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DEPARTMENT OF AGRICULTURE AND FISHERIES, SOUTH AUSTRALIA

Agronomy Branch Report

A STUDY TOUR

MANAGEMENT OF INSECT PESTS IN AGRONOMIC CROPS

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1. INTRODUCTION

In the period, 11 July - 15 September, 1976, I visited 16 research institutes in five countries (Appendix I) to study the management of insect pests in agronomic crops and pastures and, in particular, -

a. experimental techniques for assesment of insect damage.

b. practical sampling methods to reliably estimate, with minimum effort, the density of populations of insect pests in the field.

c. the acceptance and use of the above sampling methods, especially sequential decision plans, by landowners and/or commercial pest-scouting services.

d. the current philosophy and methods applied to the understanding and control of insect pests in agronomic crops and pastures.

Also, I attended and presented a contributed paper on damage assessment at the XVth International Congress of Entomology, Washington.

The first section of this report, summarises the findings on the first three objectives above. The second section discusses specific pests and other projects in accordance with the fourth objective.

2. INSECT PEST MANAGEMENT IN AGRONOMIC CROPS AND PASTURES

Most of the research groups visited were involved in insect pest management, particularly of agronomic crops and pastures. The aims of many of the groups not only included entomological research but also agronomic research pertinent to the pest(s)/crop interaction being studied. In many of these studies, there was an increasing trend to correlate the rate of development of a pest and its density (life-table studies) with crop phenology. Often crops are only susceptible to economic damage by a particular pest at a certain stage of crop growth. The above correlation was being used to predict the probability of pests occurring at a time when crops were still susceptible to damage. This information can then be used to determine, firstly, whether application of an insecticide may be required and, if so, the optimum time to sample crops for economic infestations of the pest. Also, such information may assist in better advising the use of cultural control practices, e.g. time of planting crops, the use of early or late maturing cultivars in susceptible areas, etc.

These studies were either designed and supervised by entomologists, singly or in small groups, or by interdisciplinary groups, involving entomologists, agronomists, statisticians, economists, etc. Those entomologists not working in interdisciplinary groups usually had to study the crop as well as the pest because often the require information on crop phenology was not available. In the more complex studies, interdisciplinary groups appeared to be providing a sound basis for research, but it was also evident that such groups were not necessarily the panacea for all pest problems.

Discussions on interdisciplinary groups led to the suggestion that groups are best developed by research workers and not forced by administration. The latter can cause friction within groups due to clash of personalities, differences in interests, etc. Another approach was to appoint one researcher as leader of the project and allow this person to recruit others. However, this latter method depends on the size of the Department and the finance available for contracting outside expertise.

In addition to the above programmes, there were still a number of programmes testing the efficacy of insecticides against pests. There was a general concensus among all the groups visited that insecticides are going to play an important role in pest management for many years to come. However, many of the insecticide experiments were closely allied to integrated control programmes, hence emphasis was also placed on monitoring the effects of the insecticides on parasites and predators. Two insecticides which were often used in these experiments, especially with pests of cotton, were chlordimeform and permethrin, a recently developed synthetic pyrethroid. The former was most successful as an ovicide, particularly against lepidopterous pests, and had minimal effects on parasites and predators. However, it was withdrawn from the market by Fisons-Schering late last year because of suspected carcinogenic properties. Permethrin was shown to be a broad-spectrum insecticide, even at low rates of application, and because of this its use in integrated control programmes was being seriously questioned by most researchers that had tested it.

Researchers concentrating on biological control were mainly interested in the mass-rearing and introduction of parasites against introduced pests, or in the encouragement of native predators, e.g. attracting lacewing adults to lucerne fields for the control of pea aphid. Two programmes seen were assessing insect pathogens for pest control. One was in New Zealand where the influence of four species of protozoa on population levels of the grass grub (*Costelytra zealandica*) was being studied. The other was in America where *Bacillus thuringiensis* was being tested against *Heliothis* spp. in cotton. *B. thuringiensis* was not reliable and 50-70% reductions in larval densities were being obtained.

2.1 Damage assessment

There was an almost complete recognition amongst research workers in pest management studies that economic injury levels or thresholds for a pest in a crop were a basic necessity for rational pest control. However, many stressed the difficulties which were inherent in the establishment of these, and these difficulties appeared to have limited damage assessment studies, *per se*, in the countries visited. This attitude was emphasized in America where the lack of tested economic thresholds and their use was regarded as the Archille's heel of many sophisticated pest management programmes.

2.1.1 New Zealand

In New Zealand, insect pests of pasture are of major importance to the economy; considerable effort and finance was being directed at research to develop methods for improved management of these pests. Research was being carried out by the Ministry of Agriculture and Fisheries, Department of Scientific and Industrial Research and, to a lesser extent, Universities and private industry.

The main avenues of applied research were pursued by the M.A.F. and can be summarised as:

- selecting and establishing pasture species tolerant to pest damage.
- maintaining or increasing farm production in spite of pests by increasing production from unaffected areas.
- improving the use of insecticides.
- developing other control methods, including cultural control and the use of insect pathogens.

The DSIR and Universities were involved more in fundamental research. In 1975, a National Pasture Pests Research Coordinator was appointed to coordinate all pasture insect research to prevent unnecessary duplication of research and to ensure close communication and collaboration between research workers.

Most applied research was based on field experiments. Although damage assessment was not the main aim of these experiments, many were designed to study the impact of pasture pests on different pasture species and allowed estimates of the damage caused by different levels of density of the pest. The basic philosophies and methods of some of these experiments follows to show how the approach may be used in South Australia.

Ecological studies, mainly life- tables, on grass grub, the major pasture pest, showed that survival of large numbers of young larvae depended on the proportion of white clover in the pasture during December-January. This led to field experiments testing the feasibility of the following pasture management techniques to minimise larval densities:

- replacing white clover in the grass/clover pastures with bag nitrogen (this was considered to be the most unlikely alternative)
- regulating the percentage of white clover in a grass/clover pasture during December-January.
- using resistant legumes and grasses, in particular *Lotus penduncula*ta and lucerne, and cocksfoot (*Dactylus glomerata*) and prairie grass (*Bromus uniloides*).

Initial experiments were carried out in small plots (1.5 m x 1.5 m) in districts where the plots were assured of being naturally infested with grass grubs. When testing for resistant legumes and grasses, the treatments included pure swards of each species and all combinations of a grass with a legume. The plots were mown in a manner to simulate rotational grazing. One third of each plot was treated with insecticide to control grass grubs to enable an estimate of the potential yield of the pasture. Larval densities and the yield and composition of the different treatments were measured. In some experiments, larval liveweight was also estimated. The agronomic characters e.g. establishment, persistence under grazing etc., of new, promising pasture species were also being tested by the entomologists in other field experiments.

Similar plot experiments were being carried out with other pasture pests e.g. white fringed weevil (*Graphognathus leucoloma*) and black beetle (*Heteronychus arator*).

Information from these plot experiments was going to be used to design grazing experiments using 30 ha famlets. These larger-scaled experiments were designed to simulate a farm situation and compare the profitability of different methods of pasture management in the presence of pasture pests.

Data from the plot experiments could also be used to estimate losses in the yield of pasture which could be attributed to the different densities of larvae. However, research workers had no confidence in computing economic thresholds, mainly because of the difficulties in quantifying losses in pasture quality and yield in terms of animal production and economic returns to properties. Some workers considered that the assessment of damage in terms of pasture production, and the ability to predict pest populations and their damage was all that was likely to be feasible.

Application to South Australia

In South Australia, native pasture pests do not appear to have the potential to be as great a limiting factor in the overall animal production as in New Zealand, though they can seriously limit production on individual properties in some years. In the past, most landowners have been content, both in management and economically, to rely on the rather subjective use of insecticides for the control of these pests. However, with the further accidental introductions of exotic pasture pests and the present, relatively greater increases in the cost of insecticides and their application compared to the economic returns from pastures, there is a much greater need for information on which to base more objective decisions on the need for treatment. I agree with researchers in New Zealand that economic thresholds may not be practical, mainly because of extreme variations in pasture management and types of animal production even within similar climatic and edaphic regions. One way of providing information on the expected damage caused by pasture pests may be to class the larval densities together with the expected losses of pasture dry matter caused by these densities when the pastures are grazed by livestock. Landowners can determine how much dry matter they can afford to loose in any one year and then only treat those pest infestations with a density above the corresponding density range for that loss.

In addition to those pasture pests which can be controlled with insecticides in South Australia, there are two which can not be controlled easily with insecticides for the present.

Red-headed cockchafer (*Adoryphorus colouni*) larvae damage pasture in the lower South-East. At present, there are not sufficient resources in the Entomology section of the Agronomy Branch to adequately study red-headed cockchafer. However, it is known that livestock grazing management influences the density of larval populations and a review of Departmental grazing experiments in red-headed cockchafer susceptible areas may lead to a programme where minimal sampling of existing trials may elucidate the best pasture and/or stock management to minimise larval densities and concommitant damage.

Sitona weevil (*Sitona humeralis*) is a widespread pest of medic pastures, especially annual medics. Research on the control of sitona weevil is based mainly on the introduction of parasites together with selection and testing of tolerant cultivars of medics. The testing for tolerant cultivars of medics is restricted to tolerance to adult feeding because there are no reliable techniques for rearing and measuring the effects of larvae on plants in the laboratory. The larvae are soil-dwelling and feed on the nodules of medics; this feeding is considered to be the most important damage caused to annual medics by sitona weevil. Field methods testing the tolerance of different plant species to grass grub could be adapted to test the tolerance of candidate medic cultivars to sitona weevil larvae.

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2.1.2 United States of America

The projects visited in America were involved with insect pests of agronomic crops other than pastures grazed by livestock. This was mainly because limited studies had been carried out on damage assessment and population sampling of pasture pests compared with pests in other more intensive crops. As mentioned earlier, research on economic thresholds, *per se*, was limited and most of the levels used in extension programmes were subjective, based on grower's and extension worker's observations, rather than on sound experimentation. Any experiments determining economic thresholds, now and in the past, were mainly based on standard methods. These methods used insecticides to provide pest-free areas or a range of densities of the pest, or compared yields from crops or parts of crops which were naturally infested with different densities of the pest. Such experiments were conducted with pests in crops that had yields which could be directly converted to a monetary equivalent.

Other indirect methods, not involving the damaging stage of the insect in the economic threshold, included the monitoring of adults with pheromone traps and monitoring the level of damage to the crop. In one instance, the numbers of adults of pink bollworm (*Pectinophora gossypiella*) caught in pheromone traps was being tested as a criterion for the insecticidal treatment of cotton. There was 1 trap per 8 hectares. At this stage, the treatment of different numbers of moths resulted in differing larval densities but not in the yield of cotton. In soybeans, economic thresholds for leaf-eating pests e.g. Mexican bean beetle (*Epilachna varivestis*) and bean leaf beetle (*Ceretoma trifurcata*), were based on the loss in foliage. Up until one week before blooming a loss of up to 35% of foliage could be withstood. Following blooming and during pod-fill, no more than 20% foliage loss could be tolerated because there was no replacement of the foliage at these stages. These thresholds were developed from artificial pruning of soybean plants in the field and in greenhouses.

The pest management programmes visited were mainly concerned with pests of cotton, alfalfa for hay and soybeans, and the combination of studying crop phenology together with life-tables or population dynamics of the pest(s) was most evident, especially with research on pests of cotton and soybeans. This approach appeared to provide a very sound basis for the understanding of pest/crop interactions and prediction of pest damage but, for the most part, overlooked basic damage assessment data. In addition to only studying the pests in the crop being damaged, some programmes were using a holistic approach where the pest was being studied in many divergent plant communities, both cultivated and uncultivated. This had particular significance where pests migrated into different crops at different times of the year. Most of these programmes were developing simulation computer models for the population dynamics of the pest with the aims of not only applying existing knowledge more fully but also to focus attention on research needs.

An example of the benefits obtained from studying both the crop and insect can be seen from the relatively simply recommendations for reducing the density of corn earworm (*Heliothis zea*) in soybean crops in North Carolina. Corn earworm is a major pod-feeding pest of soybeans. Soybean cultivars vary considerably in their time of sowing (e.g. late-April to early-August) and it was recommended to use early-sowing cultivars to reduce corn earworm damage. This was based on the facts that adult moths lay their eggs in flowering crops and that these moths emerge from corn fields in mid-August. Planting early cultivars meant that the stage of crop growth favourable for oviposition did not coincide with moth flights. Also, a further advantage of using early cultivars was that moths prefer open crops for oviposition. Decreasing daylength determines flowering in soybeans and the early-sown cultivars had denser foliage at the time of moth flights than the later-sown cultivars with reduced vegetative growth.

Application to South Australia

In the past, much of the research on the control of agronomic insect pests in South Australia was aimed at urgent problem solving and resulted in short-term, easily-applied control measures which depended mainly on the use of insecticides and some cultural methods. Now, most of these pests can be controlled with insecticides but the increasing environmental and economic pressures on the use of insecticides, and the greater reliance on introduced parasites and native predators for the control of some of the introduced pests has stimulated the need for a far deeper ecological understanding of many of our pest/crop interactions.

Some research on agronomic pests within the Department is providing this information on the pests e.g. sitona weevil programme, though there appears to be a greater need to study crop phenology in association with our pests. Such studies may be carried out in the Entomology Section or may involve crop agronomists. I feel that there is a well substantiated need for further damage assessment studies on which to rationalise the need to apply insecticides, especially when it is considered that there will still be a heavy dependence on insecticides for the control of most pests for some time to come, and that economic thresholds are part of the foundations of integrated pest control.

A holistic approach to pest species has appeal, especially for pests like climbing cutworm (*Heliothis punctigera*), which damage field peas during their first generation in spring and then lucerne seed crops in the following generation.

The above studies would depend on far more statistical support from within the Department.

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2.1.3 England

Research workers in England also recognised the importance of quantifying crop losses caused by insects and applied entomology was swinging towards damage assessment studies. Some of their reasons were the establishment of the economic status of individual pests, the determination of the density of the pest that justifies control and the justifiable expenditure on control, the prediction of the expected insecticidal requirements for a season, and the assessment of future research priorities and agricultural planning.

Experiments determining economic thresholds mainly involved the use of insecticides to manipulate pest densities; these experiments were carried out in crops with yields that could be directly converted to monetary equivalents. In addition to this relatively standard approach, a more fundamental approach to damage assessment included both entomologists and plant physiologists. The physiology of growth and yield in attacked crops were studied to provide an insight into the probable nature of the relationship between pest attacks and their effects on growth and yield. This philosophy was similar to that in America where crop phenology was being studied.

In the Ministry of Agriculture, Fisheries and Food, pest damage assessment data was being collected because of their responsibility for an intelligence service on plant pests and diseases in England and Wales. Each month they had a summary which covered the incidence of pests and the damage caused by them. The assessment of damage was based mainly on the subjective opinion of district-based entomologists rather than on experimentation or controlled measurement.

With some insect problems, there was a general opinion that techniques to predict economic populations of a pest was more important than economic thresholds for the damaging stage. This applied to wheat bulb fly (*Leptohylemyia coarctata*) which damaged autumn-sown wheat in Northern Europe. Wheat bulb fly eggs were laid in summer in the soil of fallow or in the soil beneath root crops, such as potatoes or sugar-beet. The eggs hatch in winter and larvae survive only if they find themselves in autumn or early-winter sown cereals. Damage occurred when larvae bored into the base of the shoots of cereals. Insecticidal seed dressings were the main control methods and the only criterion available to determine the need for treatment was the number of eggs in the soil prior to sowing. There was an arbitrary threshold of about 2.5 million eggs per hectare, above which seed dressings were recommended. However, the cost of collecting this data in each field far exceeded the cost of insecticide. Also, when a few random fields were sampled by district entomologists to give a district forecast, the information was usually too late because landowners had already ordered their treated seed. For these reasons, landowners used insecticide seed dressings prophylactically as an insurance against wheat bulb fly.

In addition to predicting economic populations of a pest for prophylactic treatment in a district, techniques were being developed to predict the likelihood of economic infestations occurring in a crop in a particular season, especially for pests whose densities fluctuated considerably from year to year e.g. the aphid, *Aphis fabae,* in field beans. If there was a chance of economic infestations occurring then landowners would be advised to sample their crops using established economic thresholds prior to applying insecticide, rather than treating crops every year as is the present situation.

Application to South Australia

Discussions in England further supported the need for damage assessment studies on pests. Also, their aims to predict economic populations or the likelihood of economic populations of a pest would be an advantage in the control of agronomic pests in South Australia. This would provide a sound basis for extension workers to advise landowners to inspect crops prior to excessive damage occurring. The occurrence and density of most agronomic pests in South Australia depend mainly on climatic conditions. Some pests can be predicted reasonably well by assessing weather patterns, though there is still a need for this for many others. Predictive studies would depend more on a holistic approach, as discussed earlier, than has previously been used.

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2.2 Sampling Insects in the Field

The methods for sampling insects in research programmes were based on the many methods which have been described and reviewed frequently in scientific journals. However, the sophistication of the equipment varied considerably depending on the insects to be sampled and the size of the programme, especially in terms of the number of sample units which had to be taken.

In New Zealand, most of the sampling for pasture pests relied on separating the immature stages of insects from soil cores. In areas where sampling was intensive, they had developed a production-line approach for floating the insects from the soil in magnesium sulphate and wet seiving. Often this involved a number of personnel to operate efficiently. In America most of the sampling was confined to insects on plant foliage. The portable, motorised suction units (e.g. D-Vac^R vacuum insect net) were used extensively for sampling both beneficial and pest species of insects in cotton and lucerne. Sweep nets were also being used to determine fluctuations in population densities, though some workers were not as confident with sweep nets in lucerne compared to sampling in cotton. Their argument was that the sampling unit in cotton could be confined to one plant. In England, one project was measuring population densities of arthropods in grassland from year to year and a bank of Tullegren Funnels were being used to separate the arthropods from the soil. The equipment could handle 250 sample units at a time, but it was expensive and it took about 4-5 days for the arthropods to drop from the soil.

Generally, criteria used to determine the number of sample units which were taken was based on the number which could be handled with the available labour. Only few researchers had estimated the expected error of means prior to sampling field experiments. In Arizona, data on the distributions of a number of insects in cotton were collected from many sources and were analysed to provide a better insight into their distribution in the field in an attempt to improve the accuracy of sampling. However, they were having problems to standardise sampling because, although most of the distributions could be described by negative binomials, the dispersion parameter could not be stabilised.

The recommended methods to sample field crops commercially to determine the need to apply insecticide varied. The simplest was sampling for the burrowing bug (*Pangaeus bilineatus*) in peanuts in Texas. Ten sample units of soil were taken from each 40 hectares of peanuts. Treatment was recommended if two or more of the sample units contained burrowing bugs. Sampling was biased to the edges of the peanut crop because the pest moved in from alternative hosts. Extension entomologists were confident with this method, especially as peanuts was a high return crop and the cost/benefit ratio was very favourable, even at low densities of the pest. In cotton, a standard method was to have a sampling site in each quarter of the approximately 30 hectare irrigated cotton fields. From this site, the number of insects from 20 buds, 20 sweeps with a standard sweep net, 20 bolls, etc. would be estimated depending on the pest(s), being sampled. The number of buds, etc., being sampled differed slightly between States. The results were entered into printed sheets which showed the economic thresholds for the different pests on which to base decisions. This method was arbitrary and not based on any prior knowledge of the spatial pattern of the pest. Sweep nets were used as a means to balance practicability with accuracy. There was also a feeling that many economic thresholds sere set too low and this allowed some room for sampling errors.

More detailed sampling methods included sequential sampling, now known as sequential decision plans. Also, it was considered that the practical use of insect population models as an aid to pest management was rapidly approaching. Models were being field tested for pests in cotton and soybeans.

The use of sequential sampling to decide whether it was economic to treat a pest infestation resulted in reductions, sometimes in excess of 50%, in the number of sample units that had to be assessed compared to conventional sampling for the same accuracy. These plans were based on an understanding of the economic threshold and the spatial pattern of the pest in the crop. Another advantage was that the economic thresholds required for sequential decision plans was a range of densities, rather than a specific density. This is probably more realistic because of the variations in economic thresholds from year to year and area to area due to biotic and abiotic factors. Also, a range of densities could lead to plans being developed in the absence of precise data. Minimal research combined with experience and astute judgement could often produce an estimated range that would include most of the actual range of economic thresholds. A comment was made that economic thresholds arising from experimentation should be applied as they were developed, even though they may not have been fully tested under all conditions. As more research and experience was gained, then the range of economic thresholds may have to be modified.

An average sample number curve (ASN) could be calculated for sequential decision plans and this indicated the expected number of sample units required to make a decision for different densities of the pest. This information could be used to determine whether a plan was commercially feasible.

Sequential decision plans were also being developed where decisions relied on the presence or absence of the pest in the sample unit rather than counting all the insects in each sample unit. These plans should further simplify sampling, hence reducing the time to sample a crop.

Plans for a number of pests have been described in scientific journals but only a few were presented as extension bulletins applicable to field use.

Application to South Australia

The methods used to sample insects in the Entomology Section of the Agronomy Branch were generally similar to those seen in other institutions. However, future consideration may be given to establishing better facilities for the flotation of insects from soil cores. At present, we usually rely on hand-sorting but if the number of sample units requiring sorting increases, flotation and wet sieving would be more efficient. Consideration should also be given to purchasing a D-Vac^R vacuum insect net because this could improve the sampling of many insects in population dynamic studies as well as experiments testing the efficacy of insecticides.

I feel, that it will be some time before the more sophisticated population models will be used in pest management decision making for agronomic pests in South Australia, however, the use of techniques such as sequential decision plans have a place in rationalising the use of insecticides.

Where there is no information on the spatial pattern of pests on which to base sampling methods with a known accuracy, it is probably best to consider some standard method, e.g. as in cotton, in an effort to educate landowners to assess pest densities in crops prior to treatment. Not only will this prevent undesirable prophylactic treatment but, in many cases, may reduce avoidable economic losses.

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2.3 Commercial Acceptance of Economic Thresholds and Sampling for Insect Pests

Generally, there was very little use of economic thresholds and soundly-based sampling methods to determine whether insect infestations required insecticidal treatment in the areas visited. From discussions with entomologists this also appeared to be true for most other areas of the world.

Criteria used to determine the need to treat insects included previous experiences of the grower or his neighbour, pressure from salesman with insecticide companies, or prophylactic treatment because of a fear of the pest or as a relatively cheap insurance for peace of mind. The latter reason was especially evident with high return crops which could economically support intensive spray programmes. In America, many felt that growers "did not like the bother" of thresholds and sampling plans and did not have confidence in them. In California, the economic threshold of pink bollworm in cotton was considered to be 4 larvae per 100 plants, this was increased to 20 and, although this was still considered to be too low, extension entomologists were not confident to increase the number further lest they loose credibility with growers.

A situation where economic thresholds and sampling were being used was through Growers Pest Management Cooperatives, especially in cotton areas. Each Cooperative had a Board of Directors and a Manager to supervise a pest scouting service for all members' fields. The crops included cotton, alfalfa, cereals and sugar beet. The Board employed casual labour to do the scouting, when required. The idea of these Cooperatives was gaining more and more acceptance in some areas. For example, in the Casa-Grande area in Arizona, about 7,000 ha of cotton out of 40,000 ha were covered by Cooperative scouts. However, this only arose out of an intensive and relatively expensive - $US 400,000 from 1971 to 1976 - extension programme. The success of the Cooperative was shown by a reduction from 13 to 6, or less, insecticidal treatments per crop per season, together with a slight yield advantage over other crops. The economic thresholds used were mainly subjective and sampling was based on practicability and not statistical criteria. Further reductions in the number of sprays were expected as more information on economic thresholds and sampling became available. These Cooperatives and other commercial pest inspectors (not insecticide company scouts) appeared to be receptive to new or more sophisticated sampling methods, if the method reduced the time for sampling.

In England, the need to treat a number of pests was based more on a district requirement rather than an individual field requirement. The Ministry of Agriculture, Fisheries and Food had district entomologists who evaluated the need for treatment of particular pests each year. They used simple sampling methods which, with pests such as aphids, were supplemented with suction-trap data. A total of 70 fields was sampled each year for each major crop in England. The number of fields sampled in each district was weighed against the area of the crop in the district. The results allowed a decision to be made on the need for treatment of all crops in any of the districts. Farmers could obtain the decision from pre-recorded telephone messages. Such messages also included a range of other agronomic or livestock information and were updated every few days. The cost ofmaking the forecasts was about £2,000 per pest per year. Entomologists were a little apprehensive on how much notice was being taken of the forecasting schemes and felt that farmers still preferred prophylactic treatment.

Although sequential decision plans have been developed for a number of pests in America, there was only a limited use of them in the field. This appeared to be due to a combination of factors which included plans not presented in an applied method, little promotion of them by research and extension entomologists and landowners not interested in sampling other than a quick perusal through crops. At present, sequential decision plans for the key arthropods in cotton in Texas have been presented in Technical Reports and are available to extension entomologists, scouts and landowners (see Section 2.2). These plans had not been promoted because of uncertainty of some of the economic thresholds, however, effort will be made to have them applied in the near future. Although, research and extension entomologists often differed in their ideas on the need for such plans, extension entomologists in Texas considered that these plans will have application. Also, there was a more general view that sampling methods, such as sequential decision plans, will be looked for more in the future as current research leads to refinements in pest management. This will include a greater need to know more confidently the densities of beneficial and pest insects at any time.

Application to South Australia

The apparent resistance of landowners against the use of sampling plans overseas should not deter their development in South Australia. The question on what density of a pest requires treatment is being asked by landowners more and more and economic thresholds provided without a means of sampling crops can be difficult to apply and, in fact, misleading. Another reason for having sampling techniques is to stimulate landowners to inspect and assess their crops prior to damage occurring. Also, sampling of crops is going to be more important as integrated control programmes are developed for agronomic pests. The successful application of sampling techniques will be dependent on their practicability and the effort and resources put into promoting them, especially by extension personnel.

The use of Growers' Pest Management Cooperatives is unlikely to be feasible with the less intensive, broad-area agronomic crops, though they may have some place in the more intensive crops, e.g. oilseed crops and horticultural crops.

Recommending the treatment of pests on a district basis is not practical for agronomic pests in South Australia. There is a large variation in the densities of pests between crops in similar districts and such a recommendation could lead to gross over-use of insecticide.

3. MISCELLANEOUS TOPICS

The following notes outline other entomological studies which were discussed during the tour.

3.1 Millipedes

The millipede, *Ommatoiulus moreletti*, was introduced from Portugal into South Australia and is now an urban pest in the higher rainfall districts of S.A. Insecticides offer little protection against this pest mainly because of the large numbers which migrate into housing blocks from adjacent scrub and grassland. The possibility of introducing parasites to control this pest was discussed with C.S.I.R.O. Officers with the Biological Control Unit at Montpellier. They did not have much experience with parasites of millipedes but understood that little was known of the occurrence and influence of parasites on millipedes in Europe.

It appeared that any research into the biological control of millipedes in South Australia would have to be initiated from South Australia.

3.2 Sitona weevil

The C.S.I.R.O. Biological Control Unit at Montpellier was studying the parasites and diseases of sitona weevil for introduction into Australia for biological control of this pest. Some of the main points which have come from their studies were -

Taxonomy: The species of sitona weevil introduced into South Australia may be *S. discoideus* and not *S. humeralis*. There are four morphologically similar species in the *S. humeralis* group, viz. -

S. humeralis - central Europe (down to Montpellier but north of Spain)

S. discoideus - southern Spain, southern France, Italy, northern Africa.

S. separandus - Yugoslavia, Greece.

S. concavirostris - Turkey

S. humeralis is mainly found on lucerne while *S. discoideus* favours annual medics.

The host preferences of the species in South Australia tends to agree more with *S. discoideus* than with *S. humeralis*. This change in identification of the species introduced into Australia is also suggested by A. Roudier, 5 Rue Gazan, F75014, Paris, who is a taxonomist revising the genus, *Sitona*.

Parasites: The *Microtonus aethiops* previously recorded from chrysomelids is not *M. aethiops* but a different species. *M. aethiopoides (= aethiops)* is specific to the genera, *Sitona* and *Hypera*. An overlap of generations of sitona weevil adults in spring appear to be necessary for *M. aethiopoides* to be successful - *M. aethiopoides* has a 10 day pupation period and adults only live for 2-3 weeks. In Europe, there was 1-2% parasitism of sitona weevil adults in spring and early-autumn following aestivation of sitona weevil. After early-autumn there is one to two generations of parasites which tend to rapidly increase the percentage parasitism (up to 60%) in overwintering adults. The timing of the increase in percentage parasitism in relation to the timing of oviposition by sitona weevil will be important in determining the effectiveness of *M. aethiopoides* in South Australia. The parasite does not become fully developed until the parasitized sitona weevil adult is sexually mature; this governs the intiation of multiplication of parasites in autumn.

By the end of 1978, C.S.I.R.O. hopes to introduce a strain of the fungal disease, *Beauvaria bassiana*, and the parasites, *Centistes* sp. and *Campogaster exigua*. All these species have discrete distributions in Europe and, although they are often found in different climatic regions from southern Australia, C.S.I.R.O. feels they are worth studying. *B. bassiana* has given up to 90% mortality of late-instar sitona weevil larvae for the last 4 years in a particular field under surveillance.

In future, surveys for parasites will be undertaken in Turkey-Iran-Iraq to find either new species of parasites or different climatic strains of known parasites.

The need for a number of different parasites (both adult and egg parasites) is suggested by the experience in South Morocco where lucerne is now being grown more extensively. *M. aethiopoides* is the only known parasite in northern Africa. The spring populations of sitona weevil adults in lucerne reached 500 to 700 per square metre. These populations were reduced to 60-80 per square meter in autumn following 5-6 generations of the parasite. However, without other parasites the density of sitona weevil builds up again during winter.

Field sampling: Life-tables for *Sitona* spp. and their parasites are being developed in different areas around Montpellier. Densities of adults are being assessed with sweep nets and densities of larvae and eggs from soil samples.

In New Zealand, sitona weevil was first found in the Napier-Hastings area on the North Island in September, 1975, feeding on volunteer burr medic. In January, 1976, it was found on the Canterbury Plains in the South Island. Entomologists were concerned about the effects sitona weevil may have on lucerne, especially as lucerne was being tested as an alternative pasture species because of its resistance to grass grub. If sitona weevil was introduced from Australia, which was considered to be highly likely, it could be *S. discoideus* rather than *S. humeralis*. If this is the case, sitona weevil may not be the problem that was expected in New Zealand. Pastures in New Zealand do not depend on annual medics and, in Australia, sitona weevil is only a major pest in areas where annual medics are used as pasture species. Sitona weevil has been in New South Wales, where annual medics are not grown extensively, since 1958 and, although it damages lucerne, it is not considered a major pest.

3.3 Urban Entomology

In America, a number of Universities had urban entomologists. These entomologists carried out research on industrial and household pests. Much of the research appeared to be involved in testing insecticides for the control of these pests, especially new insecticides because of the restrictions on use placed on some of the older, well-tested insecticides by the Environmental Protection Agency. Research also included ecological studies on the pests to develop other means of control. In one instance, an integrated control programme for cockroaches was being developed using egg parasites.

Urban entomologists were also responsible for an advisory service to householders and industry as well as producing information leaflets on urban pests.

The Entomology Section in the Agronomy Branch often becomes involved in advisory work on household and industrial pest control. In the future it may be feasible for the Department to consider research aimed at testing and improving control methods for these pests, especially as no other research organisation in South Australia carries out this research. Also, more emphasis is being placed on safe and efficient industrial and household pest control following the recent amendments to the Health Act which require pest control operators to be licenced. An urban entomologist could also be responsible for research on pests of medical importance as many of the pests are in common, and there are no medical entomologists in South Australia.

3.4 Leaf-cutter Bees

Leaf-cutter bees, *Megachile rotunda*, were initially smuggled into New Zealand and only found by chance by entomologists. Parasites were also brought in with the bees. Since 1971, bees have been imported (mainly from Canada) and released in the South Island each spring, together with cells which have been collected from the field in autumn and stored during winter. The bees have not multiplied in the field which can be seen by the change in populations from 1971 to 1976 viz., 0.89, 1.07, 0.59, 0.59, 0.68, 0.62 respectively. However, they claimed that these bees have improved pollination of lucerne. An example is on one property where the yield of seed averaged 9.8 bags from 1963 to 1971 and increased to an average of 54.8 bags from 1972 to 1976; similar areas of lucerne were reaped during these two periods.

The poor build-up in bee densities may be due to cool summer temperatures and excessive wind.

Wild populations of leaf-cutter bees now occur on the Canterbury Plains.

Predators are not considered to be a problem but parasites can limit population densities, e.g. *Melitobia hawaiiensis*, a chalcid parasite of a native wasp has reduced populations of leaf-cutter bees by up to 98%

3.5 Blue Green Aphid

The blue-green aphid, *Acyrthosiphon kondoi*, had recently been found in America (March 1975, Imperial Valley) and New Zealand (September 1975 - North Island). By mid 1976 it had been found throughout Kansas, Utah, New Mexico, Nevada, Arizona and California in America, and on the South Island of New Zealand.

Although, the extent of damage caused to lucerne by this aphid had not been fully evaluated, entomologists in both countries were concerned about the damage it could cause. This concern was not only for immediate losses in yield but also the longer-term effects due to a plant toxin thought to be associated with the feeding of the aphid. The aphid, being a cold-tolerant aphid, was most active during winter.

The blue-green aphid is a Eurasian species found from Japan through to Iran. This area was surveyed by an entomologist from California for parasites of the blue-green aphid which could be introduced into America for biological control. The wasp, *Aphidius ervi* was collected from a wide range of climatic conditions and was being reared in California.

In New Zealand, insecticide screening experiments and lucerne management experiments were being carried out to determine short-term control measures. Also, three resistant cultivars of lucerne were being introduced from California for long-term control.

The Japanese expert on blue green aphid is Dr. M. Miyazaki, National Grassland Research Institute, Nishinasuno-Machi 768, Tochigi-Ken, Japan.

4. ACKNOWLEDGMENTS

I thank the Australian Extension Services Grant for finance, and the South Australian Public Service Board and Department of Agriculture and Fisheries for granting leave. This study tour allowed a refreshing and

stimulating insight into research programmes and both research and extension officers' philosophies overseas.

Also, I sincerely thank those visited for their co-operation and generous hospitality, both of which were the basis of a successful tour.

APPENDIX I : Research Institutes and Personnel Visited.

NEW ZEALAND

Ministry of Agriculture and Fisheries

1. Private Bag, CHRISTCHURCH

Mr. T.E.T. Trought - Biology and insecticidal control of pasture pests.
Dr. R.A. French - Pasture pest management.

2. Private Bag, PALMERSTON NORTH

Dr. W.M. Kain - Pasture pest management
Miss A.J. Milne - Insect pathology (pasture pests)

3. Ruakura Agriculture Research Centre, Private Bag, HAMILTON

Dr. R.P. Pottinger - Leader, Insect Control Group
Dr. R. East - Management of grass grub in pumice soils
Mr. P.D. King -White fringed weevil
Mr. R.N. Watson - Black beetle
Mr. G.M. Dixon - Soldier fly - damage assessment
Miss P.J. Gerrard - Soldier fly - life-table studies

Department of Scientific and Industrial Research

1. Private Bag, PALMERSTON NORTH

Mr. M.J. Esson - Sitona weevil, blue green aphid

2. Private Bag, CHRISTCHURCH

Dr. W.D. Pearson - Screening plants for insect resistance
Dr. J.A. Farrell - Breeding insect resistant plants
Dr. B. Donovan - Leaf cutter and alkali bees.
Dr. J.A. Wightman - Insect energetics, sitona weevil.

3. Private Bag, AUCKLAND

Dr. J.M. Hoy - Director, Entomology Division.
Mrs. B. May - Curculionid taxonomist
Dr. R. Cumber - Biological control
Dr. P. Cameron - Biological control
Dr. R. Hill - Biological control
Dr. O. Sutherland - Insect physiology - mechanism of resistance of plants to insects
Dr. J. Longworth - Insect pathology

Lincoln College

CANTERBURY

Mr. B.P. Stephenson - Pest status of pasture cockchafer.

U.S.A.

University of California

1. Department of Entomology and Parasitology, BERKELEY, California, 94720

Prof. R.F. Smith - Integrated control
Mr. C.S. Davis - Pests of pome fruits
Mr. C.S. Koehler - Urban entomology, damage assessment in alfalfa
Dr. D.E. Pinnock - Insect pathology

2. Department of Entomology and Sciences, BERKELEY, California, 94720

Dr. K.S. Hagen - Biological control - predators
Dr. L.C. Caltagirone - Life-table studies, biological control - parasites
Dr. R. van den Bosch - Biological control

3. Department of Entomology, RIVERSIDE, California 92502

Dr. H.T. Reynolds - Pest management
Dr. D. Gonzalez - Damage assessment, insect sampling Blue green aphid parasites

Dr. V. Sevacherian - Insect sampling
Dr. V.M. Stern - Damage assessment
Dr. P. DeBach - Biological control
Dr. R.A. Van Steenwyk - Insect migration
Dr. M.S. Mulla - Mosquitoes

University of Arizona

1. Department of Entomology, TUCSON, Arizona 85721

Dr. G.W. Ware - Chairman
Mr. L. Moore - Growers Pest Management Co-operatives
Mr. T. Pack - Growers Pest Management Co-operatives
Dr. T.F. Watson - Damage assessment

Texas A & M University

1. Department of Entomology, COLLEGE STATION, Texas 77843

Prof. P.L. Adkisson - Chairman
Dr. W.L. Sterling - Sequential sampling, cotton pests
Mr. J.K. Walker - Cotton pests/cotton phenology
Dr. M.K. Harris - Pecan pests, damage assessment
Dr. J.W. Smith - Peanut pests, damage assessment
Dr. J.G. Thomas - Extension entomology, cotton
Dr. R.E. Frisbie - Extension entomology, cotton
Dr. T.L. Payne - Forest entomology - pheromones
Dr. R.L. Hanna - Insecticide control cotton pests
Dr. R.N. Coulson - Forest entomology - population dynamics
Dr. H.R. Burke - Insect taxonomist - curculionids
Dr. H.W. Van Cleave - Spittle bugs - resistant plants
Mr. T. Holtzer - Cotton leaf hopper - life-table studies

North Carolina State University

1. Department of Entomology, Box 5215 RALEIGH, North Caroline 27607

   Dr. R.L. Rabb - Pest management, soybeans
   Dr. J.R. Bradley - Pest management, soybeans
   Dr. R.E. Stinner - Population dynamics, corn earworm
   Dr. R.C. Axtell - Mosquitoes
   Dr. G.T. Weekman - Pesticide registrations, E.P.A.
   Mr. R.C. Hillman - Urban pest control
   Dr. T.J. Sheets - Pesticide residues

United States Department of Agriculture

1. TUCSON, Arizona 85721

   Dr. R.E. Fye - Insect sampling

2. COLLEGE STATION, Texas 77843

   Dr. A.W. Hartstack- Systems analysis
   Mr. J.P. Hollingworth - Systems analysis
   Mr. W. Lopez - Population dynamics, corn earworm
   Mr. R.R. Blume - Dung beetles.

ENGLAND

Rothamsted Experimental Station

1. Entomology Department, HARPENDEN, Herts. AL5 ZJQ

   Dr. R. Bardner - Pest Management, damage assessment
   Mr. K.E. Fletcher - Pest management, damage assessment
   Dr. C. Edwards - Reduced tillage - soil pests

Ministry of Agriculture, Fisheries and Food

1. Plant Pathology Laboratory, HARPENDEN, Herts. AL5 ZBD

   Dr. K.S. George - Pest forecasting, damage assessment
   Mr. Sly - Register of pesticide use
   Dr. J. King - Plant disease damage assessment

University of London

1. Imperial College Field Station, Silwood Park, ASCOT, Berks. SL5 7PY.

   Prof. M.J. Way - Pest management
   Prof. T.R.E. Southwood - Insect ecology
   Mr. M. Cammell - Pest forecasting - aphids
   Prof. A.D. Lees - Insect physiology - aphids
   Dr. P.F. Boreham - Disease transmission by mosquitoes
   Mr. M.H. Birley - Statistics - life-tables
   Miss P.M. Reader - Life-table of a white fly.

Centre for Overseas Pest Research

1. College House, Wrights Lane, LONDON, W8 555

Mr. P.T. Walker - Insect damage assessment
Mr. J. Farrington - Economist

British Museum of Natural History

1. Entomology Department, KENSINGTON, London

Mr. R. Thompson - Taxonomist, curculionids

I.C.I.

Jealotts Hill Research Station, BRACKNELL, Berks.

Mr. J. Newman - Pesticides in the environment
Mr. D. Evans - Control of soil insects
Mr. G. Roberts - Hemipteran pests
Mr. P. Edwards - Effect of pesticides on birds.

WEST GERMANY

(Bayer) Pflanzenschutz Anwendungstechnik, Beratung, 509

Leverkusen - Bayerwerk

Dr. D. Kirsch - Aministration
Dr. H. Mattaei - Domestic pests
Dr. G. Zoebelein - Agricultural pests.

FRANCE

C.S.I.R.O.
Biological Control Unit, 335 Avenue Abbe, Parguel 3400, MONTPELLIER

Dr. A.J. Wapshere - Biological control of weeds
Dr. J.P. Aeschliman - Biological control of sitona weevil