil seed crops is needed.

Education

One of the problems confronting the primary producers and agronomists with the increasing complexity of modem farming is the standard of education and the ages of primary producers. This can make it difficult to move with the times and make use of the opportunities offered as a result of modern technology. Organisations such as TAFE and the Advisory Board of Agriculture (representing the agricultural bureaux of South Australia) are addressing these problems and offering appropriate training and extension to help farmers. As we move towards the twenty first century this serious problem will need to be addressed and primary producers be encouraged to improve their understanding of the complexities of modern farming.

Conclusion

In this paper, I have given a number of examples of future developments in agriculture which will require changes of mindset by both agricultural scientists and primary producers. Farmers throughout the developed world are facing a cost-price squeeze with declining commodity prices and this represents a tremendous challenge for their survival. In order to survive, we, as agricultural scientists, must offer farmers a variety of strategies which will enable them to improve productivity without destroying the resource. The future of Australia will depend upon the proper uses of the soils used for crops and pastures, so that their productivity can be sustained indefinitely. History has demonstrated that unless civilisations have developed sustainable farming systems, their soils were destroyed, their standards of living declined and many disappeared. As agricultural scientists, we owe it to Australia and the rest of the world to use the latest technologies to produce more efficiently and to protect our soils.

Farming in the future will become even more complex than in the past and primary producers will need to integrate so much information in their farming systems that they will need support. With the demise of many extension services offered by state Departments of Agriculture farmers will have to accept the responsibility of paying for much of the advice they receive.

References

1. French. R.J. and Schultz. J.E., 1984. Aust. J. Agric. Res. 35, 765-775.

2. Graham, R.D. and Webb, M.J., 1991. In Micronutrients in Agriculture, Soil Science Soc., Amer. Book Series No. 4. pp. 329-370.

3. Gasser, C.S. and Fraley, R.T., 1992. Sci. Amer. June 1992, 34-99.

4. Helyar, K.R.T., 1991. In: Soil Acidity and Plant Growth, (Ed. A.D. Robson) (Acad. Press Aust.) pp. 61-101.

5. Hoagland, R.E., Ed. 1990. In: Microbes and Microbial Products as Herbicides, Amer. Chem. Soc. Symp. Ser. 439. p. 341.

6. Howieson, J.G. and Ewing, M.A., 1986. Aust. J. Agric. Res. 36, 55-64.

7. Howieson, J.G. and Ewing, M.A., 1989. Aust. J. Agric. Res. 60, 843-850.

8. Langridge, P. and Paull. J., 1993. Proc. (Vol. 1) 10th Aust. Plant Breeding Conf.. April 1993 (in press).

9. Lovett, J.V. and Hoult, A.H.C., 1992. Proc. 6th Aust. Soc. Agron. Conf. 1992, 426-429.

10. Matthews, J. and Powles, S., 1992. Aust. Grain June-July 1992, 3-6.

11. McIntyre, C.L., Abrahams, S.C., Bettenay, H.M., Sandeman, R.A., Hayes, C., Sharp, D.. Elliott, A., Manners, J.M. and Watson, J.M., 1992. Proc. Int. Grasslands Conf. Pamerston North (in press).

12. MacNish, G.C., 1985. Pl. Path. 34, 175-181.

13. Naidu, R., Sumner, M.W., Rengasamy, P., 1993. Aust. J. Soil Res Special Issue. (in press).

14. Peacock. W.J., 1985. ALAS Occasional Publication, Melb., Aust. Inst. Agric. Sci. 22, 47-52.:

15. Powles, S.B. and Matthews, J.M., 1992. In Achievements and Developments in Combatting Pest Resistance (Eds. I. Denholm, A. Devonshire), (Elsevier Press: London) pp. 1-13.

16. Rovira, A.D., 1992. Aust. J. Exp. Agric. Special Issue "Crop Production on Duplex Soils", 801809.

17. Rovira, A.D. and McDonald, H.J., 1986. Pl. Disease 70, 879-882.

18. Stephens, P.M., Davoran, C.W. Doube, B.M. and Ryder, M.H., 1993. Appl. Environ. Micro. (in press).

19. Stephens, P.M., Davoran, C.W., Doube, B.M. and Ryder, M.H., 1993. Soil Biol. Biochem. (in press).

20. Thompson, J.P., 1992. Proc. Int. Symp. on Management of Mycorrhizas in Agriculture and Forestry, Perth, W.A. 121, 10.

21. Thongbai, P., Hannam, R.J., Graham, A.D. and Webb, M.J.. 1993. Pl. Soil (in press).

22. Thongbai. P., Graham, R.D., Neate, S.M. and Webb, M.J., 1993. Pl. Soil (in press).

23. Tisdall, J.M., 1991. Aust. J. Soil Res. 29, 729-743.

24. van Rees, H. and Sonogan, R., 1992. Mallee Farmer. Nov. 1992, 4-5.

25. Walters, L. and Rovira, A.D., 1993. In: Environmental Knowledge, Values and Action. (Eds. L. Cosgrove, D.G. Evans and D. Yenchen) (Melb. Univ. Press: Melbourne) (in press).

26. Wilhelm, N.S., Graham. R.D. and Rovira, A.D., 1980. Aust. J. Agric. Res. 39, 1-10.

27. Xue, G.P., Orpin, C.O.. Gobius, K.S., Aylward, J.H. and Simpson, G.D., 1992. J. Gen. Micro. 138, 1413-1420.