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Proceedings of the CANADIAN AGRICULTURAL RESEARCH PRIORITIES SYMPOSIUM
Ottawa, Canada, 6–7 November 1980

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IDRC-MR33e

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CANADIAN AGRICULTURAL RESEARCH PRIORITIES SYMPOSIUM

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PROCEEDINGS

CANADIAN AGRICULTURAL RESEARCH PRIORITIES SYMPOSIUM

OTTAWA CANADA 6-7 NOVEMBER 1980

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INTRODUCTION AND RECOMMENDATIONS

At the United Nations Conference on Science and Technology for Development (UNCSTD) held in Vienna, Austria in August 1979, the Government of Canada announced the adoption of a policy encouraging the application of Canada's domestic research and development capability to the solution of problems of the developing countries. The Government of Canada has invited the International Development Research Centre (IDRC) to become the focal point of this new activity.

Although no money has been allocated by the Government of Canada for this program in the current fiscal year, IDRC has made a modest allocation from its own funds, in order that the preparatory work for cooperative research programs will have been completed when the funds become available. The officer responsible for this activity is Mr. Ernest Corea, Director, Cooperative Programs, within the President's office of IDRC.

In preparation for an earlier meeting convened by the Commission for the Application of Science to Agriculture, Forestry and Aquaculture (CASAFA), an Inter-Union Commission of the International Council of Scientific Unions (ICSU), a questionnaire was sent to international and developing country national agricultural research centres, and the relevant literature reviewed. These were in order to identify areas of basic research which until recently have been comparatively neglected but whose findings would significantly complement and assist applied research of benefit to developing countries in agriculture, forestry and aquaculture.

The recommendations drawn from this process were of an extremely general nature. Accordingly, to achieve greater specificity, it was decided to concentrate, initially, upon the needs of the semi-arid tropics (SAT), seeking to define what basic research projects undertaken in Canada might present a reasonable opportunity of improving scientific agriculture (broadly defined) in what is clearly the most depressed and impoverished agroclimatic region of the developing world.

Some participants at the earlier meeting undertook to prepare reviews of Canadian work and expertise in the relevant fields, and to make specific suggestions for future Canadian research efforts in support of applied research in developing countries. These were presented and discussed at a second meeting, the Canadian Agricultural Research Priorities Symposium, held in Ottawa on 6 and 7 November, 1980 and hosted jointly by the Cooperative Programs Office and the Agriculture, Food and Nutrition Sciences Division of IDRC. Symposium participants included Canadian Scientists of many disciplines related to agriculture and food from several universities and government departments, together with scientists from developing countries and from international agricultural research centres, in company with the entire scientific staff of the Agriculture, Food and Nutrition Sciences Division.

The specific agricultural and related areas in which research can and should be carried out in Canada, if possible supported by the fund pledged by the Government of Canada at UNCSTD, are presented in the papers which follow. The meeting declined to attempt to refine further the lists of priority areas for research as set down in the rapporteurs' reports. Rather it was preferred that the proceedings should be distributed to participants and through them to their colleagues in Canadian institutions, international agricultural research centres, and developing country national institutions, with a clear invitation to respond with critical comment.

It was suggested that as project proposals are formulated they be considered by an advisory committee representative of relevant disciplines and that the advisory committee also be invited to review projects undertaken in Canada as they progress.

Clearly it must be anticipated that many more proposals will be received in agriculture and related sciences than the funds available can support, particularly during the early years. Therefore a competent and impartial means of selecting among competing claims will be essential to ensure that the greatest degree of Canadian competence is applied to the research problems of greatest urgency.

It was certainly not possible for all scientists directly interested in the subject to be present during the Symposium. It is hoped, however, that all who receive these proceedings will review the contents critically and send to us their comments and recommendations, care of:

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INTRODUCTION ET RECOMMANDATIONS

Lors de la Conférence des Nations unies sur la science et la technique au service du développement (CNUSTD) qui a eu lieu à Vienne (Autriche) en août 1979, le Canada a fait part de sa décision d'adopter le principe de promouvoir, au sein du pays, les moyens de recherche et de développement. Pour ce faire, le gouvernement du Canada a demandé au Centre de recherches pour le développement international (CRDI) de jouer le rôle principal dans cette nouvelle entreprise.

Bien que le gouvernement du Canada n'avait affecté aucune somme pour l'application du susdit programme au cours de la présente année financière, le CRDI y est allé modestement de ses propres fonds pour mener les travaux préliminaires à ses programmes de recherche coopératifs afin d'être prêt une fois les fonds promis par le gouvernement mis à sa disposition. C'est Monsieur Ernest Corea, Directeur des Programmes coopératifs, affecté au Cabinet du Président du Centre, qui a été chargé des travaux en question.

Pour la préparation d'une réunion tenue sous l'égide de la Commission pour l'application des sciences à l'agriculture, à la foresterie et à l'aquiculture (CASAFA), qui est une commission interne du Conseil international des unions scientifiques (CIUS), un questionnaire a été adressé aux centres de recherches agricoles internationaux et aux centres nationaux des pays en développement, et la documentation recueillie sur ces sujets a été passée en revue. Il s'agissait de déterminer certains domaines de recherche fondamentale qui à date avaient été relativement négligés mais qui une fois déterminés pourraient aider d'une façon importante, et même compléter certaines recherches appliquées utiles aux pays en développement dans le domaine de l'agriculture, de la foresterie et de l'aquiculture.

Les résultats obtenus à la suite de cette étude ont une portée vraiment générale. Il a été décidé, en conséquence, pour arriver à des résultats plus spécifiques, de se concentrer au départ sur la région des tropiques semi-arides en vue de savoir quels seraient les projets de recherche fondamentale susceptibles d'être entrepris au Canada et en vue d'améliorer l'agriculture scientifique (prise dans son ensemble) dans les régions agro-climatiques les plus négligées et les plus démunies du monde en développement.

Quelques-uns des participants à cette réunion se sont engagés à préparer une étude des travaux canadiens entrepris dans les domaines en question et à faire des propositions spécifiques sur les recherches que le Canada doit entreprendre à l'avenir pour aider les travaux de recherche appliquée qui doivent être menés dans les pays en développement. Les propositions en question ont ensuite été exposées et discutées au cours du Symposium sur les priorités canadiennes en recherches agricoles qui a eu lieu à Ottawa les 6 et 7 novembre 1980 avec la collaboration du Bureau des programmes coopératifs et de la Division des sciences de l'agriculture, de l'alimentation et de la nutrition du CRDI. Les participants à ce symposium comptait des scientifiques canadiens de différentes universités et ministères gouvernementaux, spécialisés dans des domaines divers touchant à l'agriculture et à l'alimentation, ainsi que des scientifiques venant des pays en développement et des centres internationaux de recherches agricoles et enfin tout le personnel scientifique de la Division des sciences de l'agriculture, de l'alimentation et de la nutrition.

Dans les documents qui suivent, il est traité des questions précises en matière d'agriculture et de domaines connexes où des recherches peuvent et doivent être entreprises au Canada avec, si possible, les fonds prévus par le gouvernement du Canada à la réunion du CNUSTD. Lors du symposium, il a été décidé de ne pas pousser plus avant l'étude de la liste des domaines prioritaires de recherches décrits dans les comptes rendus des rapporteurs de la réunion, et qu'il faut plutôt distribuer les procès-verbaux des réunions aux participants et les inviter à les faire parvenir à leurs collègues dans les institutions canadiennes, dans les centres internationaux de recherches agricoles et enfin dans les organismes nationaux des pays en développement pour les inviter à les commenter d'une façon fonctionnelle.

Il a été proposé aussi de transmettre au fur et à mesure de leur présentation, les propositions de projets à un comité consultatif comptant des représentants des différents domaines scientifiques sur lesquels elles portent et de demander aussi au comité consultatif d'étudier les projets entrepris au Canada, au cours de leur réalisation.

Il ne fait l'objet d'aucun doute qu'il faut s'attendre à recevoir beaucoup plus de propositions de projet en matière d'agriculture et de domaines scientifiques connexes qu'il n'est possible de réaliser avec les fonds disponibles, plus particulièrement dans les toutes prochaines années. Aussi il est absolument nécessaire de choisir d'une façon impartiale et avec compétence les demandes qui seront présentées afin d'être absolument certains de pouvoir recourir aux Canadiens les plus compétents pour les charger des problèmes de recherche qui sont les plus urgents.

Il n'était certainement pas possible à tous les scientifiques directement intéressés à la question d'être présents au Symposium. Mais il y a lieu d'espérer que tous ceux qui recevront les procès-verbaux du Symposium les étudieront d'une façon efficace et qu'ils adresseront leurs commentaires et leurs recommandations à:

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LEGUME YIELD PLATEAUX
Paper by R.C. McGinnis

BIOLOGICAL N_2 FIXATION
Paper by R.W. Miller

Rapporteurs' Report
G. Hawtin and H. Doggett

1) The need for research to be relevant to the true needs of the developing world was stressed.

Food legumes have received comparatively little research attention in the past. In view of the importance of these crops in the SAT it was suggested that consideration be given, throughout the meeting, to establishing research priorities for food legumes, not only in relation to yield plateaux and N_2 fixation but also in connection with other topics to be discussed, eg. plant nutrition, tissue culture, grain quality and pest management.

2) The main legume species, as listed in the paper on yield plateaux, of importance in the SAT are: peanuts, soybeans, faba beans, chickpeas, cowpeas, lentils, phaseolus beans, winged beans, black gram and mung beans.

3) The need for stabilizing yields was pointed out as being of equal importance to raising yield potential. In this connection the following research areas were noted as being of highest priority and amenable to work in Canada:

a) Diseases

Ascochyta blight, root rot/wilt diseases, powdery mildews, rusts and viruses were all considered important in the SAT.

The suggestion was made that in view of the importance of Ascochyta blight, and the work already being undertaken in Canada on this disease in faba beans, Canada might take the initiative to coordinate research internationally on Ascochyta blight of all legumes.

b) Stress

Both moisture and temperature stresses are extremely important in limiting yields in the SAT.

The work on drought stress in sorghum, being conducted at Saskatchewan might be a useful base on which to develop parallel research on food legumes. Indeed the extension of this research to groundnuts was envisaged when the project was originally set up.

Salt stress and extreme pH conditions were mentioned as being important in some areas, and require considerable study.

c) Parasitic Weeds

Orobanche and Striga were mentioned as being very important in some areas.

The extent to which research on such weeds can be conducted in Canada was questioned, but it may be possible for certain basic research to be carried out at Canadian institutions.

d) Insect Pests attacking Food Legumes

It was noted that little attention has been given in Canada to research on insect pests attacking food legumes.

In the SAT these are extremely important and some basic studies on host plant resistance and possibly other non-location specific factors could be conducted in Canada.

e) Nematodes

Nematodes were mentioned as being important in many areas of the SAT. In particular the stem nematode Ditylenchus dipsaci was mentioned although others, e.g. root knot nematodes can be important in some areas.

4) Although much of the actual breeding work has to be conducted in the SAT countries, research on breeding methodologies may be readily transferable. In this regard the following were mentioned:

a) The development of gametocides to enable larger numbers of crosses to be made;

b) The development of male sterility both for use as a breeding tool and possibly for use in the production of hybrid varieties;

c) The need for methodologies for speeding up generation time and thus reduce the time taken to develop a new cultivar;

d) The development of methodologies for giving maximum seed increases, e.g. through tissue culture or hydroponic techniques;

e) The development of techniques for making large numbers of crosses to enable population improvement methodologies to be used in legume improvement. Studies on pollinating insects are needed in this regard;

f) Studies on wide crossing, particularly between cultivated species and related wild species could also prove to be extremely valuable.

5) Research on plant physiology could have considerable pay-off and in many cases the results of basic physiological research conducted in Canada could be widely applicable in the developing countries. The physiology of tolerance to moisture, temperature, salt and extreme soil pH stresses has already been mentioned. Research on photoperiod x temperature effects was also considered to be of particular importance. Such research frequently requires controlled environment conditions which may not be available in the developing world. The use of Canadian facilities for such studies could prove highly beneficial.

6) In many parts of the SAT the high cost of labour, particularly for harvesting, can limit the production of legumes. Research on the mechanization of production is needed urgently. High labour costs can also limit research on legumes. The development of machinery to handle field plot research is considered a priority.

7) Aspects of grain quality were considered to be of priority for research. In this respect the need to develop methods for the rapid determination of cooking time was stressed. Research on toxic factors (favism, Lathyrism) was considered of high priority as was research on anti-nutrional factors such as polyphenols, anti-tripsins, etc. Other aspects, such as uses and food preparation methods, should also be studied.

8) It was pointed out that legumes are very frequently given low priority by farmers: they may be grown on the poorer soils and be provided with fewer inputs compared with more profitable crops such as cereals. It is imperative that socio-economic factors of legume production be studied and that all production-oriented research be conducted against a background of the economic realities of production. The potential social and economic benefits of research must be considered in all cases when deciding on research priorities. Improved cultivars may shift the profitability of using better management and more inputs in a positive direction.

9) The importance of biological N_2 fixation was stressed, especially in relation to reducing the requirement of artificial N_2 fertilizers (and hence fossil fuels) by agriculture.

Although research on aspects of genetic engineering may have a long term benefit in the future, the opinion was expressed that the immediate priority is to better exploit existing genetic variation and to concentrate research efforts on legume-Rhiziobium systems.

The following were mentioned as being priority areas for such research:

a) Studies on the dynamics of N_2 in the whole farming system with particular reference to the quantification of N made available by legumes for other crops in the system. Nitrogen balance studies require both expensive starting material and unwieldy mass spectrometric analyses. Recently a low cost, rapid emission spectrometer for N isotope analysis has been developed in Agriculture Canada.

b) Studies on "Legume-Rhiziobium" combinations for stress environments, particularly cold, drought, high temperature and saline conditions.

c) Studies on the competition of introduced, efficient Rhizobium strains with native Rhizobium. Technology for carrying out meaningful competition experiments with Rhizobia will be available in the near future. Application of these techniques in various geographical locations would be of mutual benefit to Canadians and overseas researchers.

10) It was noted that although only two oilseeds were included in the list of leguminous crops, there are several non-leguminous oilseed crops in the third world suffering from almost complete neglect, yet of great importance in the diet of the ordinary people, especially the poor. IDRC is establishing a network of research projects on these crops, and attention was drawn to the big contribution which Canadian research institutions and universities could make in that area.

11) It was agreed that the purpose of CARPS could only be properly fulfilled by forging good links between research activities in Canada and research in the developing world. Canadian institutions could play a leading role in coordinating research efforts internationally.

12) One link mentioned involves the much greater use of post-graduate students, both Canadian and from the LDCs, in collaborative research projects. However, this requires the provision of adequate supervision of the thesis work by Canadian academic staff so that the student receives proper guidance and the reputation of the Canadian degree is upheld.

13) Effective use could be made of the enthusiasm and dedication which has characterized young people working in organizations such as CUSO, while at the same time equipping them for their future careers.

REPORT OF THE WORKING GROUP ON YIELD PLATEAUX ON GRAIN LEGUMES

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INTRODUCTION

A meeting of the Working Group on Yield Plateaux in Grain Legumes was held at The University of Manitoba on August 14, 1980. Expert members in attendance were:

Dr. A. Slinkard, Breeder, Crop Science Department, University of Saskatchewan (lentils, peas, and fababeans);

Dr. J. Tanner, Breeder, Crop Science Department, University of Guelph (soybeans, white beans, groundnuts);

Dr. H.H. Muendel, Breeder, Agriculture Canada, Lethbridge (soybeans, field beans);

Dr. S.T. Ali-Khan, Breeder, Agriculture Canada, Morden (lentils, chickpeas);

Dr. L.E. Evans, Breeder, Plant Science Department, The University of Manitoba (fababeans, soybeans, lentils, lupines);

Dr. C.C. Bernier, Pathologist, Plant Science Department, The University of Manitoba;

Dr. K.W. Clark, N-fixation, Plant Science Department, The University of Manitoba;

Dr. R.A. Hedlin, Soil Fertility, Department of Soil Science, The University of Manitoba;

Dr. R.C. McGinnis, Chairman, Faculty of Agriculture, The University of Manitoba.

The objectives of the meeting were threefold:

1. To identify the major constraints to increasing yield in the major grain legumes grown in the SAT;
2. To propose research projects that might be undertaken at Canadian institutions, the results of which would be useful and transferable to the developing countries of the SAT;
3. To assess the present Canadian capability and strengths and suggest the most appropriate location for particular research projects to be undertaken.

Discussion during the meeting was confined to the problems of the SAT, although it was recognized that much research would be of value to the improvement of Canadian grain legume crops as well and, therefore, a dual purpose could and should be served. The group quickly brought to light the scant research effort presently applied to grain legume improvement in Canada and the apparent low research priority of this important food source by governments and universities.

It was considered that the yield plateaux of a number of these crops is the direct result of neglect; the payoff from a sustained research effort would be directly proportional to the size of the program. According to a recent report to the Canadian Agricultural Research Council, prepared by Dr. D.G. Hamilton, the total research effort on pulse crops at present in Canada is 27.4 man years. The group considered the crops that are commonly grown in the SAT for food and are also adapted to parts of Canada or could be researched under controlled environment conditions. Among the important crops falling into this category are peanuts, fababeans, chickpeas, cowpeas, lentils, lupines, soybeans, Phaseolus beans, and possibly wing beans.

I. Constraints to Increasing Yield

The group agreed that the most rapid way of achieving higher yields quickly is by better management of the cultivars presently available. However, breeding for the higher yielding cultivars, with as much protection against the usual yield reducers, must ultimately be the major objective. The following constraints were therefore discussed:

A. Genetic

Until recently no real effort has been made to breed for high yield. Therefore, the potential for increasing yield is wide open. Much more use should be made of the diversity of germplasm that is available internationally. This would call for a closer collaboration with a number of the International Agricultural Research Centres (IARCs) that are well equipped to evaluate new materials in the developing countries. Basic physiological studies related to plant breeding and varietal improvement have not been researched which leaves a major gap in our knowledge and understanding of how to increase yield. Fundamental genetic studies to determine the inheritance of important characteristics are also scarce. The harvest index is presently very low in most crops and is another area of neglect.

B. Disease

This was identified as a major constraint but is variable from area to area, crop to crop, and year to year. Studies on the epidemiology of many of the pathogens are almost lacking but are of great importance to the control of the diseases. Disease complexes and their inter-relationships are not well understood and identification of races of the various pathogens has not been undertaken as yet to any extent. Some of the IARCs, such as ICARDA and ICRISAT, have made an excellent start in disease complex identification. Particularly notable is the research at ICRISAT leading to the identification of three distinct diseases which can be considered as components of the so-called "wilt complex" of chickpeas and the preliminary work on race identification in Fusarum oxysporum. However, in relation to the total disease problem, the amount of research currently underway is quite inadequate. The working group considered fababeans to have the greatest disease problem, being susceptible to virus, rust, and ascochyta blight attacks at the same time. Very few studies have been conducted on the inheritance of resistance to the various diseases which is also a very large potential research area.

C. Insects and Pests

The group recognized that from time to time serious yield losses in all the grain legumes will result from attacks of numerous insects. Similarly, birds may take their toll. However, it was considered to be impractical to undertake research in these areas at Canadian institutions. On-site research is necessary for insects and birds and some excellent research is already underway through IARCs. Should there be an opportunity for collaboration on a specific problem it would likely be at the invitation of the concerned IARC and would likely be fundamental laboratory studies, e.g. pheremones, insecticide screening and degradation of these chemicals, etc.

Weeds are also among the most limiting problems faced by farmers in the SAT. They are also among the most limiting factors in production in Canada. The group could see some possibilities for research in this area at Canadian institutions, recognizing the limitation that relatively few species are common to both environments. This is particularly true for the parasitic weeds such as Striga. However, tillage practices and herbicide screening would be important.

D. Soil Fertility

In the SAT, soil fertility can be a major constraint to production. Not only are the major nutrients frequently deficient but also minor elements such as zinc, copper, iron, manganese, etc., are not always available at sufficient levels. Symptoms of minor element deficiencies are not well documented and described. It is known that some genotypes are tolerant to low levels of minor elements (e.g. some varieties of beans grown normally under low zinc) but screening for genotypes with such tolerances has not proceeded very rapidly. Toxicity from too low or high pH and salinity are also major problems in many regions. Screening and breeding for tolerance to these problems is indeed limited at present.

E. Seed

It is difficult to maintain viability in some grain legumes such as soybeans. Storage facilities are frequently inadequate. In storage there is also a problem of seed discoloration in crops such as peas, lentils, and soybeans, where some of the seed coats turn brown, probably predisposing them to seed rot when planted. Seed treatment is not a common practice.

F. Seed Inoculation

For the grain legumes traditionally grown in a region, there is probably a good concentration of the Rhizobium strains specific for these crops already in the soil. However, when introducing a new legume into a country, it is important that it be accompanied by the proper Rhizobium culture. The group attributed many of the early failures of introduced grain legumes into developing countries to this deficiency.

It was also emphasized that inoculum in the granular form is much more effective than the older preparations. Currently granular inoculum is available for soybeans, peanuts, and fababeans. The group expressed concern that Canada is totally reliant on the U.S.A. for this form of inoculum and felt strongly that a Canadian company should be encouraged to get into production.

G. Stress

Grain legumes suffer from drought and heat stress. In many years this can be a serious constraint to production. Relatively little has been done in screening and breeding for tolerance to these stress factors, although good work is underway at a number of IARCs.

Other factors such as flower drop were discussed. Flower drop occurs in fababeans, soybeans, and lentils under conditions of lush growth and extreme heat at the time of flowering. It would appear to be a physiomorphological problem.

II. Proposed Research Areas Within Canadian Capability

Canadian institutions collectively have a great deal of potential to mount a significant research effort in several of the more fundamental areas which would relate to the production problems faced by SAT countries. There are many well-equipped laboratories for pathology, entomology, physiology, cytogenetics, soil chemistry, breeding, etc., as well as excellent field and controlled environment facilities. Several Canadian institutions have been in the forefront in the development of small plot equipment.

The group felt it would be important to identify major areas of research that Canadian institutions have the capability to undertake, rather than make individual, detailed, specific project proposals. These included:

A. Genetic Studies

There is an unending list of inheritance studies that should be undertaken, including the genetics of disease resistance, height, seed color, seed size, maturity, photo period sensitivity, stress factors, tolerance to pH and salt levels, etc. The group included cytogenetic studies also under this heading. Fundamental cytological studies are relatively scarce in crops such as lentils, chickpeas, Phaseolus beans, and fababeans, but such studies are very important in complementing genetic and plant breeding studies.

B. Plant Breeding Methodology

This is still a wide open field with each plant breeder essentially following his own self-styled system. More should be learned about the best method of handling self-pollinated and cross-pollinated crops, as well as species within these broad categories. The production of hybrids could also make an important contribution in the plant breeding field. Plant breeding methods should be adaptable to suit specific local or regional problems, for example to incorporate multiple disease resistance while simultaneously maintaining or adding genes for high yield. The ultimate aim of all programs is to increase yield.

C. Physiological Studies

A good deal of useful work could be done in such areas as physiology of yield to identify the components of yield, and also physiology of stress in collaboration with genetic studies on stress.

D. Disease and Race Identification

This is a large area in which a number of institutions could become involved. In collaboration with geneticists there should also be studies on host-pathogen interaction and inheritance of pathogenicity.

E. Other Possibilities

- N-fixation in relation to the vegetative and reproductive phases and the fate of fixed N after harvest;
- seed quality as it relates to germination and nutrition;
- screening germplasm for tolerance to herbicides;
- physiology of flower drop;
- screening germplasm for better N-fixing genotypes;
- screening Rhizobium strains for better host-strain symbiosis;
- hard seededness in fababeans.

The group felt that a number of projects could be undertaken by graduate students, both foreign and Canadian. Where feasible, some or all of the research should be conducted in an appropriate SAT country or preferably at an IARC headquarters or regional station. The supervisory professor would be expected to make on-site reviews of the project from time to time as well. IDRC has alreading been involved in such collaboration.

III. Canadian Institutions

The group identified a number of institutions across Canada that are presently working on some aspect of grain legume research. However, there may well be other institutions doing important work of which the group was unaware. For example, none of the members were aware of any on-going programs in the Maritimes but, lacking representation from these provinces, this may not reflect the true situation and the list of institutions may be incomplete. It is assumed that the institutions listed would be able to contribute to SAT problems in their area or closely related areas of specialization.

BRITISH COLUMBIA

AGRICULTURE CANADA

Vancouver	- a virus unit capable of research on peas and lentils, specializing in seed-borne viruses;

ALBERTA

AGRICULTURE CANADA

Lethbridge	- breeding soybeans and field beans; - Rhizobium studies; - agronomic studies, particularly on water use; - weed control; - physiological studies;
Lacombe	- fababeans silage;

UNIVERSITY OF ALBERTA

Plant Science Department	- equipped for virus studies;

SASKATCHEWAN

AGRICULTURE CANADA

Swift Current	- crop rotation involving wheat and lentils; - evaluating inoculum sources for peas;
Melfort	- grain legume cooperative trials (testing);
Indian Head	- herbicide trials and phosphorus studies;

UNIVERSITY OF SASKATCHEWAN

Crop Science Department	- breeding peas, lentils, fababeans; - agronomic studies (management) including irrigation and soil fertility; - weed control; - plant pathology; - quality factors, i.e. protein, amino acid analysis, tannins, tripsin inhibitors, digestability by prerumenant calves; - mycorrhiza with fababeans;

PRAIRIE REGIONAL LABORATORY	- consumer products;

MANITOBA

AGRICULTURE CANADA

Morden	- breeding lentils, chickpeas, and peas; - agronomy studies (management); - plant pathology; - herbicide studies;
Brandon	- soybean breeding, physiology, and soil fertility;

UNIVERSITY OF MANITOBA

Plant Science Department	- breeding fababeans, lentils, soybeans, lupines; - pathology; - N-fixation; - weed control; - agronomy (management);
Soil Science Department	- N & P metabolism, micronutrients;
Animal Science Department	- anti-nutritional factors, general utilization;
Home Economics	- product development; - nutrition;

ONTARIO

AGRICULTURE CANADA

Harrow	- soybeans, white bean breeding; - soybean physiology; - pathology; - white bean quality;
Delhi	- groundnut agronomy;
Ottawa Research Station	- soybean breeding and quality studies;
Food Research Institute	- white bean quality;

UNIVERSITY OF GUELPH

Crop Science Department	- soybean, white bean, groundnut breeding; - soybean, white bean, groundnut physiology; - N-fixation in white bean, groundnut and soybean; - weed control in all three crops; - serological identification of strains of Rhizobium;

Food Science Department	- quality factors in white bean;
NATIONAL HEALTH AND WELFARE	- favism and nutritional factors;

QUEBEC

UNIVERSITE LAVAL

Departement de Phytologie	- field testing grain legume species; - nutritive value of grain legumes for man.

The group concluded that, considering the importance of grain legumes both internationally and domestically, the total research effort in Canada is woefully inadequate. Although very good facilities for research already exist at many institutions or could be put in place quickly, the most important component, the scientist resource, has not kept pace with the demand for his skills. The group complimented the IDRC initiative to have a more thorough look at the total Canadian picture and would welcome an opportunity to participate in research programs that might be mutually beneficial to the SAT countries and Canada.

RESEARCH ON BIOLOGICAL NITROGEN FIXATION IN CANADA

A report prepared for I.D.R.C.

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September 18, 1980

RESEARCH ON BIOLOGICAL NITROGEN FIXATION IN CANADA

Introduction - This report has been designed to provide a brief synopsis of federally funded research on biological nitrogen fixation in Canada. The purpose of a review of research projects in this area is to define basic priorities to which Canadian scientists might make particularly effective contributions of benefit to the Canadian agriculture and forestry industries as well as to less developed countries. It has been necessary to consider separately fundamental research projects which will be expected to come to fruition on short (1-5 yr) and long (5 yr plus) term bases. Since the ultimate contribution of long term projects depends on progress being made in other related long term research, statements of the expected impact of this type of project tends to be of a speculative nature. However, it seems reasonable to expect that the greatest advances and benefits from research in nitrogen fixation will come ultimately as a result of sustained effort in the fields of genetic engineering and the application of recombinant DNA technology.

Current research on nitrogen fixation is closely related to energy utilization in the food production system. Chemically fixed nitrogen is the most energy costly industrial input into agricultural productivity. About one-third of all fossil energy used in current agricultural production goes into chemical nitrogen fertilizer synthesis. Research directed towards increasing biologically fixed nitrogen offers hope of an alternative to continued expansion in the use of non-renewable resources for growing crops. The problem is to develop crops which can use nitrogen fixed by microorganisms efficiently in place of nitrogen fertilizers. In broad terms, the two aspects of symbiotic and associative symbiotic plant-microorganism relationships are of major concern both in Canada and less well developed countries.

This report will be limited to research on biological nitrogen fixation although there are clearly important links between legume breeding for environmental adaptation and disease tolerance and root infection, nodulation and nitrogenase activity.

Discussion of Canadian Nitrogen Fixation Research Having Short Term Benefits (I).

I. A.* The role of environmental factors such as pesticides, air pollutants, nutrient levels, soil moisture and soil nitrogen in influencing symbiotic nitrogen fixation in various legume crops is being determined through the joint efforts of university and government laboratories in several parts of Canada. Since nitrogen fixation is only one component of the overall nitrogen cycle, comprehensive studies of denitrification and related processes are complementary and provide an evaluation of important environmental factors which may encourage or discourage symbiotic nitrogen fixation. Closely related to soil environmental parameters are ecological factors affecting symbiotic rhizobia, free living bacteria, and algal species all of which increase biologically fixed nitrogen available for crop growth. Competition between rhizobial strains for nodulating a given legume has now been recognized as one prime factor in determining the effectiveness of symbiotic nitrogen fixation.

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* Paragraph numbers refer to Appendices I and II which list research projects, institutions and principal investigators.

I. B. - Development of rapid techniques for the identification, selection and screening (for nitrogen fixation) of rhizobia is clearly of major importance in assessing the effectiveness of present legume inoculants and in developing improved innoculants. Specific criteria for selection of inoculant strains which are being applied are: successful nodulation under adverse soil conditions (pH, low temperature), competitive ability with respect to naturally occurring rhizobia having low potential nitrogen fixing capacity, maximum nitrogenase activity, maximum crop yields and maximum survival in soils.

I. C. - Legume breeding programs have only recently been initiated to specifically optimize symbiotic nitrogen fixation. Physiological criteria for selections of host plants are being developed rapidly for application in these programs (alfalfa, soybean). Selection for increased photosynthetic capacity and translocation of photosynthate will be a major strategy since nitrogen fixation is limited by photosynthate supply. Extension of nitrogen fixation activity into the pod filling cycle in grain legumes through selection may enhance total protein content in these crops. Root morphology and its effect on nodulation is also being used as a selection criterion. In forage legumes, it has been found that seedlings of presently available cultivars are better adapted to early growth on chemically fixed nitrogen than on symbiotically fixed nitrogen. Transition to high growth coefficients on symbiotic nitrogen does not occur ordinarily until well into the 5th week of growth. Selections must be made for development of forage cultivars on symbiotic nitrogen to eliminate the initial lag in growth now observed in the absence of nitrate or other chemical nitrogen sources.

In short, while many symbiotic relationships have evolved in legume species, these are not necessarily optimal for efficient cropping systems and much can be done to improve the situation in both forage and grain legumes in a relatively short period.

I. D. - The role of symbiotic nitrogen fixation in forest biomass production is receiving increasing attention from the standpoint of soil fertility maintenance. Recent discoveries of the identity of the organisms (Actinomycetes) which nodulate angiosperms and the developmental morphology of these systems have inspired additional efforts in this important field. The physiology of symbiotic nitrogen fixation in these systems requires a great deal of investigation.

I. E. - Associative symbiotic relationships between certain bacterial species and the roots of C_3 grasses, prairie grasses and certain wheat lines have been identified. The quantification of the contribution of this type of interaction to total plant nitrogen is well advanced. Indications of benefits of associative symbiosis hold promise of possible additional contributions to the nitrogen economy of grain crops.

I. F. - Research on nitrogen fixation by free living bacteria and algae has not been emphasized in the Canadian research community. However, the contribution of bacteria and algae in arctic ecosystems is being assessed.

Summary of impact of short term nitrogen fixation research projects - Major contributions of Canadian scientists are originating from environmental, ecological and improved inoculant development projects. The identification of wild type rhizobial strains in the field is an area which has been either shunned or abandoned by laboratories in other countries. The C.B.R.I. group is developing simultaneously 3 criteria (immunological, endogenous antibiotic resistance and phage susceptibility) for identification of *R. meliloti* isolates. These techniques should allow comprehensive ecological studies to be carried out to determine conditions for optimal performance and survival of inocula.

Assessment of the relative importance of soil nutrients, metal ion concentrations, pesticides, pollutants and soil parameters such as pH, temperature moisture and oxygen levels will ultimately allow small but significant short term increases in biologically fixed nitrogen. All of this technology under development could provide a basis for collaborative research benefiting less developed countries.

Discussion of Canadian Nitrogen Fixation Research Having Probable Long Term Benefits (II).

II. A. Major limitations on the nitrogen fixation capacity of legumes are set by the supply and efficiency of utilization of photosynthetically derived metabolites. Energy is released from these metabolites by bacterial respiration and this energy is converted to low potential reducing equivalents and ATP both of which are essential for denitrogen reduction in all nitrogen fixing microorganisms. Hence, analyses of photosynthetic capacity and translocation in various crops is basic to a full assessment of the potential benefits of increasing either source or sink strengths in legumes. For example it is well established that 30% of the energy used by alfalfa bacteroids is wasted in hydrogen gas evolution. This is not so in the case of soybean nodules which are inhabited by another *Rhizobium* species. The difference is due to the presence of an hydrogen gas recycling system in many strains of *R. japonicum*.

II. B. - Both nodulation and nitrogenase activity in legumes are repressed by ammonium ions in soil. Other soil nitrogen forms may also repress nodulation. Nodule nitrogenase activity is regulated at the enzyme level by the biochemical environment inside the nodule. In addition, nitrogen fixation is regulated at the translational and transcriptional levels through a very complex series of molecular regulatory processes. For example, expression of nitrogenase activity through synthesis of the enzyme proteins and cofactors is repressed by oxygen as well as by ammonium ions. The complex nature of the regulation of symbiotic nitrogen fixation is just beginning to be appreciated. Hence projects labelled as long term studies of the molecular biology or regulation of nitrogen fixation will be essential to the success of other more glamorous sounding long term projects such as transfer of nitrogen fixing genes, or host symbiotic genes, from one species to another.

Surprisingly, details of the mode of action by which energy (ATP) is utilized by the nitrogenase system are not well characterized. Even the way in which bacteroid membranes generate and transfer low potential reducing equivalents to nitrogenase are not completely understood. The postulate that recycling of hydrogen gas can enhance nodular nitrogen fixation is not yet accompanied by complete knowledge of the biochemical events necessary for this process. Clearly, these outstanding questions must be answered before long term attempts at genetic transfer can accomplish the desired end results, even after the techniques for the actual genetic manipulation are worked out. The federal government has supported very modest efforts in the biochemistry of nitrogen fixation and a small number of more ambitious projects in the areas of regulation and genetic engineering research.

II. C. - Genetic manipulation of the bacterial genes coding for nitrogen fixation capability and the plant genes for support of symbiotic nitrogen fixation is truly long term research. These projects depend on the development of techniques for genetic modification, gene transfer and recombinant DNA, in general. While the validity of this approach has been established for simpler genetic systems, having now been successfully applied in a small number of cases, the transfer (and successful phenotypic expression) of a minimum of 14 genes for the nitrogenase system between microorganisms is considerably more difficult. This, coupled to the requirement for additional genetic systems coupled to symbiotic fixation (e.g. hydrogen recycling system, high oxygen affinity respiratory systems, porphrin biosynthesis and other support systems) gives a clear picture of the level of difficulty of introducing efficient nitrogenase systems into new microorganisms or into higher plants.

On the plant side, the host genes required for support of symbiotic nitrogen fixation have only recently begun to be defined and no definite number can be placed on these genes at present. Two active groups in Montreal are addressing the problems of identifying the symbiotic genes and of isolation of hybridization probes for these genes.

Transferring of symbiotic capability to new plant species will not likely be accomplished in this decade. If and when this is accomplished it will be useless unless the regulation and molecular biology of microbial nitrogen fixation is fully understood. Unfortunately the actual genetics of the microbial process has only been worked out in free living bacteria. Rhizobial genetics, the isolation and characterization of the Nif genes of rhizobia, is being supported in Ottawa but will require many years for completion even with the full cooperation of foreign laboratories.

II. D. - The study of nitrogen fixation in algae and free living bacteria has not been adequately supported in Canada. A project involving transfer of genetic material between rhizobia and a free living fixer, *A. vinelandii*, should be supported (U. of Alberta). A single project on the regulation of nitrogen fixation in blue-green algae relevant to the nitrogen economy of arctic soils represents a good approach to algal associations under adverse conditions.

Summary of long term research efforts on nitrogen fixation - While the immediate relevance on the long term research described above to cropping systems in Canada and less developed countries may not be immediately apparent, in the long run, it will be to our benefit to have developed expertise in these areas. Since new strains of microorganisms created by recombinant DNA techniques are now patentable in certain countries, we and our colleagues in less developed countries will ultimately be placed in the position of buying this technology at a much higher price than that of a sustained research effort. Since chemically fixed nitrogen may be equated with a major energy input for all crop systems, we can assume that the cost of this component will increase inversely with the dwindling supply of, and directly with the cost of fossil fuels. Research on nitrogen fixation should be viewed in the same light as research on new renewable energy sources and energy self-sufficiency for less developed countries.

Categories of Federally Funded Canadian Nitrogen Fixation Research

Appendix I. Short term basic research projects

Category	Institution
A. Environmental Factors influencing legume growth and nitrogen fixation	
1) Impact of air pollutants	U. of Guelph (G. Hofstra)
2) Impact of pesticides	London Res. Inst. (C.M. Tu) C.B.R.I. (J.C. Sirois, E. Peterson, R. Miller)
3) Role of total nitrogen cycle, denitrification and related processes	Macdonald College (R. Knowles)
4) Irrigated culture, alfalfa	Swift Current (V.O. Beiderbeck)
5) Soil environment, nutrition and microfloral competition	Laval U. (LaChance) C.B.R.I. (R. Miller, E. Peterson, S. Lesley) Beaverlodge (W.A. Rice)
B. Enhancement of legume nitrogen fixation through identification, screening, selection, and control of inoculant rhizobia	
1. Identification of rhizobia	C.B.R.I. (S. Lesley, E. Peterson)
2. Rhizobium strain selection and screening for improved nodulation and nitrogenase activity. Research on inoculant testing.	U. of Manitoba (K.W. Clark) Ste. Foy (L. Bordeleau) C.B.R.I. (J.C. Sirois, S. Lesley, E. Peterson) Beaverlodge (W.A. Rice) Swift Current (V.O. Biederbeck) Lethbridge (R.J. Rennie)
C. Legume breeding and nitrogen fixation	
1. Physiological criteria for host selections in rhizobia-legume systems	C.B.R.I. (F.D.H. Macdowall, J.C. Sirois) Harrow Res. Sta. (B. Buttery)

Category	Institution
2. Alfalfa breeding	O.R.S. (M. Faris)
3. Soybean breeding	O.R.S. (H. Voldeng)
4. Alfalfa improvement for Eastern Canada	Ste. Foy
D. Role of symbiotic nitrogen fixation in forest ecology	
1. Forest biomass production	Laval U. (J.A. Fortin)
2. Nitrogen fixation in angiosperms	Dalhousie U. (D.G. Patriquin)
3. Nodule development and morphology in angiosperms	Queens U. (W. Newcomb)
E. Associative symbiosis, grasses and wheat	
1. Interaction of wheat lines with *B. polymyxa*	Lethbridge (R.J. Rennie)
2. C_3 grasses	Dalhousie U. (D.G. Patriquin)
3. Prairie grasses	Lethbridge (R.J. Rennie)
F. Nitrogen fixation by free living organisms	
1. Evaluation of contribution of bacteria and algae in high arctic ecosystem	U. of Guelph (D.C. Jordan)

Appendix II. Long term basic research

Category	Institution
A. Increase in energy supply for support of symbiotic nitrogen fixation	
1. Analysis of energy supply in legumes	Queens U. (D.T. Canvin)
2. Analysis of mode of utilization of energy by bacteroid nitrogenase systems	C.B.R.I. (R. Miller)
	P.R.L., N.R.C., Saskatoon (J. Child)
3. Relationship between photosynthetic capacity and nitrogen fixation	Harrow Res. Sta. (B. Buttery)
	C.B.R.I. (F.D.H. Macdowall)
4. Genetic system for recycling hydrogen gas as an energy source for enhanced nitrogen fixation	C.B.R.I. (R.M. Behki) Carleton U, (V.M. Iyer)
B. Regulation of nitrogen fixation in legumes	
1. Role of soil nitrogen and ammonia	U. of B.C. (J.K. Gordon)
	C.B.R.I. (F.D.H. Macdowall)
2. Genetic regulation, phenotypic expression and control nitrogen fixation	McGill U. (D.O.S. Verma)
	U. of Newfoundland (A.K. Bal)
	U. of B.C. (F.B. Holl)
	Macdonald College (H.M. Schulman)
	C.B.R.I. (R.M. Behki)
C. Genetic manipulation of genes for nitrogen fixation	
1. Isolation and characterizations of Nif genes in rhizobium	Carleton U. (V.M. Iyer)
2. Transfer of legume genes to other plant species	Lady Davis Res. Inst. (H. Schulman)
D. Nitrogen Fixation in Algae and free-living bacteria	
1. Regulation of nitrogen fixation in blue green algae	U. Montreal (R.J. Cedargreen)
2. Transfer of rhizobia DNA to *A. vinelandii*	U. of Alberta (W.J. Page)

PHOSPHORUS EFFICIENCY IN CROPS
Paper by R.J. Soper

Al AND Mn TOXICITY IN ACID SOILS
Paper by P.B. Hoyt

Rapporteurs' Report

F.R. Bidinger and F. Kishk

Summary of the Problems

A. The Phosphorus Problem

1. Most soils of the world are P-deficient. Crop production is limited by P availability. This is very true for the SAT.
2. P-fertilizers are costly and beyond the reach of the small farmer in low-input farming systems.
3. P-fertilizers are very inefficiently utilized due to losses through fixation and immobilization in the soil. It is estimated that only about 10% of added P is utilized by the crop and the rest is only very slowly available.
4. There is a need to reduce the requirement of crops for added P and/or increase the efficiency of fertilizer P-uptake.

B. The Al and Mn Toxicity Problem

1. In acid soils Al and Mn can reach toxic levels and become a limiting factor for crop production.
2. There are both direct effects of acidity on plant growth and indirect effects due to reduction in availability of various elements, mainly phosphorus.

The Approach

A. Acid soils must be treated as such:

1. Expensive inputs such as liming and high rates of soluble P application cannot be considered in marginal low-input farming systems.

2. Breeding for tolerance to acidity, including Al and Mn toxicity, and for the ability to obtain nutrient elements from acid soils, is a more realistic approach.

3. Utilize the natural soil acidity to transform cheap sources of P such as untreated Rock-P or partially treated Rock-P to soluble P.

4. Encourage microbial action to improve P supply to crops (mycorrhizae).

B. Calcareous Soils:

1. Select and breed for crops that flourish under calcareous conditions.

2. Select plants that are more efficient in utilizing available soil P.

3. Improve placement methods of added P-fertilizer.

4. Encourage microbial action.

5. Develop methods to retard the immobilization of added P.

Areas where research by Canadian Institutions and Universities may be of importance.

A. Exploitation of within-species differences in the capability to take up phosphorus from soil with low phosphorus status and/or a high phosphorus fixing capacity.

1. Investigation of physiological and morphological factors related to differences in phosphorus uptake capability.

2. Development of methods of breeding for improved phosphorus uptake capability, including both rapid screening methods and breeding methodologies appropriate to the problem and the crops of interest.

3. This research should be directed both to improving the utilization of native soil phosphorus as well as the utilization of small to moderate applications of fertilizer phosphorus to the crop in question or to a preceeding crop in the rotation.

B. Exploitation of within-species differences in tolerance of high levels of Aluminium and Manganese in acid soils.

1. Basic research on the mechanisms by which some species or cultivars are able to tolerate levels of Al and Mn which are toxic to other species or cultivars.

2. Development of methods for breeding for improved tolerance to high levels of Al and Mn in the crops of interest in those areas where the problems occur.

C. The role of mycorrhizae in phosphorus and minor element nutrition of crops of importance to the SAT and the Mediterranean regions.

1. Basic research on the ways in which mycorrhizae enhance phosphorus and minor element uptake in the crops and soils of interest.

2. Studies on the interactions of crop species, soil chemical and physical characteristics and mycorrhizae species under field conditions.

3. Evaluation of the utility of innoculation with mycorrhizae strains other than those existing in the soil at present.

4. Depending upon the findings in the above research areas, research in the production and utilization of mycorrhizae innoculum in the SAT and Mediterranean regions.

D. Improvement in the efficiency of utilization of fertilizer phosphorus in the soils of the SAT and Mediterranean regions.

1. For basic and alkaline soils, research on methodology of placement, fertilizer amendments, etc., to improve the availability and uptake of soluble phosphate fertilizer.

2. For acid soils: research on methods of improving the utilization of rock phosphate through low cost treatment of the rock phosphate and methods of application to individual crops and crop sequences.

3. Basic research on the possibility of modifying the crop to increase its uptake of fertilizer phosphorus in both acid and basic soil conditions.

E. Evaluation of the possibility for selecting or breeding native or weedy species already possessing adaptation to problem soil conditions, particularly as forage and "bush fallow" crops.

<u>Institutes where work on soil P is in progress</u>

<u>Universities</u>

Alberta
Saskatoon
Manitoba
Guelph
Laval

<u>Agriculture Canada</u>

Lethbridge
Brandon

NOTE: i) Research projects should be multidisciplinary dealing with the soil and the crop.

ii) Joint efforts between Canadian institutions and developing country institutions would be necessary.

Phosphorus Efficiency in Crops

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Symposium on Canadian Agricultural Research Priorities

Introduction

The purpose of this report is to outline areas of research in phosphorus nutrition which would be useful to developing countries of the semi-arid tropics and to Canada.

It has long been recognized that most soils of the world are phosphorus deficient and hence maximum or even modest production of food crops cannot be achieved without the addition of phosphorus in some form. In spite of the fact that phosphorus has received a great deal of research attention, it is still true that the chemistry of phosphorus in soils and its mode of uptake by crops is only poorly understood. Extension people around the world recognize the need for phosphorus fertilization, but are at times reluctant to recommend phosphate to farmers of developing countries because the price is prohibitive or it may not be readily available. To help overcome phosphorus deficiency as a limitation to food production, we must either diminish the needs of crops for added phosphorus or greatly increase the efficiency of fertilizer phosphorus uptake.

A. Soil Phosphorus

Plants absorb soil phosphorus from the soil solution. The amounts of phosphorus contained in the soil solution are extremely small; with plant growth these amounts must be frequently replenished. Unless the soil has been manured or treated with phosphate fertilizer, this supply is usually not enough for adequate plant growth. Plant species differ in their abilities to extract phosphorus from the soil solution. These differences have been partially explained through variations in root morphology such as root radius, root length, root surface/shoot mass ratio and root hair density. Physiological characteristics of the root are also important in the kinetics of phosphorus uptake. In addition roots may influence the chemical processes in the soil and hasten the dissolution of the solid-phase soil phosphorus. Differences among crop cultivars have also been reported. Maize cultivars, for example, have shown wide differences in physiological and morphological root characteristics that have resulted in differential uptakes of phosphorus. Researchers have developed models which predict the uptake of phosphorus by considering soil parameters as well as root morphology and physiology. From their work, it appears that genotypes could be developed or selected that would be more efficient in absorbing phosphorus from soils. Plant breeders all too often do not look at plant roots; it is, of course, much easier to observe the above-ground portion of crops. Also, selections are usually made on soils having adequate available phosphorus and hence the plants may be quite inefficient with regard to phosphorus uptake.

Infection of several species of crops by mycorrhizal fungus has been shown to increase the uptake of phosphorus, copper and zinc. This increased uptake is considerably greater in phosphorus deficient soils. The mycorrhizae form a symbiotic relationship with the plant by invading the roots. Although the root is invaded, portions of the mycorrhizae remain outside. All the mechanisms by which the mycorrhizae aid in phosphorus nutrition are not known, but results suggest that mycorrhizal plants are better able to exploit soil phosphate and utilize sparingly soluble sources. Usually it is considered that the mycorrhizal infection acts only to extend the root system beyond the root hairs. It is also possible that mycorrhizal infection increases the desorption or solubility of phosphate, thus increasing the labile pool. Direct evidence for the latter is however lacking.

Although the mycorrhizal effect of plant nutrition has not been fully explored evidence is accumulating that mycorrhizae may be quite important in phosphorus uptake by plants. The addition of phosphorus decreases the effectiveness of mycorrhizae, but the effect has been shown to persist up to reasonably high rates of added phosphorus. Mycorrhizal infection has been shown to increase the availability of rock phosphate.

Mycorrhizae also aid in the uptake of zinc and copper. A reduction in infection due to the addition of phosphorus has been shown to reduce the uptake of zinc and copper, thus explaining in part the negative interaction which often occurs with added phosphorus and the uptake of zinc and copper.

Mycorrhizal infection is a natural condition of most plant species and thus it has been difficult to demonstrate yield responses to the introduction of new strains in the field. In the laboratory, however, some introduced strains have proven to be more efficient than indigenous fungi. Also there have been promising results from Saskatchewan. Workers there achieved increases in yield and phosphorus uptake by field grown fababeans by inoculating the soil with Glamus morsae. Much research remains to be done, but it is possible that one day crops may be inoculated with mycorrhizal fungi to supplement indigenous populations and reduce the need for fertilizer.

B. Fertilizer Phosphorus

Water soluble phosphate fertilizers react very quickly in moist soils to form less soluble compounds. With time these reaction products become more insoluble and unavailable. Due to the low solubility of these compounds, phosphorus does not readily move in the soil, but is concentrated around the point of application. The availability of the added phosphorus depends upon the nature of the phosphate fertilizer, the characteristics of the soil and the species of plant.

Plant species vary greatly in their abilities to respond to the addition of phosphate fertilizer. Although the uptake of phosphorus by plant roots is complex, it has been shown that two factors are important:

(a) the ability of roots to absorb phosphorus per mass of roots,

(b) the quantity of roots in contact with added phosphorus.

Four crops commonly grown in western Canada were shown to vary greatly in their abilities to extract added phosphorus per gm of roots (Table 1). The same crops were shown to differ also in the percentage of roots in the fertilizer reaction zone (Table 2). Field results indicated that rape and buckwheat responded quite well to the addition of phosphorus on phosphorus deficient soils while wheat had a variable response and flax did not respond at all. These responses were in keeping with the data in Tables 1 and 2.

Use was made of these findings to design placements of phosphorus which would be advantageous for flax. It was found that when flax roots were forced through a fertilizer reaction zone, thereby increasing the percentage of roots in contact with the fertilizer, the uptake of P was substantially increased and flax increased in yield. As flax has a tap root, it was reasoned that if phosphorus were placed directly below the seed this might be a practical way to increase the quantity of roots in the fertilizer reaction zone. This treatment was tried in the field by several Prairie workers and indeed flax responded to phosphorus quite well where it formerly had not.

Soybeans have roots which resemble those of flax in their uptake of phosphorus. Work in Manitoba demonstrated that they too responded to phosphorus when it was placed directly below the seed, but not when varying amounts were mixed in the surface of the soil. In a growth chamber the depth of placement was found to be quite critical. Changing the placement from 2.5 cm below the seed to 5 cm reduced the uptake of added phosphorus by 60 percent.

These data serve to demonstrate the importance of studying the roots of plants if effective work is to be done with phosphate fertilizer. Plant breeders could also take note and select plants with more efficient roots for fertilizer phosphorus utilization. To my knowledge very little has been done in this regard.

There has been an increased interest in rock phosphate or modified forms of rock phosphate as a direct source of phosphorus for crops. There are many techniques to assess the availability of phosphorus in rock phosphate, but the task is complicated since the sources are different chemically, the speed of reaction of rock phosphate varies with the soil type, and plant species are able to extract different amounts of phosphorus. Research at I.A.E.A. in Vienna has lead to techniques using P^{32} which can assess the effectiveness of rock phosphate versus soluble phosphate without the necessity of yield responses. Using this technique the ability of plant species to utilize rock phosphate can be determined. Placements and the residual effects of rock phosphate can also be evaluated.

C. <u>Proposed Research Areas Within Canadian Capability.</u>

Significant research projects could arise from the areas of phosphorus nutrition discussed in this report. Cooperation between Plant Scientists and Soil Scientists would be required. All institutions in Canada that have soil sections have done significant work in phosphorus and hence there is a good potential for future studies. An assessment of the capabilities of institutions to conduct the plant science aspects of phosphorus nutrition is better left to someone else.

Table 1. Apparent rates of phosphorus absorption.

Crop	P Applied	Rate of P Absorption mg P/g root/day
Flax	none	0.32
	DCPD*	1.88
Wheat	none	0.41
	DCPD	5.23
Rape	none	0.21
	DCPD	4.44
Buckwheat	none	0.24
	DCPD	15.50

*Dicalcium phosphate dihydrate.

Table 2. Proportion of flax, wheat, rape and buckwheat root system recovered from a simulated phosphorus reaction zone.

Soil and Crop		% of Total Roots Recovered from a Simulated Fertilizer Reaction Zone	
		No Applied P	DCPP* Applied
Firdale	Flax	1.5	2.1
	Wheat	1.6	2.9
	Rape	2.1	8.1
	Buckwheat	2.4	5.5
Lakeland	Flax	0.7	1.2
	Wheat	0.6	1.5
	Rape	1.9	4.9
	Buckwheat	1.6	2.5

*Dicalcium phosphate dihydrate.

MEASUREMENT OF TOXIC ALUMINUM (Al) AND MANGANESE (Mn) IN ACID SOILS AND SELECTION OF TOLERANT CROP STRAINS

by PAUL B. HOYT

Introduction

The need for adapting plants to tolerate adverse soil conditions has become an accepted view. Viets (1977), in a bicentennial paper presented before the Soil Science Society of America, pointed out this need as one of the major concerns for future research. It is recognized that toxic Al and other adverse soil conditions can not always be corrected by the technology of costly inputs. This is especially true in the Developing Countries.

In the Peace River region of northern Alberta and British Columbia, crop growth is adversely affected by soil acidity on about 30% of the land (Hoyt et al. 1974). Adapting the crops to the acid soils will be necessary until lime becomes available at reasonable costs and so the problem is somewhat similar to that in the semi-arid tropics (SAT).

Toxic quantities of Al and Mn are probably the major causes of damage to crops in acid soils. Some crops are susceptible to toxic Al but not to toxic Mn, while other crops may be susceptible to Mn but not to Al. Also, Al and Mn in soil are not always closely related to soil pH or to one another. Hence, accurate measurements of both soil Al and Mn are essential in order to choose and adapt crops and cultivars that are tolerant to them.

Measurement of Toxic Al and Mn

Basic work on the lime potential and associated properties of acid soils has received much attention by the Soil Research Institute in Ottawa (for example, Turner and Clark 1965). Using this basic research for background, Hoyt and

Nyborg (1971) at the Beaverlodge Research Station developed a practical method for the simultaneous extraction of Al and Mn from acid soils. Later, Hoyt and Webber (1974), while at the Soil Research Institute, improved on the speed of this method, and also found that it has wide application to soils from across Canada. Although Canada is in the forefront on this research, measurement of soil Al as a criterion for damage to crops and need for liming is receiving attention elsewhere, for example, the use of exchangeable Al for assessing liming needs on Oxisols (Reeve and Sumner 1970).

At the Beaverlodge Research Station, there are ongoing long-term field experiments on relating crop responses from lime to toxic Al and Mn in the soil. At the Summerland Research Station, in the Okanagan Valley of B.C., toxic Al and Mn are being measured to help sort out the harmful effects of soil acidity on production of tree fruits.

Selection of Tolerant Crop Strains

Genetic control of Al tolerance is possible. One major dominant gene controls Al tolerance in certain barley populations and at least one degree of Al tolerance is also probably under one gene in certain wheat populations (Foy et al. 1978). However, the genes controlling Mn tolerance are much more complex. Selection procedures for tolerant species and cultivars to Al and Mn have been investigated by Foy and Associates in the U.S.A. Wheat cultivars are being bred for Al tolerance for extensive areas in Brazil. CIMMYT has a program to transfer Al tolerance of certain low yielding weak strawed wheats into high yielding disease resistant semidwarf bread wheats (CIMMYT Review 1979). This is being expedited by shuttle breeding (two crops per year) between CIMMYT in Mexico and several research organizations in Brazil. Also, triticale x bread wheat crosses are being used to transfer triticale's Al tolerance into wheat. By 1978, considerable success was reported for both approaches.

In the 1950's and 1960's, selection of tolerant crop strains to Mn toxicity was made in Quebec and selection of tolerant barley varieties to Al toxicity was made in New Brunswick, but little further work has been reported from there. The Beaverlodge Research Station has done considerable agronomic work on the selection of acid soil tolerant species of forage grasses and legumes and of grain crops (Elliot et al. 1973; Hoyt et al. 1974). Twenty barley cultivars are currently being compared on acid and non-acid soils at three sites in the Peace River region, and some cultivars are showing better acid soil tolerance than others (Faris et al. 1980). Also, a long-term program at the Beaverlodge Research Station has been in effect to select acid tolerant strains of *Rhizobium meliloti* bacteria for nitrogen fixation in Alfalfa and Sweet Clover (Rice 1977). From 100 "isolates" obtained from alfalfa plants growing on acid soils, two strains were selected and released for inclusion in inoculants sold in western Canada for alfalfa and sweet clover.

Future Research

Until infrastructure is developed for supplying cheap sources of lime, the approach for farming acid soils in the Peace River region and elsewhere on the Great Plains of western Canada will be one of selecting and adapting species and cultivars. Even when the soils are limed to where toxic Al and Mn are eliminated in the topsoil, acidity in the subsoil could cause poor root growth because of toxic Al, in which case, tolerant cultivars would still have an advantage.

The methods for measuring soil Al and Mn should be further examined. There is need to resolve which is the better way of measuring toxic Al, whether it should be measured on the cation exchange sites or in solution (such as that extractable by dilute calcium chloride). This will require basic research in both physical chemistry and soil-plant relationships. Also, because Mn availability is governed by a complexity of soil parameters and therefore ideal measurement made difficult, comparisons of methods and development of new ones should be pursued. The results of this research on measuring Al and Mn should have broad application and especially in SAT where the physical chemistry of the soils is probably similar to that of soils in western Canada.

The genetic control of tolerance to Al and Mn has received little attention in Canada. New research on genetic control would have benefit in the Peace River region and elsewhere on the Great Plains, and the techniques developed in such research could easily be applied to soils of the SAT.

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APPENDIX

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INTEGRATED PEST MANAGEMENT (IPM)
R.M. Prentice

Rapporteurs' Report
H.C. Weltzien and A.D.R. Ker

1. General

Integrated pest management is an organized approach to crop protection. It aims at the application of all existing knowledge on pest-host relationship, population dynamics or eqidemiology; agronomy and crop physiology; resistance breeding; biological and chemical control.

Remarkable progress has been made by Canadian researchers during the past decade in developing practical IPM systems. Alfalfa is an outstanding example for forage as well as seed production. In cereals, grasshopper and leaf beetle (Qulema) management is quite advanced. The IPM system is particularly applicable to fruit tree orchards and vegetable and greenhouse crops.

2. Possibilities in the Semi-Arid Tropics

The technology of IPM is production specific for a given agroecological environment. It cannot be transferred in toto. However its elements are transferable, especially the basic methodology.

The potential application of IPM under the production conditions of less developed countries must be judged with caution. Wherever a fast increase in food production has the highest priority, direct control of major pest, diseases and weeds become necessary. However this should be with careful attention to already identified hazards which seriously threaten food quality, human health and environmental stability.

A high priority therefore must be given to quantitative pest, disease and weed surveys, to identify the organisms which deserve attention first. Monitoring of population dynamics and epidemiological studies should follow for those organisms with high frequencies and a wide distribution. If possible, economic thresholds of major pests should be determined in order to judge when centrol action is required.

The available pesticides also need careful screening for their relative efficacy under given production conditions. This may involve biological activities and side-effects, toxicity, prices, mode of application and fitness for a given socioeconomic situation.

In general, IPM as a principle can be introduced to developing countries in a step by step procedure and all conventional pesticide use should be undertsood and interpreted as the first step in this direction.

3. Recommendations

Areas requiring work (roughly in order to priority) are:

A. Regular and timely monitoring of insect pests, diseases and vertebrate pests.

Examples

Legumes:	Sitona	Cereals:	Stem borer
	Aphids		Saw flies
	Leaf Miner		Birds
	Rodents		Rodents
	Birds		

B. Integrated pest management systems for:

Orchard crops - citris, olives, pistachios, deciduous fruit such as apples, pears, peaches, and apricots

Grain legumes - Alfalfa

Sorghum & maize

Oilseed crops

Cereal/legume mixtures and rotations

C. Improved pesticide selection and application including:

Selectivity	Timing	Assessment
Persistance	Dosages	
Toxicity	Form of application	

D. Resistance breeding:
By priorities
Identification of causes and resistance
Competition to weeds

E. Biological control:
Enclosed environments
Reforestation programs
Introduced plant species
Introduced pests or weeds (cassava mealy bug and mites)

It is recognized that integrated pest management is a highly site specific system. Nonetheless, there are certain research areas where cooperation between Canadian and developing country or international centre researchers would likely prove fruitful.

1. Assistance in the application of monitoring methods which are now well worked out in Canada (for example: pheromone and other trapping technology and the development of keys for disease identification some of which are now in world wide use).

2. Basic research on pest organisms which are common to Canada and the SAT such as Sitona beetles, faba bean aphids and certain stem nematodes. In particular it was suggested that a significant Canadian contribution might be the compiling of a worldwide inventory of parasites of greenhouse pests. It is recognized that IPM systems for greenhouses are to a considerable degree independent of the environment in which they are placed and are therefore transferrable in large measure as complete systems.

3. Most important perhaps would be basic research in breeding for resistance to pests and in the physiology of such resistance.

INTEGRATED PEST MANAGEMENT
IN AGRICULTURAL CROPS IN CANADA

A review paper prepared for Tripartite
(U.S., U.K., Canada) discussions on
research in Agriculture

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Research Branch
Agriculture Canada
May 23, 1980

C O N T E N T S

(i) SUMMARY

Integrated pest management (IPM) is the combined use of chemical, biological, cultural and genetic methods for effective and economical pest control with a minimum effect on non-target organisms and the environment. This is a concept that is now accepted in Canada as a practical approach and is gaining momentum particularly in dealing with insect pests of agricultural crops.

This report is a status statement on programs being carried out by the Research Branch, Agriculture Canada. It includes a review of basic research underway on a variety of control techniques and IPM programs being developed or in place for pests of a number of agricultural commodities.

Although many of the IPM programs are still heavily dependent on chemical pesticides substantial gains have been made in reducing the amounts of pesticides required to bring insect pest losses to acceptable economic injury levels. This is particularly true in the area of orchard crops.

Several areas of basic research on control methods and techniques are identified that would benefit by closer international cooperation. Although there has been collaboration between workers in Canada and the United States there would be advantages to more formal consultation and communication in specific program areas.

1. INTRODUCTION

The purpose of this report is to review the current status of research and development on integrated pest management of insect pests of agricultural crops in Canada. The report has been prepared in response to a recommendation advanced at the December 1979 Tripartite Meeting of senior representatives of federal agricultural research in the United Kingdom, United States and Canada. The recommendation called for each country to prepare a position statement on the status of integrated pest management as a basis for promoting more effective cooperation and interplay in problem and program areas common to the three countries.

The following report is intended only as a status statement on Canadian programs being carried out by the Research Branch, Agriculture Canada, some of which are in cooperation with Canadian universities. The report falls into three sections. The first dealing with basic research underway on component techniques and control methods applicable to integrated pest management. The second section deals with IPM programs in place and accepted by producers as well as programs in various stages of development. These are arranged in order of agricultural crops. The last section deals with areas of research and development that would benefit from closer cooperation between research scientists in the United Kingdom, United States and Canada. The recommendations for the most part were advanced by lead scientists of the Research Branch in key areas of research and development of integrated pest management systems.

The final appendix is a computer print-out of Research Branch projects related to control programs. The print-out identifies the name and location of scientists involved and serves as reference for further contact and communication between workers in Tripartite countries.

2. CONTROL METHODS AND TECHNIQUES

Integrated pest management (IPM) is a control system that utilizes all suitable methods and techniques in as compatible a manner as possible to maintain pest populations at levels below those causing economic losses. It involves the use of a combination of techniques such as natural population controls, chemical pesticides, autocidal control, attractants, etc. against a firm background of the population dynamics of the pest involved. Basic research is underway in Canada on specific control methods and techniques that may form component parts of control systems. The following section is a brief review of research being carried out by Research Branch, Agriculture Canada. Included is a statement dealing with weed control which forms a part of the total Canadian program on biological control.

2.1 Biological Control of Insects

Classical biological control wherein parasites and predators are introduced to control accidentally introduced agricultural pests has been an important component of pest control programs in Canada since the turn of the century. Control attempts have been directed at 40 insect species and partial or full success has been recorded for 10 of these. Two major reviews of the Canadian experience have been published. The first covered the period up until 1958[1] and the second the period 1959-1968[2].

Europe has been the source of most accidentally introduced foreign insects, and biological control through the introduction of control agents has required close collaboration with European workers. The principle agency involved in the Canadian program is the Commonwealth Institute of Biological Control, a unit within the Commonwealth Agricultural Bureau. The program has been

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[1] 1962. A Review of Biological Control Attempts Against Insects and Weeds in Canada. Tech. Commun. No. 2. Commonwealth Inst. of Biol. Control. Commonwealth Agr. Bur. Farnham Royal, Bucks, England.

[2] 1971. Biological Control Attempts Against Insects & Weeds in Canada 1959-1968. Tech. Commun. No. 4. Commonwealth Inst. of Biol. Control. Commonwealth Agr. Bur. Farnham Royal, Bucks, England.

centred for the most part at the Delémont Station, Switzerland. Biological control attempts have involved a careful study of control agents operating against the target pest in Canada and a survey of natural enemies operating against the pest in Europe that may be candidates for introduction. After careful screening both in Canada and Europe species are selected for introduction released in Canada with follow-up surveys for establishment and effectiveness.

It is generally conceded that during the early years introduction programs were poorly planned with no firm basis for follow-up and assessment. During the late 1940's and early 1960's, when synthetic pesticides became available in large quantities, biological control interests and programs were neglected. With current concerns over the widespread use and reliance on chemicals for insect control more emphasis is being placed on alternative methods including classical biological control. The increased emphasis on integrated pest management has been in part responsible for a revitalized interest for research in this area. Introduction of biological control agents can now be reviewed and considered as a component of a pest management system with a somewhat firmer basis for selecting introductions, understanding their interactions with other components of control and assessing their establishment and effectiveness.

Currently, Canadian biological control efforts are directed against eleven agricultural pests. The species involved and the current status of programs are outlined in Appendix 1.

2.2 Biological Control of Weeds

Biological control of weed species in Canada has met with considerable success. However, the program has been limited to weeds that occur in forage and rangeland areas that can not be economically controlled by chemicals or other means. To date 32 plant-feeding insect species have been introduced, mostly from Europe, against 17 species of weeds. Over 50 per cent of the introduced insects have become established and large regional reductions have been recorded for *Carduus nutans*, nodding thistle; *Hypericum performatum*, St. John's wort; *Senecio jacobaeae*, tansy ragwort; *Linaria vulgaris*, yellow toadflax; and

Cardius acanthoides, welted thistle. Also there has been an estimated 90 per cent reduction in seed production of Centaurea diffresa; Centaurea diffusa and Arcium vulgare.

It is mandatory that any agent introduced for biological control of a weed is narrowly host specific so that it is not a threat to cultivated crops. Most of the Canadian introductions have been from Europe where the same arrangements exist for cooperative studies with the Commonwealth Institute of Biological Control as with parasite introductions for insect pests. Of the 30 species released in Canada to date none have moved to alternate host plants or had any serious side-effects on non-target host plants.

The Canadian program is closely coordinated with that in the United States to assure approval of both countries before release of an introduced insect, avoid possible conflict of interests and expedite the use of the control agent in both countries.

The current status of active Canadian projects on biological control of weeds is outlined in Appendix 2.

2.3 Insect Pathogens

The potential for the use of insect pathogens as biological control agents has been recognized since the turn of the century. Despite their potential the Canadian experience in their use as applied control agents has not been particularly encouraging although some excellent basic research has been carried out on these materials. Pathogens now being studied and tested as control agents include bacteria, protozon, viruses and fungi.

Two formulations of Bacillus thuringiensis (Thuricide HPC and Dipel HD-1) have been tested, evaluated and registered for use in Canada. Although their major use in agriculture has been for control of cabbage looper and cabbageworm attacking cruciferous crops they are also used for control of lepidopterous pests on tomato, celery, spinach and tobacco. It has been recently demonstrated that formulations of the bacterium in combination with low dosages of chemicals is extremely effective and less costly.

Certain protozoa, particularly microsporidia, have shown promise and several species are now being tested and evaluated. Nosema locustae has shown potential as a control agent in reducing grasshopper populations in western Canada. It is an obligate parasite of most economic species of grasshoppers but is non-infectious for most other insect and vertebrates. Field tests, which are, in part, an extension of trials in the United States, have resulted in a 60 per cent population reduction with a significant reduction in eggs laid by surviving numbers. Nosema pyraustae a microsporidian disease of corn borer is being tested in eastern Canada and shows some potential as a control agent.

Several insect viruses attacking agricultural pests have been identified, tested and evaluated in Canada with encouraging results. Three nuclear polyhedral viruses have been shown to be extremely effective in control of cabbage looper and a granulosis virus of codling moth is known to have considerable potential as a control component of integrated pest management.

The fungus Entomophthora phytonomi is known to be a highly contagious disease affecting alfalfa weevil that has been known to decimate populations of this species and terminate outbreaks. The potential of the disease as an applied control alternative is now under study but the fungus has been found extremely difficult to culture and mass produce under artificial conditions.

The most serious obstacle to the use of insect pathogens as control agents is the problem of registration. Of the pathogens discussed above only two formulations of Bacillus are now registered in Canada. Canadian registration requirements for pathogens under the Pest Control Products Act are still not clearly defined and at present health authorities are seeking additional safety data for even the Bacillus formulations. This is in contrast to attitudes in the U.S. where EPA is tending to streamline procedures for registration of insect pathogens.

2.4 Insect Pheromones and Attractants

Synthetic pheromones or attractant blends have been developed and field tested for 15 lepidopteran field crop pests in Canada. Most of the basic research in this area is being carried out at the Lethbridge Research Station with field experiments and testing of material at various research stations across the country.

The prime initial use of sex pheromones in pest management will be for monitoring the population density of specific insects as a basis for control decisions. Procedures have been worked out for the codling moth in apple orchards and field testing programs are underway with other lepidopteran species to correlate pheromone trap collections with probable population levels. The objective is to develop reliable models for forecasting abundance of these species.

Control of field crop pests by pheromone mating-disruption has not been evaluated in Canada and it is generally felt that control of sporadic pests over extensive agricultural areas may not be feasible. Control by mass trapping may be possible for pests on small acreages and it has been shown to be of some value for codling moth in apple orchards in British Columbia.

Pheromone chemicals or blends are not commercially available in Canada and chemical companies have been reluctant to get into production of these materials for either monitoring or control. At present most of the pheromone blends for experimental work in Canada are being produced at federal laboratories. A pheromone trap manufacturing company has been established at Saskatoon and considerable research is being done on trap designs for monitoring.

Registration of pheromones under the Pest Control Products Act is not required in Canada when the chemicals are used for monitoring purposes, but registration will be required if they are to be used for control applications. Registration regulations need to be carefully considered and the requirements should be rather different than those for chemical insecticides since the same chemicals are used for many of the pheromone blends as opposed to every insecticide being structurally different. The question of pheromone registration should be given international consideration and hopefully it will not be a limiting factor in the development of control programs.

2.5 Autocidal Control

Three agricultural insects the codling moth, cattle grubs, and onion maggot have been the principal targets for research and development on autocidal control in Canada. Work on the codling moth is well advanced but is still in the developmental and testing stage for the other two species.

Research on autocidal control of codling moth has been underway at the Summerland Research Station since the late 1950's. Initial research was on mass rearing and sterilization techniques and the results of that work have been well publicized. Mass rearing and sterilization facilities were established at Summerland in the early 70's by the federal and provincial governments. Between 1972 and 1978 excellent control, bordering on extinction of codling moth, was achieved in approximately 625 hectares of apple and pear orchards in the Similkamaeen Valley in south-central British Columbia. The control strategy was to reduce codling moth populations as low as possible with cover sprays of azinphos-methyl and the following year release sterile moths starting at blossom time to mid-September. The rate of release was such that the ratio of wild male moths to sterile male moths was greater than 1:40. Repeating this release pattern for two or three consecutive years resulted in almost complete elimination of the codling moth. No further controls for codling moth were required for an additional two years following the release program.

Despite the initial success of the sterile moth program in British Columbia there are still major problems to be overcome. There is a serious problem in controlling granulosis virus in rearing colonies, and this has added substantially to the cost of sterile moth production. Also an economic evaluation of the program shows the cost of the sterile moth method is about $250 per hectare compared to $100 per hectare for control by the conventional pesticide application. Producers are reluctant to accept the cost differential and the future of the sterile moth approach rests on a substantial reduction in cost to producers either through government subsidies or through more economical methods for producing and distributing sterile moths.

Work is underway at the Lethbridge Research Station to test and evaluate sterile male releases in integrated pest management of warble flies on cattle. These insects have adapted to minimize the impact of systemic insecticide and thus allow for survival of substantial numbers in the host animal following treatment. The sterile male release principle was adapted to supplement insecticidal treatment and determine the possibility of totally eliminating grub populations. A pilot study on a 225 km^2 ranch containing about 5,000 cattle has shown considerable promise. Cattle grub populations were reduced to base line levels after 3 years treatment with systemic insecticides. This was followed by 2 years of insecticide treatment and sterile male releases that eliminated cattle grub in the study area. This study has not progressed sufficiently to judge acceptance by producers. A joint Canada-U.S.A. project is now being planned to determine the effectiveness and economic evaluation of integrated cattle grub control along the Canadian-U.S.A. border.

Research over the past 5 years at the London Research Institute indicates that the sterile male technique may be feasible for control of onion maggot. Through research funds provided by the government of Ontario, the University of Guelph is constructing rearing facilities that will produce 300,000,000 sterile male onion maggots a year. Operational field trials will be initiated over the next three-year period.

2.6 Chemical Control

Chemical insecticides have proved to be Canada's most effective method in terms of application, cost and flexibility in handling outbreaks of agricultural insects. Without these materials at a time when alternatives to chemical control are still very much in the developmental stage effective crop protection from insect attack may be in serious jeopardy.

The statement is often made that the supply of new pesticides is diminishing due to restrictive legislation resulting from environmental and health concerns. It is probably truer to state that while the overall number of new materials may not have decreased drastically, there has been a shift in emphasis to satisfy major market requirements. Thus herbicides are a growth area while new fumigants, seed dressings, and soil and animal insecticides have been slow growth areas.

From the point of view of the pesticide manufacturer this is not too surprising since an economic return must be obtained for the time invested (7-9 years) and the costs involved ($10-15 million) in the development of a new material. Thus the emphasis has been on developing broad spectrum pesticides for use on major market areas such as cereals, cotton and rice.

Despite our reliance on chemical insecticides the Canadian market is relatively small and with the exception of cereals we are looked on as a minor user of insecticides. Economically it does not pay the manufacturer to carry out the work required for minor use registration and much of the data have to be generated by the Research Branch, Agriculture Canada. Thus a very substantial component of the Canadian program on crop protection relates to the insecticide evaluation process by developing data on efficacy, crop safety and environmental impact of candidate materials and new uses of registered products. Restrictive legislation leads in many cases to excessive demands for data to satisfy real and imagined environmental and health concerns. These requirements have evolved over the years and are aimed at present day control chemicals. If these same requirements are applied to new generation chemicals required for IPM, difficulties may be encountered with their registration. Such difficulties have already been encountered in Canada with regard to the registration of bacterial and viral control agents. Since pesticides will continue to play an important role in IPM programs, it is essential that realistic, flexible guidelines and protocols be developed for the registration of new materials with regard to their intended use.

It would be unwise, however, to place all our trust in present day chemical controls. Manipulation and monitoring of pest populations by a variety of chemicals can be envisaged in the future, dictated by the needs of IPM programs. These will include pheromones, chemosterilants, repellents, attractants, etc. Apart from these more obvious examples one can foresee new, specific chemical control methods being developed based on a fundamental knowledge of the biochemistry and physiology of the pest. For example a unique enzyme has been isolated at the London Research Institute which is involved in the grasshopper molting process and is only present in quantity at this stage of the life-cycle. The possibility of chemical control by inhibition of this specific target site is readily apparent. These and other avenues of research offer exciting possibilities for the future in which chemicals used in IPM programs will be applied with finesse rather than the shotgun approach largely employed at present.

3. STATUS OF INTEGRATED PEST MANAGEMENT PROGRAMS

In this section, brief descriptions are given of the IPM programs currently in place at various research Stations across Canada. All of these aim to develop interactive systems that combine biological, biochemical, and cultural control methods to reduce reliance on chemical pesticides. In some cases, the level of sophistication and activities in technology transfer are already high. In other cases, developmental aspects are still being worked out. Not surprisingly, the character and scope of the programs vary greatly in their attempt to satisfy the regional nature and diverse needs of Canada's agricultural industry.

Threshold densities have been established for most pests. As a rule, monitoring programs are in place to detect economic infestations and the timing of control actions (cultural or chemical) is relayed to producers on the basis of degree day summations. In some cases, computers are used to receive and transmit population forecasts on a wide-area basis, and pest and/or crop models are used to optimize crop protection. Occasionally, trained field scouts are used to monitor and communicate pest information. Parasite release programs are underway at several locations and in some cases, detailed population dynamics studies have been carried out to pinpoint manipulative key factors in the pest's life system.

Stations supporting IPM programs reported in the following section are as follows: Summerland (fruit pests), Lethbridge (forage and animal pests), Saskatoon (forage and cereal pests), Winnipeg (oilseed and storage pests), Harrow (greenhouse pests), Delhi (tobacco pests), Vineland and London (fruit and vegetable pests), Ottawa (cereal, forage, and greenhouse pests), St. Jean (fruit pests), Fredericton (vegetable pests), and Kentville (fruit pests).

3.1 Forage Pests

At the present time, alfalfa is the only forage crop under pest management in Canada. In eastern Canada where the crop is grown mainly for forage purposes, the alfalfa weevil, *Hypera postica* is the most common and destructive pest. In western Canada where alfalfa is grown for seed production the alfalfa weevil, the pea aphid, *Acyrthosiphon pisum* and several species of plant bugs, *Lygus* spp., *Adelphocoris* spp., and *Plagiognathus medicagus* are all important pests.

Forage alfalfa

Following its discovery in Ontario during the late 1960's, populations of the alfalfa weevil increased at an alarming rate. Damage reached its peak in 1974 when the combination of unusual spring temperatures and record weevil populations resulted in a multi-million dollar loss of alfalfa. Farmers in the dairy-intensive Bay of Quinte area, and in parts of western Ontario, were hardest hit.

Following its spread to the Quinte area, populations of the weevil increased geometrically for 4 successive years. However, in 1973 this pattern was abruptly halted by a disease that attacked and killed the larvae and cocooned stages. The pathogen was identified as *Entomophthora phytonomi*, a fungus new to the insect in North America. In 1974, weevil populations peaked in most fields throughout the Quinte area. The first general decline was noted in 1975 and by 1976 its numbers had dropped to a manageable level.

Since 1976 weevil populations have been constrained at a density close to the economic threshold. But the fungus is not perfectly compensating in its action and this imposes population oscillations that periodically exceed the damage threshold and growers must constantly be on the alert for sudden population flareups. However, in the past 3 years the adult weevils have been increasingly attacked by *Microctonus aethiopoides*, a European parasite released in southern Ontario during the early 1970's. Studies have shown that this parasite is well adapted to eastern Canada and is highly compatible with the fungus organism since it attacks only those individuals that survive disease in the juvenile stages.

Since 1972, studies at the Ottawa Research Station have focused on weevil population dynamics and construction of ecological life tables. This has resulted in a mathematical model that demonstrates the role of intrinsic and extrinsic factors in causing seasonal and annual changes in the species population. Validation and refinement of the model is underway.

At every opportunity, Ontario growers are reminded of the delicate population balance that exists between the weevil and its biocontrol agents, and all action-decisions stress the minimal use of chemicals as a population suppressant. Thus, in economic situations, early harvest is the recommended control practice since this will kill the weevil larvae without disturbing its natural enemies. However, in some years, warm and dry weather in early spring brings the weevil out of hibernation ahead of schedule. This type of weather also slows down the alfalfa so that when the insects are at their worst, the crop is too immature to be cut. In this case, chemical treatment is the only option.

To minimize the danger of unnoticed early attacks, heat unit models have been developed for both the insect and crop, and during the forage season temperature data are brought in on-line from 5 representative areas of Ontario. When used in concert with trend forecasting from the life tables and sequential decision sampling to pinpoint economic pockets of infestation, these data have permitted the development of a grower alert system which is tied into a weekly radio advisory for the Quinte area. At present the advisory is limited to this area but owing to its popularity it is hoped to extend it to other parts of the province in the near future.

Alfalfa seed production

In western Canada, alfalfa is grown for seed production. With proper crop pest and pollinator management, yields in excess of 1100 kg/ha have been recorded in southern Alberta. However, yields may be considerably reduced by a complex of insect pests that includes the alfalfa weevil, the pea aphid, *Acyrthosiphon pisum*, and several species of plant bugs, *Lygus* spp., *Adelphocoris* spp., and *Plagiognathus medicagus*. To counter this difficulty, the Lethbridge Research Station in cooperation with the Alberta Government, Newell County, and a number of seed growers initiated an IPM program in 1978. Students were hired as scouts to systematically survey for pests and beneficial insects during the months of May through August. Weekly population counts were plotted to depict population trends for each participating grower. This enabled him to make more effective control decisions and to schedule pesticide applications to coincide with the vulnerable stages of the pest, while not endangering non-target species. A phenology model has also been devised as an early-warning device to alert the pest manager to initiate intensive sampling operations.

This program has been well received and in 1979 it was expanded from 1350 to 1820 ha. For 1980 the projected increase will be an excess of 2400 ha. Because of grower confidence, the IPM-initiated insecticide recommendations are followed more readily and this has resulted in reductions in the cost of insecticide application.

At the Saskatoon Research Station in Saskatchewan, control programs recommended for plant bugs utilize cultural and chemical practices. Burning alfalfa stubble and harvesting debris in early spring before growth starts destroys the eggs of Adelphocoris and Plagiognathus, and promotes general field sanitation. However, the effect of spring burning on natural enemies of plant bugs and general insect fauna of alfalfa has not been investigated.

Saskatchewan growers are encouraged to sample their crop to determine population levels of pest insects as the season progresses. The economic threshold population of plant bug nymphs is 5 nymphs per sweep of either species, alone or mixed. This is the minimum population at which economic seed yield increases have been demonstrated and is offered as a guideline only.

In fields that have been burned, sampling can be delayed until the alfalfa is well into the bud stage. However, in fields not burned, sampling must begin at bud formation. At infestation levels in excess of the threshold, a "clean-up" application of insecticide is recommended. This controls the active stages, provides a residual toxicity of about 5 days to kill hatching nymphs, and suppresses populations of the pea aphid. Aphid control is desirable because populations of parasites and predators destroyed by the clean-up treatment require about 2 weeks to begin recovery and omission of an aphicide in the 'clean-up' mixture can result in severe aphid infestations later in the season. A single, properly-timed application of a recommended insecticide can provide season-long protection even in regions of the prairie provinces where some of the plant bug species are bivoltine. Where controls are necessary for alfalfa in bloom, the choice of insecticides is limited to those that are not toxic to pollinators or can be applied so as not to pose a hazard to them.

3.2 Cereal Pests

Grasshoppers in Western Canada

Grasshoppers are the principal pests of prairie-grown spring wheat. Scientists at the Saskatoon Research Station are developing a grasshopper IPM system with 3 major components: 1) grasshopper dynamics, 2) crop dynamics, and 3) crop protection optimization. Weather-driven models are being developed for each. For this purpose, the province has been divided into several areas based on climatic conditions and soil capability. From May to October, daily weather data from 18 weather stations in Saskatchewan are updated weekly. Several weather variables are created to determine various biological events.

Oviposition and grasshopper hatch are interdependent and rely on the distribution of adults of the previous generation. The egg development sub-model estimates development per day based on soil moisture availability as well as accumulation of heat units. The moisture threshold for egg development varies in relation to soil type and is usually the same as the wilting point of a particular soil. Nymphal development is a function of temperature alone. A simulation model is being developed to determine the sensitivity of different variables (biotic and abiotic) that affect survival of nymphs and adults. Studies are also in progress to determine how food consumption and oviposition are affected by temperature and grasshopper density.

Annual surveys provide essential information on adult population density and distribution of the 4 major species in Saskatchewan. These are generally conducted in August but must be timed for peak occurrence of adult grasshoppers. In late fall, a forecast is made on the potential of grasshopper infestations for the following year in the province so that control plans can be made if necessary. An egg survey during early October helps to confirm the density levels measured during the adult survey and also provides information on the distribution of egg development before freeze-up as well as the parasitism of egg populations in different areas of the province.

A growth model for spring wheat that estimates development through time is being developed to assess partitioning of dry matter of different plant components (e.g. leaves, stems and heads) under different temperature and soil moisture conditions and also yield loss from various levels of defoliation due to grasshoppers.

To optimize crop protection, a series of equations is being developed to describe the dynamic changes in grasshopper populations through time as a combined function of abiotic and biotic factors, components of the crop system, and management decisions.

Crop damage is closely related to the state of growth and the response of host plants when grasshoppers are feeding. Therefore, the temporal synchrony between grasshopper incidence and the developmental stage of crops as well as degree of water and nutrient stress are the determinants of the effect of feeding on crop yield. The management objective for grasshopper populations depends on the concept of economic threshold which is defined as the minimum grasshopper density at which an insecticide treatment is justified if marginal revenue equals marginal costs.

An information delivery system has been initiated as an alert mechanism to the growers. This is comprised of maps and reports showing the distribution of egg hatch and nymphal development and hence, the damage potential throughout Saskatchewan. These are updated weekly throughout the growing season. Information on wheat phenology, growth, aspects of economic decisions, and strategies will ultimately be included.

Cereal leaf beetle

In eastern Canada, the cereal leaf beetle, *Oulema melanopus*, constitutes the major threat to cereal grains. An introduced pest, it first reached economic status in southern Ontario during the early 1970's. In 1975, life table studies at the Ottawa Research Station and extensive population surveys across Ontario showed that *Tetrastichus julis*, a European larval endoparasite of the beetle was widely established throughout the province; dispersal into Ontario was natural and was attributed to extensive colonization of the parasitoid in the midwest United States.

In 1975, overall parasitism in Ontario was 84% and annual surveys have shown it to continue near this rate. Since 1975 only trace populations of the beetle have been found. However, monitoring of the beetle and its parasite will continue on a limited scale at key sites during the next 2 or 3 years. The surveys consist of taking a series of net sweeps. Timing is based on the accumulation of 400-430 degree-days (base 9°C) after April 1, when maximum numbers of third and fourth instar larvae are present.

3.3 Oilseed Pests

Rapeseed, mustard, and sunflower have been grown commercially in the prairie provinces for about 40 years. Rapeseed and mustard are attacked by the flea beetles *Phyllotreta cruciferae* and *P. striolata*, the bertha armyworm, *Mamestra configurata*, the red turnip beetle, *Entomoscelis americana*, and the diamondback moth, *Plutella xylostella*. In addition, general feeders such as cutworms may cause losses. Sunflowers are attacked by several insects, of which the sunflower beetle, *Zygogramma exclamationis*, and cutworms cause the most damage.

Economic thresholds have been developed for most of the insect pests and are being used by growers to reach decisions on the need for chemical control applications. At the Winnipeg Research Station in Manitoba, current research projects on the bertha armyworm, the red turnip beetle, and the sunflower moth seek to establish yield loss over a wide range of pest abundance and to determine the effects of the stage of crop development, pest phenology, and weather on this relationship. Similar research on flea beetles attacking newly-germinated rapeseed is complicated by their habits and small size and the degree of feeding damage to the cotyledons and first true leaves is being examined as an alternative to direct estimates of beetle abundance.

Monitoring methods are in various stages of development and use. Sex attractant chemicals for males of the bertha armyworm, diamondback moth, and sunflower moth are available and currently are being used by provincial extension services to monitor moth abundance. At the same time, scientists at the Station are gathering data on the abundance of the progeny of these moths to develop methods of predicting larval abundance more accurately than at present. For flea beetles, boll weevil traps have been modified to dispense an attractant (allyl isothiocyanate) for use in monitoring populations. Monitoring of the sunflower beetle depends on the ability of growers to find and count ovipositing females and eggs on the young plants early enough in the season to detect economic infestations before damage occurs.

A biological control program against the flea beetles on rape is currently in progress. Following comparative studies of the parasite complex of *P. cruciferae* and *P. striolata* in Manitoba and in Europe, introductions were made of the braconid *Microctonus bicolor*. However, a comparison of the parasite complex of *M. configurata* in Canada and the closely related *M. brassicae* in Europe revealed that their parasites were too similar to warrant introductions from Europe.

Cultural practices, such as fall cultivation, have been shown to reduce survival of the eggs of the red turnip beetle to almost zero and of pupae of the bertha armyworm by more than 50%. At present, most rape fields are cultivated in the fall, but widespread interest among growers in minimum tillage makes it essential to continue studies of the effects of cultivation on pest survival. The possibility of using a trap crop of winter rape around the periphery of a crop of spring rape to attract and concentrate flea beetles when the latter mature is also being tested.

3.4 Orchard Pests

In Canada, research and development of integrated pest management systems for orchard pests has a longer history and has met with more success in terms of producer acceptance than for any other agricultural commodity. Management systems either in place or being developed in the four major fruit growing regions are briefly reviewed in the following section:

British Columbia

Apple and pear production in British Columbia is centred mainly in the Okanagan district in the south-central part of the province. There are approximately 9000 ha of apple and 1500 ha of pear orchards. Individually, the orchards are relatively small, averaging ca 4 ha. Fruit production occurs on alluvial flats and benches in the bottom of long narrow mountain valleys and intensity of pest problems in individual orchards varies from year to year. The approach to the development of IPM programs at the Summerland Research Station has been to devise techniques that will identify and quantify pest populations in small orchards, and relate pest population densities to potential crop damage. Recommendations for chemical control measures are made on the basis of short term predictive or immediate needs.

Monitoring methods include: collection and microscopic examination of fruit spur samples from apple and pear in the dormant period for assessment of European red mite eggs; collection and processing by leaf brushing during the summer season for assessment of European red mite, McDaniel spider mite, apple rust mite, pear rust mite, and pear psylla; visual counts of apple leaf samples during the summer for apple aphid and white apple leafhopper; beating tray limb-tap samples during the blossom period for assessment of leafrollers, green fruitworm, Bruce spanworm, eyespotted budmoth, and *Campylomma verbasci*; collection and processing through a Berlese type separator of blossom clusters from susceptible apple varieties for assessment of western flower thrips; and finally the deployment of sex pheromone traps for assessment of codling moth. The need to apply control measures for San Jose and European fruit scales is determined by assessment of scale on fruit at harvest in the previous year.

Integrated mite control, involving monitoring of the phytophagous species and the predaceous mite, *Typhlodromus occidentalis*, has been widely used by the apple industry for 10 years. A similar program for phytophagous mites and pear psylla on pear has been in use for 5 years. These limited programs have been provided by the fruit packing houses to their cooperating fruit growers at cost; student personnel collect and process the samples, and data interpretation and control recommendations are made by trained fieldmen or government extension specialists. Broader IPM programs, involving a larger number of pest species, have been provided during the past 2 years by independent pest management consultants. Currently, there are 2 of these, with service contracts for 800 ha of apples and pears.

Ontario

Roughly two-thirds of the apple acreage in Ontario is under IPM directed at major pests such as the codling moth, apple maggot, tentiform leaf miner, European red mite, apple scab, and several species of leafrollers. At the Vineland Research Station, located in the heart of the Niagara fruit belt, the activity and abundance of the codling moth and the red-banded and oblique-banded leafrollers are monitored with sex pheromone traps and the apple maggot with chemical attractants. Foliage samples are used to monitor the tentiform leafminer, the European red mite and apple scab, and foliage tapping is used to estimate plum curculio and plant bug populations. Forecasts of insect activity are made using degree-day summations based on developmental threshold temperatures. The basic modified spray program generally uses 4 to 6 insecticide sprays and one miticide spray. Additional sprays may be required, depending on the occurrence of secondary pests. Scab control is based on monitoring spore release in the orchard and the onset of infection periods based on temperature and precipitation. Insecticide use under the program is 40-50% less than conventional protective programs.

An IPM program for peach insect control is well established on the Niagara Peninsula. Principal pests are the oriental fruit moth, which requires repeated chemical controls, peach tree borer, the red mite and various scale insects. The oblique-banded leafroller and comstock mealybug are troublesome in some areas, while the tarnished plant bug and the plum curculio occur periodically in sufficient numbers to cause economic injury. The Oriental fruit moth, oblique-banded leafroller, and peach tree borer are monitored by sex pheromone traps, the red mite with foliage samples, and mealy bugs and scales by limb and fruit examination. Foliage tapping is used to monitor plant bugs and plum curculio.

The IPM program for full season peach varieties requires 4 sprays for oriental fruit moth control, but 1-3 additional sprays may be required, depending on the occurrence of secondary pests. Grower acceptance of the program has been excellent and implementation is mainly a provincial responsibility.

The European red mite is monitored each season on different tree fruits and at different locations. For this purpose, a predictive system has been developed to warn growers of sudden mite buildup and of optimum spraying periods. The system is based on computer runs of a simulation model developed at the Station and in 1979 it was accurate for a one-week trial period in different climatic areas of Ontario.

Quebec

Apple production in Quebec is largely confined to the southwest corner of the province within 80 km of the city of Montreal. Using day-degree summations, scientists at the St. Jean Research Station monitor most of the major pest species to predict seasonal emergence trends. Insect bait traps and sex pheromones are placed in representative orchards, and captures of the following pests are related to injury and pesticide treatment levels: the codling moth, *Laspeyresia pomonella*, the redbanded leafroller, *Argyrotaenia velutinana*, the lesser appleworm, *Grapholitha prunivora*, the fruit tree leafroller, *Choristoneura rosaceana*, the tarnished plant bug, *Lygus lineolaris*, and the green fruitworm, *Orthosia hibisci*. This is an expanding program aimed at reducing pesticide loads by 20%.

Nova Scotia

Apple production in Nova Scotia is centred in the eastern end of the Annapolis Valley where there are approximately 4500 ha grown mostly in small orchards 2 to 12 ha in size. At the Kentville Research Station, pest management procedures have been developed for 5 major groups of pests. These stress the use of narrow-spectrum chemical sprays, low dosages of broad-spectrum chemicals, removal of wild or derelict trees, and encouragement of parasites and predators. Monitoring methods include trapping of adults using baits and pheromones for the winter moth and codling moth, examination of twig and leaf samples for mites, coloured bait traps for apple maggot flies, and visual counts of scale insects on fruit. Selection of pesticides is based on a detailed knowledge of toxicities to the different orchard faunal components, optimum timing of sprays to avoid non-target organisms, and minimal dosages of chemicals. Most Nova Scotia growers accept the IPM concept and make day-to-day control decisions that favour preservation of beneficial arthropod species in their orchards.

3.5 Vegetable Pests

Potatoes

Three-quarters of Canada's potato crop is produced in Eastern Canada. The major potato pest species are late blight, Phytophora infestans, potato leaf roll virus (PLRV), potato mosaic virus (mostly PVY), green peach aphid, Myzus persicae, potato aphid, Macrosiphum euphorbiae, and buckthorn aphid, Aphis nasturtii.

At the Fredericton Research Station in New Brunswick, a forecasting service for late blight has been developed for the Maritime Provinces to aid growers in timing the application of fungicides. In 1979, weekly bulletins were released, based on a computerized forecast using temperature, humidity, rainfall and disease data collected from 8 monitoring stations. The data were relayed by telephone to network headquarters, the forecast determined, and relayed back.

The New Brunswick pest management program reflects the dual role of aphids as plant feeders and vectors of PLRV and PVY. In the Field Monitoring Service, table stock and processing potatoes are examined in the field weekly from the time of emergence to top kill. Numbers of aphids and the percentage of plants infested are recorded. In these same fields plant quarantine officials determine the incidence of disease (PLRV, PVY, and others) early in the season from foliage symptoms, a reflection of the quality of seed planted. Tubers are lifted at different times during the growing season and after harvest to determine the time of introduction and amount of current season disease infection. Supplementing these data, populations of the Colorado potato beetle, Leptinotarsa decemlineata, and the potato flea beetle, Epitrix cucumeris, are recorded because some control practices for these allow aphid populations to increase. In 1979, collections of the parasites and predators of potato insects were made at all stations to assess their value as management agents. Fifty-six growers were monitored in this manner in 1979.

In the Aphid Warning Service yellow water traps are used to attract and monitor the flight of aphids into potato fields. The objective is to recommend dates to kill down the above ground parts of the potato plant (top kill) based on the in-flights of *M. persicae* and to prevent it from transmitting PLRV to the crop.

Traps were operated at 131 monitoring stations in 1979. Once green peach aphid flights begin, each grower operator receives a weekly print-out of a density map depicting the potato growing area along the Saint John River, the green peach aphid flights taking place, and the probability of PLRV spread. Computer print-outs are sent weekly to each co-operator. These record the results of his trap catches and field counts. When insect populations are critical, direct contact is made with the grower by telephone or in person. Radio and television releases warn the grower population at large.

Other vegetable pests

Production of fresh market and processing vegetables is an important component of Canadian agriculture. In Ontario, more than 71,000 ha of vegetables are grown each year with a value in excess of $180 million. Major pests are the European corn borer, cabbage caterpillars, root maggots, carrot rustfly, Colorado potato beetle, and several species of cutworms and aphids. Based on research centred at the Vineland Research Station, monitoring programs are in place or under development for the carrot rustfly, carrot weevil, leaf blights, and the six-spotted leafhopper, which transmits aster yellows disease to carrots and other crops.

The major thrust of IPM research for vegetable pests in Ontario has been directed towards the onion maggot. This insect causes annual losses in excess of $4 million and is resistant to most organophosphorus and carbamate insecticides. Research over the past 5 years at the London Research Institute in laboratory and small-scale field trials indicates that the sterile male technique is feasible and in cooperation with the University of Guelph, a program aimed at mass production and release of sterile males has been initiated. In addition, several insect growth regulators with potential for onion maggot control have been identified.

3.6 Tobacco Pests

Annual production of tobacco in Canada ranges from 38,000 to 52,000 ha, and 90% of the crop is grown in Ontario. Major insect pests include the darksided cutworm, *Euxoa messoria*, the green peach aphid, *Myzus persicae*, and the tomato hornworm, *Manduca quinquemaculata*.

At the Delhi Research Station, monitoring and economic threshold data have been developed for the 3 species. For *E. messoria*, which attacks the young transplants, the hatching rate of overwintered eggs is determined in the spring at intervals from late March to mid April. When 85% of the eggs have hatched, the rotation rye crop is treated with a pesticide to minimize the invasion of tobacco by migrating larvae. After transplanting (late May to mid June), the crop is regularly checked for feeding injury and cutworm larvae in the soil near the plants. Chemicals are applied if there are 2 or more cutworms per 100 plants, or 5% of the transplants are severely damaged.

For *M. Persicae*, which is a multivoltine sporadic pest, population influxes are detected by counting alates in water traps set in the field. To monitor densities of the feeding stages, plants are checked at regular intervals from late May to late July. Chemicals are applied if 20% of the plants have 5 or more aphid colonies on the underside of each upper leaf.

For *M. quinquemaculata*, which is mostly univoltine and winters as a pupa in the soil, early detection methods involve the capture of moths in light traps. Larval densities are monitored from mid-July to mid-August. Chemicals are applied when 5 or more 'large' (> 3 cm) larvae are found per 100 plants.

Chemical insecticides have been and will continue to be an essential part of tobacco crop protection, and they will also play an important role in future IPM programs. Consequently, research in evaluation of insecticidal control of insect pests in tobacco has been directed toward the more effective and safe materials. For example, the broad-spectrum pyrethroids, permethrin and cypermethrin, are non-hazardous and have been registered for both preplanting (on the rye cover crop or soil surface) and postplanting control of cutworms. In addition, 2 commercial preparations of *Bacillus thuringiensis* are as effective as chemical insecticides for control of the hornworm.

3.7 Greenhouse Pests

The greenhouse environment is particularly favourable for use of IPM programs. At the Harrow Research Station, practical applications have been developed and present research is aimed at providing a complete range of compatible insect and disease control mechanisms with empahsis on biological control. In southwestern Ontario, the parasite *Encarsia formosa* is widely used for the control of the greenhouse whitefly *Trialeurodes vaporariorum*, on tomatoes and cucumbers. Production of the parasite is sponsored by the growers through their Marketing Board and by the Ontario Ministry of Agriculture and Food. Commercial production of *E. formosa* is on a small scale but may be expanded in 1980 through a federally sponsored COPI (Co-operative Project with Industry) grant. The recent registration of permethrin for control of the whitefly has caused some growers to revert to chemical control but because of its high cost it is expected that knowledgeable growers will continue to use biological control.

Control of the two-spotted spider mite, *Tetranychus urticae*, on greenhouse cucumbers by the predaceous mite *Phytoseiulus persimilis* is effective during the spring months on commercial crops but it appears that temperature and humidity conditions in June are not favourable for the predator. For example, the opening of greenhouse vents reduces the humidity and *P. persimilis* eggs do not hatch. *P. persimilis* is being propagated commercially on a small scale and sales are increasing. Control of the mite by chemicals is unreliable because of resistance patterns which vary greatly between greenhouses. Furthermore, few miticides are registered for greenhouse use.

At the Ottawa Research Station, 5 components, each of which restrict pest development to a limited degree, have been used to develop a management program for the whitefly on poinsetta. These are: a) selection of partially-resistant host plants, b) the chalcid *Encarsia formosa*, c) the selective insecticides, methoprene or potassium oleate, d) trap plants -- selected for enhanced attractiveness to adult whitefly -- these are soil-drenched with Orthene, and e) the fungicide, Truban, applied as a soil drench. Under this system only 2 applications of the selective insecticides are necessary in an 11- or 12-week period. In addition, the number of black scales (host pupae parasitized by *E. formosa*) per leaf are reduced to an acceptable level.

Control of pests on long-stemmed roses is based on maintaining the pests and their natural enemies on the lower half of the plants. Component control methods are as follows: a) two-spotted mite -- the plants are sprayed with the selective acaracide at very low dosages and the predator P. persimilis is later released on infested plants. Usually, only one spray is necessary in a 26-week period, but in some cases the predator is eliminated following drastic reduction in prey density by the natural enemy. Hence, a second release of the natural enemy and/or additional applications of the acaricide may be required. An improved method of rearing and handling the predator is being developed, b) aphids -- Pirimor is the standard selective aphidicide but strains of the yellow rose aphid, Aulacorthum porosum, resistant to Pirimor are sometimes encountered. When this occurs it is necessary to spray the upper half of the plants with potassium oleate and the bottom half with household detergent, c) greenhouse whitefly -- E. formosa combined with sprays of potassium oleate to the upper half of plants will control whitefly, d) thrips -- spraying with potassium oleate as above and soil drenches of the insecticide Sevin will control thrips. The latter will also control sow bugs.

3.8 Animal Pests

Two research programs related to integrated management of animal pests are underway at the Lethbridge Research Station in Alberta which is the main centre for research and development in this area.

Cattle grubs

In warble control programs in western Canada, area-wide, legislated use of systematic insecticides by cattle farmers and ranchers has significantly reduced populations of the cattle grubs, Hypoderma bovis and H. lineatum in recent years. However, light infestations still persist. Studies have identified natural mortality in the young warble larvae migrating within the host as a density-dependent key factor, which functions to stabilize grub populations by limiting excessive increase and by permitting greater survival at low population levels. Thus, the pests are adapted to minimize the impact of systemic insecticides which are aimed at this stage. In addition, a pattern of pupal development in the spring that concentrates the emergence period of flies and reproductive behavior that aggregates the flies at special mating sites combine to aid in survival and recovery of a population reduced by insecticides. Hence, an integrated approach to management of these pests was indicated.

In 1971, the sterile male release principle was chosen to supplement insecticidal treatment in a pilot study to determine the possibility of eliminating the grub populations. The location was a semi-isolated commercial ranch of 80 sq mi (225 km) containing about 5,000 cattle, whose young stock were known to be heavily infested. Using the legislated treatment program using systemic insecticides, grub populations were reduced to baseline levels by 1974. Then, continued treatment with the systemics coupled with sterile male releases of *H. lineatum* completely eliminated that species on the ranch within the next 2 years. It has not been found since that time, though parts of the herd have not been treated since 1976. During the study period, *H. bovis* populations, subjected only to insecticidal treatment, maintained their low levels and then increased slightly when parts of the herd were not treated. On neighboring ranches, both species of warble flies survived in low numbers despite continuous systemic treatment. Present activities, aimed at eliminating *H. bovis* by sterile male releases, are now entering a second annual release season.

Larval infestations are monitored in late February and early April, timed to measure peak numbers of grubs of the 2 species. Upwards of 1200 young cattle are sampled on the ranch, from which all grubs are squeezed out for species determination. On neighboring ranches 300-500 young cattle are similarly sampled. Degree of sexual sterility for each batch of sterile males released is assessed by mating and egg incubation tests in the laboratory.

Black flies

Black flies are a long-standing prevalent problem for livestock producers in northerly agricultural areas of Canada. Extensive outbreaks on farms cause losses in reduced growth and gain in weight of beef cattle, mortality among newborn calves, sterility in bulls, delayed conception in cows, reduced milk in dairy herds, and generally interrupt calving and grazing schedules so that pastures are underutilized. Losses and the expense of protective husbandry are a major economic factor in all but the smallest production units, and they are the most important obstacle to northern expansion of the livestock industry.

Detailed surveys have shown that more than 90% of attacks on cattle and horses during the most damaging outbreaks are by black flies of one species, *Simulium arcticum*.

Sources of development of this pest are confined to large drainage systems such as the Athabasca and Saskatchewan Rivers from which emerging adults are capable of dispersing for distances of at least 150 km to invade farms. Although outbreaks may be effectively reduced by treatments of these breeding areas by pesticides such as methoxychlor, the threat of pesticidal damage to complex aquatic ecosystems has prevented its official registration for use in abatement operations.

Led by scientists at the Lethbridge Station, a 5-year interagency and interdisciplinary study was completed in 1977 to develop and evaluate treatment of breeding sources of S. arcticum with methoxychlor as an essential part of an integrated pest management program for the Athabasca River in northern Alberta. The program was designed to synchronize limited use of methoxychlor with the phenology of the aquatic ecosystem. Analysis of chemical residues in water, bed load, and delta deposits within the hydraulic model of the river has shown no significant hazard of pesticidal pollution in the applied design of treatments.

Pest management operations were defined in an initial complete survey including identification, distribution, and production of flies from breeding sites in the river. A standardized monitoring system with artificial substrates employed for 8 weeks following the breakup of ice in spring provides the decision-making indices on potential development of pest outbreaks for the implementation and optimum scheduling of annual pest management programs.

A pest management program was initiated under contract in 1979 with registration of methoxychlor for use according to specifications established for the hydraulics of the Athabasca River. At the present stage of development it is designed to reduce the impact of black fly outbreaks on farms by at least 70%. Provision is made in the program for addition of other components such as repellents, resistant breeds of cattle, and modified livestock management to alleviate the lesser but broader impact of various species of biting flies on farms. The present program is in demand by the livestock industry because the cost is less than 20 cents per head. The benefit/cost ratio of the program to livestock producers in terms of previous annual losses is estimated to be more than 30:1 for average infestations, and is much higher during severe outbreaks.

3.9 Storage Pests

Storage pests are a long-standing problem in Canada and research on pest management is centred at the Winnipeg Research Station in Manitoba. The program recommended to the grain industry has consistently been a management program involving the judicious use of various pest control techniques selected on the basis of experience and circumstances under which they will be used. The first step involves monitoring populations to determine the species and extent of infestations. Samples are obtained from farms, primary elevators, and terminal elevators. Trouble spots such as crusted grain, and where high temperatures or off-odours are detected are checked regularly. Empty granaries are cleaned to remove residues of dust and infested grain. Grain spills are disposed of since they are potential sources of infestation. Limits of temperature and moisture content are prescribed for safe storage of grain and insecticides are recommended for treatment of empty grain storages. Fumigants are recommended to control established infestations of pests in granaries.

Traps have been tested for more sensitive detection of low density populations as well as more refined sampling procedures. Berelese-Tullgren funnels are used in the laboratory to extract insect larvae from samples for more accurate determination of population levels.

A number of synthetic growth regulator compounds are being studied and evaluated in control programs. Pheromones are being isolated, identified, and synthesized in the laboratory. When available in sufficient quantities, active components will be field-tested in grain storages. Locomotory and feeding behavior of stored product insects and their response to moisture and volatile compounds of micro-organisms are also under investigation.

4. COOPERATION BETWEEN TRIPARTITE COUNTRIES

The preceding sections reviewed the Canadian position in terms of research and development of insect control methods and techniques and IPM systems either in place or at various stages of development. Following are some specific program areas that would benefit by closer collaboration and interplay between Tripartite countries. They are advanced here as a basis for review and discussion by the Tripartite executive.

4.1 R&D in Control Methods and Techniques

Biological control

Many of the insect and weed species affecting agricultural production in Canada and the United States have been accidentally introduced from Europe. Both countries carry out biological control programs involving the introduction of control agents. Although there have been informal arrangements for cooperation on these programs there would be advantages to a more formal Tripartite working group that would establish common protocols and guidelines for the introduction of biological control agents and arrange for timely exchange of information. This committee would also serve to consider the feasibility of sharing common facilities and services for overseas exploration and screening of candidate material for introduction in cooperation with the U.K. and the institutes of the Commonwealth Agricultural Bureau.

Registration of biocides

Registration requirements for insect pathogens as a control alternative in pest management have still to be clearly defined for Canada and the United Kingdom. At present only formulation of the bacterium, *Bacillus thuringiensis* have been registered although several viruses, fungi and protozoa show considerable promise. Registration requirements are more clearly defined in the United States and the Environmental Protection Agency is attempting to streamline registration procedures. Virus formulations for cotton boll worm, trussock moth and gypsy moth as well as a protozoa (Nosema sp.) for grasshopper control are now registered and available for use on an operational scale. Although several international agencies are seeking to develop common standards and protocols for registration of insect pathogens, there would be advantages to a smaller working group within Tripartite countries. Such a group could also ensure more effective coordination of costly programs aimed at gathering efficacy and safety data as a basis for registration of these materials.

Insect pheromones

All Tripartite countries are involved in research related to the isolation, identification and synthesis of insect pheromones and attractants for use in pest management programs. Some target pests are common to two or more member countries and there would be benefits from closer collaboration and interplay between scientists. Pheromone chemicals and blends are not commercially available in Canada and facilities for commercial production are limited in both the U.S. and U.K. With the impetus towards integrated pest management programs the question of supply and demand should be reviewed with the aim of encouraging commercial production on a scale that would assure future demand for operational programs. Registration of pheromones is not required in Canada when they are used for control applications. Registration requirements should be carefully considered at an international level.

4.2 Integrated Pest Management Programs

Many of the IPM programs discussed in Section 3 of this report are aimed at target pests common to both Canada and the United States. Although there has been close collaboration between workers on both sides of the border in developing control programs for most of these species, there may be advantages to more formal consultation and communication. An area of particular interest to Canada is technology transfer of integrated pest management principles to the producers. The Canadian experience indicates some reluctance on the part of growers to accept integrated pest management as an alternative to tried and proven techniques. A review and appraisal of government sponsored pilot demonstration and incentive programs may be of interest to all Tripartite members.

Canadian Biological Control Programs Currently Underway Against Agricultural Insect Pests

Target Pest	Introduced Parasite (s)	European and Canadian Surveys	Cooper-ation with USDA	Degree of Success
Adelphocoris lineata, alfalfa plant bug		X		
Agriotes obscurus, dusky wireworm		X		
Agromyza frontella, alfalfa blotch leafminer	*Dacnusa dryas* *Chrysocharis punctifacies*		X	established not recovered yet
Cerapteryx grominis, an antler moth		X		
Dasineura mali, apple leaf midge	*Platygaster* species "A" *Inostemma contariniae*	X		
Entomoscelis americana, red turnip beetle		X		
Hypera postica, alfalfa weevil	*Microctonus aethiopoides*		X	complete control in some areas
Lithocolletis blancardella, an apple leafminer	*Apanteles pedius* (ex New Zealand)			established
Lygus lineolaris, tarnished plant bug	*Perilitus digoneutis* *P. stygicus*			not recovered yet
Mamestra configurata, bertha armyworm	*Microplitis mediator*	X		
Oulema melanopus, cereal leaf beetle	*Tetrastichus julis*		X	complete control
Phyllotreta cruciferae, crucifer flea beetle	*Microctonus bicolor*			not recovered yet
Thymelicus lineola, European skipper	*Syspasis scutellator* *Phryxe vulgaris*			not recovered yet

APPENDIX 1.

Canadian Biological Control Programs Currently Underway Against Weed Pests

Target Weed	Survey: Canada	Survey: Overseas	Screening studies	Collecting or rearing for release	Monitoring release
Convolvulus arvensis, field bindweed; *Convolvulus sepium*, hedge bindweed	Complete	USA	USA		
Rhamnus cathartica, buckthorn		Complete			
Taraxacum officinale, dandelion	Complete		Can.		
Centaurea repens, Russian knapweed					X
Centaurea diffusa, diffuse knapweed	Complete	Complete	Can. CIBC		X
Centaurea maculosa, spotted knapweed	Complete	CIBC	CIBC		X
Crepis tectorum, narrow-leaved hawksbeard		OIBC 1982			
Sonchus arvensis, perennial sow thistle	Complete		Can.	Can.	X
Euphorbia virgata? *Euphorbia pseudovirgata*?, leafy spurge	Complete	Complete	Can. CIBC USA	CIBC	X
Senecio jacobaea, tansy ragwort					X

APPENDIX 1.

... 2

Canadian Biological Control Programs Currently Underway
Against Weed Pests (cont'd)

Target Weed	Survey		Screening studies	Collecting or rearing for release	Monitoring release
	Canada	Overseas			
Cirsium arvensis, Canada thistle	Complete	Complete			X
Cirsium vulgare, bull thistle	Complete	Complete			X
Carduus acanthoides, plumeless thistle *Carduus nutans*, nodding thistle	Complete	Complete	USA		X
Hypericum perforatum, St. John's-wort	Complete	Complete			X

The table indicates Canadian studies planned, in progress (X) or completed, studies done by the CIBC with funding from Canada and those done on a cooperative basis by U.S.A.

APPENDIX 2.

APPENDIX 3.

AGRICULTURE CANADA RESEARCH BRANCH

PROJECTS RELATED TO NON-CHEMICAL CONTROL OF INSECTS AND INTEGRATED PEST MANAGEMENT

LIST OF RESEARCH ESTABLISHMENTS

LISTE DES ETABLISSEMENTS DE RECHERCHE

CODES	ESTABLISHMENT NAMES / NOMS D'ETABLISSEMENTS
100	A.C.-R.B. ST. JOHN'S, NEWFOUNDLAND
203	A.C.-R.B. CHARLOTTETOWN, PRINCE EDWARD ISLAND
306	A.C.-R.B. KENTVILLE, NOVA SCOTIA
307	A.C.-R.B. NAPPAN, NOVA SCOTIA
409	A.C.-R.B. FREDERICTON, NEW BRUNSWICK
524	A.C.-R.B. L'ASSOMPTION, QUEBEC
526	A.C.-R.B. LENNOXVILLE, QUEBEC
528	A.C.-R.B. NORMANDIN, QUEBEC
531	A.C.-R.B. LA POCATIERE, QUEBEC
535	A.C.-R.B. ST.-JEAN, QUEBEC
536	A.C.-R.B. STE.-FOY, QUEBEC
610	A.C.-R.B. CHEMISTRY & BIOLOGY RESEARCH INSTITUTE, OTTAWA, ONTARIO
630	A.C.-R.B. LAND RESOURCES RESEARCH INSTITUTE, OTTAWA, ONTARIO
638	A.C.-R.B. OTTAWA RESEARCH STATION, OTTAWA, ONTARIO
640	A.C.-R.B. ENGINEERING & STATISTICAL RESEARCH INSTITUTE, OTTAWA, ONT.
641	A.C.-R.B. THUNDER BAY, ONTARIO
643	A.C.-R.B. DELHI, ONTARIO
644	A.C.-R.B. HARROW, ONTARIO
646	A.C.-R.B. KAPUSKASING, ONTARIO
648	A.C.-R.B. SMITHFIELD, ONTARIO
650	A.C.-R.B. ANIMAL RESEARCH INSTITUTE, OTTAWA, ONTARIO
652	A.C.-R.B. VINELAND STATION, ONTARIO
680	A.C.-R.B. RESEARCH INSTITUTE, LONDON, ONTARIO
690	A.C.-R.B. BIOSYSTEMATICS RESEARCH INSTITUTE, OTTAWA, ONTARIO
695	A.C.-R.B. FOOD RESEARCH INSTITUTE, OTTAWA, ONTARIO
760	A.C.-R.B. BRANDON, MANITOBA
762	A.C.-R.B. MORDEN, MANITOBA
764	A.C.-R.B. WINNIPEG, MANITOBA
870	A.C.-R.B. INDIAN HEAD, SASKATCHEWAN
872	A.C.-R.B. MELFORT, SASKATCHEWAN
874	A.C.-R.B. REGINA, SASKATCHEWAN
875	A.C.-R.B. SASKATOON, SASKATCHEWAN
879	A.C.-R.B. SWIFT CURRENT, SASKATCHEWAN
900	A.C.-R.B. BEAVERLODGE, ALBERTA
905	A.C.-R.B. LACOMBE, ALBERTA
907	A.C.-R.B. LETHBRIDGE, ALBERTA
1002	A.C.-R.B. SUMMERLAND, BRITISH COLUMBIA
1004	A.C.-R.B. VANCOUVER, BRITISH COLUMBIA
1090	A.C.-R.B. AGASSIZ, BRITISH COLUMBIA
1093	A.C.-R.B. KAMLOOPS, BRITISH COLUMBIA
1095	A.C.-R.B. PRINCE GEORGE, BRITISH COLUMBIA
1098	A.C.-R.B. SIDNEY, BRITISH COLUMBIA

NON-CHEMICAL CONTROL OF INSECTS

Note: person-years for each staff member are given in terms of "PROJECT" (person-years for the project as a whole) and in terms of "EFFORT" (person-years within a project allocated for this specific aspect of research)

ESTAB ETABL	PROJECT # # PROJET	PROJECT TITLE TITRE DE PROJET	STAFF PERSONNEL	PERSON YEARS ANNEES-PERSONNES EFFORT EFFORT	PERSON YEARS ANNEES-PERSONNES PROJECT PROJET	KEYWORDS MOT CLE
> 203		DISEASES AND INSECTS OF FORAGE GRASSES	TECH.	0.160	0.800	
			THOMPSON L S	0.100	0.200	
			WILLIS C B	0.000	0.000	
> 203		DETERMINATION OF ECONOMIC LOSSES FROM, AND CONTROL OF, ALFALFA BLOTCH LEAF MINER CAGROMYZA FRONTELLAS IN THE ATLANTIC REGION	TECH.	0.100	0.200	ALFALFA LEAF MINER
			THOMPSON L S	0.200	0.400	
> 203		EFFECTS OF MANAGEMENT ON EUROPEAN CORN BORER POPULATIONS AND EVALUATION OF NEW VARIETIES FOR BORER RESISTANCE	TECH.	0.050	0.100	
			THOMPSON L S	0.050	0.100	
			WHITE R P	0.000	0.000	
> 306		THE SELECTION AND DEVELOPMENT OF INTEGRATED CONTROLS FOR TREE FRUIT PESTS				PESTICIDE TOXICITY PESTS BENEFICIAL ARTHROPODS ORCHARD LABORATORY
			SANFORD K H	0.500	1.000	
			TECH.	0.500	1.000	
> 306		DEVELOP FURTHER PREDICTIVE METHODS FOR APPLE ORCHARD PEST MANAGEMENT				MEASURE PESTS NATURAL CONTROL AGENTS
			MACPHEE A W	0.200	0.200	
			TECH.	0.200	0.200	
> 306		VEGETABLE INSECT INVESTIGATIONS				PEST DETECTION PHEROMONE BLACKLIGHT CHEMICAL CONTROL CLIMATOLOGICAL EFFECTS
			SPECHT H B	0.150	0.300	
			TECH.	0.150	0.300	
> 306	306-78-02	APPLE MAGGOT CONTROL				ARSENICALS ALTERNATIVES SANITATION ECOLOGICAL APPROACH

ESTAB ETABL	PROJECT # # PROJET	PROJECT TITLE TITRE DE PROJET	STAFF PERSONNEL	PERSON YEARS / ANNEES-PERSONNES EFFORT EFFORT	PERSON YEARS / ANNEES-PERSONNES PROJECT PROJET	KEYWORDS MOT CLE
			NEILSON W T A	0.500	1.000	
			TECH.	0.500	1.000	
306		CUTWORM INVESTIGATIONS				TOBACCO MIGRATION PATTERNS BLACK CUTWORM VARIEGATED CUTWORM
			SPECHT H B	0.033	0.100	
			TECH.	0.033	0.100	
306		THE POPULATION DYNAMICS OF WINTER MOTH IN NOVA SCOTIA ORCHARDS				MEASURE POPULATION MORTALITY BIOLOGICAL CONTROL
			MACPHEE A W	0.198	0.600	
			TECH.	0.198	0.600	
306		THE MAINTENANCE OF EFFECTIVE POPULATIONS OF GENERAL PREDATORS OF PESTS IN APPLE ORCHARDS				ACARINA PHYTOPHAGO MITES ENHANCE DENSITY PREDACIOUS SPECIES
			HERBERT H J	0.330	1.000	
			TECH.	0.165	0.500	
409	309-78-04	BLUEBERRY PEST MANAGEMENT				
			TECH.	1.100	1.100	
			WOOD G W	0.800	0.800	
409		THE DISTRIBUTION, ABUNDANCE, HOST RANGE AND FIELD DEVELOPMENT OF POTATO-INFESTING APHIDS IN NEW BRUNSWICK				
			MACGILLIVRAY M E	0.200	0.500	
535		LUTTE INTEGREE CONTRE LES OLETHREUTIDES ET LES TORTRICIDES DANS LES POMMERAIES DU QUEBEC				
			PARADIS R O	0.400	0.400	
535		LUTTE INTEGREE AUX COCHENILLES NUISIBLES AUX VERGERS DU QUEBEC				SUPRACIDE LORSBAN LS68-1323
			BOSTANIAN N J	0.700	0.700	
535						

ESTAB / ETABL	PROJECT TITLE / TITRE DE PROJET	PROJECT # / # PROJET	STAFF / PERSONNEL	PERSON YEARS / ANNEES-PERSONNES: EFFORT / EFFORT	PROJECT / PROJET	KEYWORDS / MOT CLE
	PERTES DE RENDEMENTS CAUSEES PAR PYRALE-FUSARIOSE CHEZ LE MAIS GRAIN					ATRAZINE ALACHLORE
			HUDON M	0.050	0.100	
			TECH.	0.050	0.100	
535	METHODES CULTURALES POUR REDUCTION DES COUTS DE PRODUCTION. AUGMENTATION DE RENDEMENTS AND LUTTE CONTRE LA PYRALE DU MAIS					
			HUDON M	0.050	0.100	
			TECH.	0.050	0.100	
535	ECOLOGIE ET REPRESSION DE LA MOUCHE DE LA POMME					
			RIVARD I	0.400	0.400	
			TECH.	0.400	0.400	
638	INTEGRATED CONTROL OF PESTS ON ORNAMENTAL PLANTS	30121002				PEST CONTROL
			BURNETT T	0.600	0.600	
			TECH.	0.600	0.600	
638	CEREAL LEAF BEETLE					
			GUPPY J C	0.090	0.300	
			HARCOURT D G	0.090	0.300	
			TECH.	0.090	0.900	
638	ALFALFA WEEVIL					
			GUPPY J C	0.280	0.700	
			HARCOURT D G	0.280	0.700	
			TECH.	1.050	2.100	
644	EGG LAYING BY EUROPEAN BORER MATHS ON SWEET CORN AND PEPPERS					PEPPER OSTRINIA MATING OVIPOSITION FLIGHT
			ELLIOTT W M	0.120	0.600	
			TECH.	0.150	0.600	
644	ECOLOGY AND ECONOMIC IMPORTANCE OF THE EUROPEAN CORN BORER. OSTRINIA NUBILALIS (HUBNER) IN FIELD CORN IN SOUTHWESTERN ONTARIO					
			FOOTT W H	0.100	1.000	
			TECH.	0.100	1.000	

ESTAB / ETABL	PROJECT # / # PROJET	PROJECT TITLE / TITRE DE PROJET	STAFF / PERSONNEL	PERSON YEARS / ANNEES-PERSONNES: EFFORT / EFFORT	PERSON YEARS / ANNEES-PERSONNES: PROJECT / PROJET	KEYWORDS / MOT CLE
> 644		BIOLOGY AND CONTROL OF LEAFMINERS ON GREENHOUSE CROPS	MCCLANAHAN R J	0.150	0.500	TOMATO PYRETHROID
			TECH.	0.250	1.000	
> 644		CONTROL OF ECONOMIC DAMAGE CAUSED BY CORN ROOTWORMS ON CORN	SMITH B C	0.750	1.000	CORN ROOTWORMS
			TECH.	0.500	1.000	
> 644		FACTORS INFLUENCING CONTROL OF PIERIS RAPAE AND OTHER VEGETABLE INSECTS BY VIRUSES	JAQUES R P	1.000	1.000	INSECT DISEASES
			TECH.	1.000	1.000	
> 648	3-1-1-9	INTEGRATED PEST CONTROL IN TREE FRUITS	TECH.	0.100	0.200	MONITORING REDUCED SPRAY PROGRAM
> 648	3-1-1-10	MANIPULATION OF ORCHARDS TO FACILITATE THE BEHAVIOURAL AND BIOLOGICAL CONTROL OF APPLE PESTS	TECH.	0.201	0.300	TRAP TREES
> 652	352-75-01	ASSESSMENT OF PEST MANAGEMENT PROGRAMS FOR CONTROL OF PEACH INSECTS	PREE D J	0.300	0.300	
			TECH.	0.300	0.300	
> 652	352-68-05	CHEMICAL AND BIOLOGICAL CONTROL OF PHYTOPHAGOUS MITES ON FRUIT IN ONTARIO WITH SPECIAL REFERENCE TO THE ETIOLOGY OF RESISTANCE AND CROSS-RESISTANCE TO PESTICIDES	HERNE D H C	1.000	1.000	
			TECH.	2.000	2.000	
> 652	352-70-01	INTEGRATED CONTROL OF APPLE PESTS	HAGLEY E A C	1.000	1.000	
			TECH.	1.000	1.000	
> 652	352-70-06	PEST MANAGEMENT IN VEGETABLE CROPS	STEVENSON A B	1.000	1.000	CARROTS
			TECH.	1.000	1.000	

ESTAB ETABL	PROJECT # # PROJET / PROJECT TITLE TITRE DE PROJET	STAFF PERSONNEL	PERSON YEARS ANNEES-PERSONNES EFFORT EFFORT	PROJECT PROJET	KEYWORDS MOT CLE
680	280-73-07 FACTORS INFLUENCING THE EFFECTIVENESS AND PERSISTENCE OF SOIL INSECTICIDES				SOIL INSECTICIDES CARBOFURAN FENSULFOTHION FMC 45498 ONION MAGGOT PERMETHRIN PHORATE PYRETHROIDS TERBUFOS
		HARRIS C R	1.000	1.000	
		TECH.	6.000	6.000	
680	280-71-12 THE IMPROVEMENT OF PEST CONTROL PROGRAMS BY EVALUATING AND PREDICTING THE SPATIAL AND TEMPORAL DISTRIBUTION OF INSECT POPULATIONS				INSECTS PREDICTING POPULATION EUROPEAN CORN BORER PHEROMONES
		MCLEOD D G R	0.900	0.900	
		STARRATT A N	0.100	0.100	
		TECH.	1.500	1.500	
680	280-73-19 CHEMICAL CHARACTERIZATION AND SYNTHESIS OF INSECT BEHAVIORAL AGENTS				INSECTS BEHAVIORAL AGENTS CHARACTERIZATION EUROPEAN CORN BORER PHEROMONES PROCTOLIN ANALOGUES TOBACCO HORNWORM
		MCLEOD D G R	0.100	0.100	
		STARRATT A N	0.400	0.400	
		TECH.	1.400	1.400	
680	280-73-17 APPLICATION OF RADIOISOTOPES AND MASS SPECTHOMETRY TO PESTICIDE STUDIES				INSECTICIDES RADIOISOTOPES MASS SPECTROMETRY METABOLISM CARBOFURAN
		ROBINSON J R	1.000	1.000	
		TECH.	1.000	1.000	
764	INTEGRATED MANAGEMENT OF RAPESEED PESTS				NOCTUIDAE CHRYSOMELIDAE
		LAMB R	0.500	1.000	

ESTAB ETABL	PROJECT TITLE TITRE DE PROJET	PROJECT # # PROJET	STAFF PERSONNEL	PERSON YEARS ANNEES-PERSONNES EFFORT EFFORT	PROJECT PROJET	KEYWORDS MOT CLE
			TECH.	0.250	2.500	
			TURNOCK W J	0.700	1.000	
> 764	PHYSICAL AND CHEMICAL CONTROL OF STORED PRODUCTS INSECTS					VARIOUS PHYSICAL
			TECH.	0.050	1.000	
			WATTERS F L	0.050	1.000	
> 764	BIOLOGY AND CONTROL OF THE RED TURNIP BEETLE					CHRYSOMELIDAE
			GERBER G H	0.330	1.000	
			TECH.	0.330	1.000	
> 764	RELATION OF DENSITY TO ECONOMIC LOSS FOR CLIMBING CUTWORMS ON RAPESEED					NOCTUIDAE
			BRACKEN G K	0.340	1.000	
			TECH.	0.340	1.000	
> 764	INSECT PARASITES OF RAPESEED PESTS					CHRYSOMELIDAE NOCTUIDAE
			TECH.	0.330	1.000	
			WYLIE H G	0.330	1.000	
> 764	PATHOLOGY OF CROP INSECTS					NOCTUIDAE CHRYSOMELIDAE
			BUCHER G F	0.330	1.000	
			TECH.	0.330	1.000	
> 875	STUDIES ON BASIC FACTORS AFFECTING THE PERFORMANCE OF INSECTICIDES					SPRAY DRIFT INSECTICIDES
			FORD R J	0.800	1.000	
			MCKINLAY K S	0.800	1.000	
			TECH.	1.340	2.000	
> 875	CHEMICAL CONTROLS IN GRASSHOPPER AND WIREWORM MANAGEMENT SYSTEMS					CHEMICAL CONTROL GRASSHOPPERS WIREWORMS
			BURRAGE R H	0.280	0.700	
			TECH.	0.938	1.400	
> 875	BIOLOGY OF LEPIDOPTEROUS PESTS OF RAPE, FLAX AND SUNFLOWERS AND THEIR PARASITES					BERTHA ARMYWORM SUNFLOWER MOTH

ESTAB ETABL	PROJECT # # PROJET	PROJECT TITLE TITRE DE PROJET	STAFF PERSONNEL	PERSON YEARS ANNEES-PERSONNES EFFORT EFFORT	PERSON YEARS ANNEES-PERSONNES PROJECT PROJET	KEYWORDS MOT CLE
						FLAX BOLLWORM
			ARTHUR A P	0.100	1.000	
			TECH.	0.330	1.000	
> 987	13000009	TO DEVELOP ENVIRONMENTALLY ACCEPTABLE PESTICIDE CONTROLS FOR CROP INSECTS PESTS				DEPOSITION DRIFT CONTROL EFFICACY
			CHARNETSKI W A	0.500	0.500	
			TECH.	0.200	0.200	
> 987	30000068	CONTROL OF INSECT PESTS OF LEGUME FORAGE CROPS				ALFALFA WEEVIL
			SCHABER B D	0.500	1.000	
			TECH.	0.500	1.000	
> 987	56001010	EVALUATION OF THE STERILE MALE TECHNIQUE FOR CONTROL OF THE COMMON CATTLE GRUB HYPODERMA LINEATUM (DE VILL.)				HYPODERMOSIS CATTLE GRUB
			TECH.	0.400	0.800	
			WEINTRAUB J	0.150	0.300	
> 987	56001013	ALTERNATIVES TO SPRAYING CATTLE TO CONTROL TICK PARALYSIS				BEHAVIOR CULTURES
			TECH.	0.050	0.200	
			WILKINSON P R	0.100	0.400	
> 987	56001015	INVESTIGATIONS INTO ENVIRONMENTALLY ACCEPTABLE METHODS FOR CONTROLLING AQUATIC STAGES OF BITING FLIES AS RELATED TO AGRICULTURAL PRODUCTION				BLOOD SUCKING FLIES FUNGI COELOMONYCES BITING FLIES
			SHEMANCHUK J A	0.200	0.400	
			TECH.	0.250	0.500	
> 987	56001017	IMMUNOLOGICAL ASPECTS OF CATTLE GRUB INFESTATIONS				CATTLE GRUB INFESTATION CIRCULATING ANTIBODY LEVELS ANTIGEN CHARACTERIZATION IMMUNIZATION
			BARON R W	0.125	0.500	
			TECH.	0.000	0.500	
> 987	73054004	IDENTIFICATION AND FIELD TESTING OF SEX ATTRACTANTS OF INSECT CROP PESTS				BEET WEBWORM EUXOA TRISTICULA
			LILLY C E	0.268	0.400	

	ESTAB / ETABL	PROJECT # / # PROJET	PROJECT TITLE / TITRE DE PROJET	STAFF / PERSONNEL	PERSON YEARS / ANNEES-PERSONNES: EFFORT / EFFORT	PERSON YEARS / ANNEES-PERSONNES: PROJECT / PROJET	KEYWORDS / MOT CLE
				TECH.	0.200	0.400	
>	987	77056001	BIOLOGY, ECOLOGY, AND CONTROL OF THE PEA APHID IN ALBERTA	HARPER A M	0.400	1.000	PEA APHID
				TECH.	0.330	1.000	
>	987	77089001	PLANT RESISTANCE TO THE WHEAT STEM SAWFLY, CEPHUS CINCTUS NORT.	HOLMES N D	0.900	0.900	WHEAT STEM SAWFLY
>	987	78009001	IDENTIFICATION, SYNTHESIS, AND FIELD TESTING OF SEX PHEROMONES AND ATTRACTANTS OF INSECT CROP PESTS	STRUBLE D L	0.500	1.000	LEPIDOPTERA ATTRACTANTS
				TECH.	0.500	1.000	
>	987	82001002	THE CONTROL AND UTILIZATION OF INSECTS THAT RECYCLE ANIMAL WASTES WITH EMPHASIS ON CATTLE FEEDLOT WASTES	TECH.	0.100	0.500	MANURE INSECTS ORGANOPHOSPHATES
				WEINTRAUB J	0.060	0.300	
>	987	85006035	INSECTICIDE RESIDUES IN THE ATHABASCA RIVER	CHARNETSKI W A	0.040	0.200	BLACKFLY CONTROL INSECTICIDES METHOXYCHLOR NON-TARGET INSECTS RIVERS
				TECH.	0.040	0.200	
>	1002		MANAGEMENT OF INSECTS AND MITES ASSOCIATED WITH APPLES IN THE INTERIOR DISTRICTS OF B.C.	GAUNCE A P	0.050	0.100	
				MADSEN H F	0.500	1.000	
				TECH.	0.500	1.000	
>	1002		BIOLOGY AND CONTROL OF INSECTS AND MITES ON GRAPES	BANHAM F L	0.250	0.500	
				GAUNCE A P	0.050	0.100	
				TECH.	0.250	0.500	
>	1002		INTEGRATED CONTROL OF STONE FRUIT INSECTS	BANHAM F L	0.250	0.500	

ESTAB ETABL	PROJECT # # PROJET	PROJECT TITLE TITRE DE PROJET	STAFF PERSONNEL	PERSON YEARS ANNEES-PERSONNES EFFORT EFFORT	PERSON YEARS ANNEES-PERSONNES PROJECT PROJET	KEYWORDS MOT CLE
			TECH.	0.250	0.500	
> 1002		CONTROL OF THE CODLING MOTH, CARPOCAPSA POMONELLA (L.) BY THE RELEASE OF SEXUALLY STERILE MOTHS	PROVERBS M D	0.500	1.000	
			TECH.	1.000	2.000	
> 1002		CONTROL OF ORCHARD MITES	DOWNING R S	0.330	1.000	
			TECH.	0.330	1.000	
> 1002		PEST MANAGEMENT OF INSECTS AND MITES ON PEARS	GAUNCE A P	0.100	0.100	
			MCMULLEN R D	0.400	0.400	
			TECH.	0.400	0.400	
> 1004	30132001	CONTROL OF INSECT PESTS ATTACKING SMALL FRUITS IN B.C.	CRAM W T	0.200	0.200	
			RAINE J	0.200	0.200	
> 1004	39000003	PESTICIDE LABORATORY AND FIELD TESTS	FINLAYSON D G	0.600	1.000	ALL COLE CROPS MANY PESTICIDES CARROT ONION
			TECH.	0.600	1.000	
> 1004	77139003	BIOLOGICAL AND CHEMICAL CONTROL OF LEATHERJACKETS TIPULA PALUDOSA	WILKINSON A T S	0.200	0.400	LAWN PESTICIDES-SEVERAL
> 1098	30000001	PEST CONTROL MANAGEMENT FOR NURSERY AND GREENHOUSE ORNAMENTALS	TECH.	0.250	0.250	GREENHOUSE
			TONGS N V	0.500	0.500	
> 1098	30000002	CHEMICAL BIOLOGICAL AND INTEGRATED CONTROLS OF INSECT AND MITE PESTS OF GREENHOUSE VEGETABLES	TECH.	0.167	0.250	GREENHOUSE ACARICIDES INSECTICIDES
			TONKS N V	0.335	0.500	

INTEGRATED PEST MANAGEMENT

Note: person-years for each staff member are given in terms of person-years for the project as a whole and do not necessarily reflect the effort on any specific aspect of research

KEYWORDS: INTEGRATED PEST MGMT., PEST MANAGEMENT, MONITOR RELEASES, MONITORING, MONITORING SYSTEM, MONITORING TRAPPING, BIOLOGICAL CONTROL, PHEROMONE(S), INSECT MANAGEMENT, SEX PHEROMONE(S)

1

ESTAB. ETABL.	STAFF PERSONNEL	P-YRS AN-P	PROJECT TITLE TITRE DE PROJET	KEYWORDS MOT CLE
306			VEGETABLE INSECT INVESTIGATIONS	PEST DETECTION PHEROMONE BLACKLIGHT CHEMICAL CONTROL CLIMATOLOGICAL EFFECTS
	SPECHT H B	0.30		
	TECH.	0.30		
306			THE POPULATION DYNAMICS OF WINTER MOTH IN NOVA SCOTIA ORCHARDS	MEASURE POPULATION MORTALITY BIOLOGICAL CONTROL
	MACPHEE A W	0.60		
	TECH.	0.60		
306			CORN INSECTS	VARIOUS INSECTS BORER EARWORM MONITORING TRAPPING SEX PHEROMONE PLANT RESISTANCE
	SPECHT H B	0.30		
	TECH.	0.30		
306			BERRY CROP INSECT INVESTIGATIONS	APHICIDES MONITORING DEVELOP MANAGEMENT SYSTEMS
	SPECHT H B	0.30		
	TECH.	0.30		
638			HONEY BEE BEHAVIOUR	PHEROMONE
	BOCH R	0.80		
	TECH.	0.50		
640			MECHANICS OF COMBINE HARVESTERS: ANALYSIS AND CONTROL	
	FELDMAN M	0.00		MICROPROCESSORS MONITORING DESIGN PRINCIPLES 2.4.4.1.
643			TOBACCO INSECT ECOLOGY AND CONTROL	BIOLOGICAL INTEGRATED PEST MGMT.
	CHENG H H	1.00		
	TECH.	1.00		
648			INTEGRATED PEST CONTROL IN TREE FRUITS	

ESTAB. ETABL.	STAFF PERSONNEL	P-YRS AN-P	PROJECT TITLE TITRE DE PROJET	KEYWORDS MOT CLE
				MONITORING
				REDUCED SPRAY PROGRAM
	TECH.	0.20		
648			DEVELOPMENT OF ARTIFICIAL DIETS FOR INS ECTS WITH PARTICULAR REFERENCE TO DIET AND SYNTHETIC "HOST" TO MASS REAR A HYM ENOPTEROUS PARASITOID	
				NUTRITION
				PARASITE REARING
				ITOPLECTIS
				BIOLOGICAL CONTROL
	HOUSE H L	1.00		
	TECH.	1.00		
680			CHEMICAL CHARACTERIZATION AND SYNTHESIS OF INSECT BEHAVIORAL AGENTS	
				INSECTS
				BEHAVIORAL AGENTS
				CHARACTERIZATION
	STARRATT A N	0.40		
	MCLEOD D G R	0.10		
	TECH.	1.40		
				EUROPEAN CORN BORER
				PHEROMONES
				PROCTOLIN ANALOGUES
				TOBACCO HORNWORM
680			THE IMPROVEMENT OF PEST CONTROL PROGRAM S BY EVALUATING AND PREDICTING THE SPATIAL AND TEMPORAL DISTRIBUTION O F INSECT POPULATIONS	
				INSECTS
				PREDICTING POPULATION
	MCLEOD D G R	0.90		
	STARRATT A N	0.10		
	TECH.	1.50		
				EUROPEAN CORN BORER
				PHEROMONES
680			ECOLOGICAL IMPACT OF INSECTICIDES ON NO N-TARGET SOIL INVERTEBRATES	
				SOIL INVERTEBRATES
				INSECTICIDES
	TOMLIN A D	1.00		
	TECH.	1.00		
	GRAD. STUDENT	1.00		
				BENOMYL
				CARBOFURAN
				EARTHWORMS

ESTAB. ETABL.	STAFF PERSONNEL	P-YRS AN-P	PROJECT TITLE TITRE DE PROJET	KEYWORDS MOT CLE
				PHEROMONES
				SPRINGTAILS
680			TO DEFINE MODE OF ACTION OF SEX PHEROMO	
			NE AT THE RECEPTOR CELL LEVEL	
				INSECTS
				RECEPTOR CELL
				PHEROMONES
	NAGAI T	1.00		
	TECH.	1.50		
				ELECTROANTENNOGRAM
				EUROPEAN CORN BORER
874			FACTORS AFFECTING THE PRESENCE OF 2,4-D	
			IN THE ATMOSPHERE	
				DRIFT CONTROL
				VOLATILITY
				MONITORING
	GROVER R	0.60		
	TECH.	0.60		
875			INSECT POPULATION MANAGEMENT IN THE PRA	
			IRIE PROVINCES	
				GRASSHOPPERS
				POPULATION DYNAMICS
				INSECT MANAGEMENT
	OLFERT O O	1.00		
	TECH.	2.00		
987			CONTROL OF POTATO INSECTS IN SOUTHERN A	
			LBERTA	
				INSECTICIDES
				SEX PHEROMONES
	LILLY C E	0.20		
	TECH.	0.20		
1093			CONTROL OF RANGE WEEDS USING BIOLOGICAL	
			AND CHEMICAL METHODS	
				HERBICIDE ON CORN
				BIOLOGICAL CONTROL
				KNAPWEED
				HERBICIDE ON ALFALFA
	STAFF NOT REPORTED	0.10		
	TECH.	0.00		

NATURAL PRODUCTS IN AGRICULTURE
J. Lambert

Rapporteurs' Report

H.C. Weltzien and A.D.R. Ker

1. General

Though natural plant products are frequently interpreted as an alternative to agrochemicals, they are in principle more an addition to the list of agrochemicals than an alternative. Advantages, disadvantages and hazards connected with their application are also in principle the same as with other agrochemicals. However, they may offer better, cheaper and safer solutions to existing production or health problems, especially in developing countries with no agrochemical industries.

Some plant products are excellent, widely used insecticides and herbicides and there is reason to assume that many more plant products may be discovered. Intercropping, soil amendments and allelopathic affects may add to the potentials of plant products in agriculture.

2. Possibilities in the Semi-arid Tropics

The major emphasis should be in the identification of biological phenomena which may be related to plant products. There is little doubt that traditional agricultural systems contain a wealth of information on such unexplored relationships. Thus much information may be gained through careful observations and interviews on the farm level.

This information has to be collected and screened to understand the underlying principles. Only after a careful analysis of the causes and biological interrelationships can a plant product effect be identified and used on a scientific basis. It seems obvious that conventional agrochemicals have to be used at present, wherever fast production increase is the first priority.

3. Recommendations

A. Collection of ethno-botanical information

Literature survey

Abstracts

Workshop

B. Development of promising products

Screening methods

Production technology

Application

NATURAL PLANT PRODUCTS AND AGRICULTURE

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In a hungry and energy-deficient world any method that can be applied to simultaneously produce more food and reduce energy dependency should be thoroughly investigated. Agricultural practices as carried out in North America call for highly sophisticated technology and high petroleum dependence for example in the production of fertilizers and biocides. This is one of the reasons that, now more than ever, it is dangerous to contemplate such a technology in developing nations. There are also other reasons: political, social, and cultural. The realistic approach now is to look for inexpensive but effective technology.

One alternative approach to some of these problems is the substitution of natural products for costly synthetic biocides. The natural products approach seeks to exploit secondary metabolites which have evolved over millions of years in plants to discourage their natural enemies: pathogens, competing plants, and herbivorous organisms including insects. Many plant products of proven effectiveness in agriculture and medicine are already known (Table 1) (1). These include for example, rotenone, nicotine and pyrethium, botanical insecticides that have been in use for sometime. Recently Ambrosia has been shown to be effective in the control of snails transmitting Bilharzia in Egypt (2). However, the use of natural products, especially from tropical plants, is still a largely unexploited area.

Table 1. Secondary Products and Their Role in Plant Protection*

Class	No. of known structures	Example	Afford protection against
Acetylenes	750	Wyerone	Fungi
Alkaloids	4,500	Lupanine	Mammals
Amino Acids	250	Canavanine	Insects
Carotenoids	300	β-Carotene	Photoprotection
Coumarins	150	Scopoletin	Fungi
Cyanogenic glucosides	50	Linamarin	Molluscs
Flavonoids	1,200	Procyanidin tannins	Insects
Glucosinolates	80	Sinigrin	Insects
Lignans	50	Excelsin	Insects
Lipids	100	Waxes	Fungi
Phenolic Acids	100	Vanillic acid	Plants
Polyketides	500	Ilircinol	Fungi
Quinones	200	Juglone	Plants
Terpenes**	1,100	Glaucolide-A	Insects
Steroids	600	Ecdysones	Insects
Miscellaneous	500	Tuliposide	Fungi
Proteins	?	Lectins	Insect
Polysaccharides	?	Acylated polysaccharides	Fungi
Other polymers	?	Cutin	Fungi

* Taken from T. Swain[1].
** Excluding carotenoids and steroids.

Food production has been greatly hampered in less developed countries by the following factors:

1. Control of pest - insects, weeds, rodents, nematodes, and disease-carrying organisms.
2. Lack of supplies of inexpensive medicines to control diseases that affect the labor force - malaria, yellow fever, sleeping sickness, Leishmania, Schistosomiasis.
3. Loss of soil quality.

The past approach to alleviate these problems has been to import North American monocropping systems and chemical and mechanical technology. These solutions work in the short-term, but are proving less successful in the long-term. The expense of importing technology and the high cost of energy for producing chemicals make these solutions impractical. In 1975, users in the U.S.A. spent $1.8 billion on pesticides alone (3). The effect of these plans has also been diminishing, as seen in DDT resistance. In North America, a large number of biocides have been banned or have restricted uses. Because large quantities of such pesticides have to be sold, the obvious market is the Third World. Then, the chemicals are often used without adequate controls or monitoring programs as to their effect on people, crops and insects.

Our suggested approach to the major problems listed is based on ecological principles. We would put these skills to work in developing herbicides, medicines, insecticides, and green manures from the vast array of plants available in tropical countries for agricultural and health protection. The development of plant products must be combined with agricultural systems based on ecological principles (4). For example, mechanical monocropping in the tropics leads to serious pest problems and declining soil fertility, which are greatly reduced in the more ecologically sound inter- and multi-cropping techniques. Insecticides are required for the control of grain pests such as Sitophilus, and Anopheles, the vector of malaria. The former might be controlled by intercropping of insect repellent plants in the field; the latter, by use of inexpensive or simple extracts, crude powdered plant materials for larvicides. Another approach to crop protection would be to identify in plants - cultivated or otherwise - those characteristics which will inhibit feeding by insects or infestation by micro-organisms.

A three stage programme is envisaged for identifying new plant products, and develping products of proven potential. The first phase involves the screening of plants for various kinds of biological activity. An integral part of this program is the collection of ethnobotanical data from local farmers and a review of the scientific literature which may point the way to the identification of many useful species. Procedures for rapid screening of plants for anti-microbial activity and light-mediated cytotoxic activity have been described by Camm (5). Mosquito larvicide tests (6, 7) also used by us may be adapted for crude plant extracts to determine their toxicity to insects. An alternate approach used by Philogene (8) is to determine the antifeedant properties of plant products. This is a promising area of pest control since antifeedants such as Aizediractin from the Neem tree are effective at low concentrations against the locust S. gregaria. Allelopathic compounds produced in the roots of certain species of plants inhibit the growth of competing plants. We believe some of these have potential as herbicides.

Green manures are an alternative to energy-dependent artificial fertilizers and have the added advantage of adding organic matter to the soil. In our agriculture work in Central America we have tested approximately

50 indigenous plants for nutrient content (9, 10). Some species such as Piper amalago have a high phosphate content (4.6 mg/g) and are an excellent green manure for the phosphate deficient soils of Central America. A more extensive programme is needed if we are to find the best nutrient concentrating plants.

Other kinds of screening are of course possible, and further tests may be added with time. In addition plant extracts can be prepared and sent to various laboratories, such as those searching for anti-cancer agents.

The second stage of the programme is to work up the active compounds detected in crude extracts. Bio-assays may be used to follow activity as compounds are purified by standard chromatographic methods. This technique, for example, was used in our identification of the photo-toxic activity by polyacetylenes (11). At this stage LD_{50}'s, effect of compounds on non-target organisms, etc., must be determined (5). Because these are naturally occurring compounds, we believe their use is likely to create fewer environmental hazards than synthetics. For the less developed countries we are particularly interested in the development of crude powdered plant materials which may be an inexpensive substitute for purified compounds.

This year we are field testing α-terthienyl, a naturally occurring polyacetylene derivative of Tagetes erecter (common marigold) to determine its herbicidal properties. Initial trials show that it is selective for some weedy species such as Ascelpias syriaca - (milkweed) and Chenopodium album (lambsquarters) but has no effect on associated forage species (12),

Alpha-terthienyl has been shown to be effective as a mosquito larvicide and more toxic than DDT (5).

The agroecosystems approach attempts to exploit ecologically sound methods for increased crop production in tropical agriculture. Intercropping is one technique that has been shown to increase yields over monocropping in the tropics (13). Intercropping leads to better weed control by filling all available land with crop species. Increased species diversity in intercropping also reduces pest problems. Details of cultigen selection and optimal plant spacing need to be worked out for specific situations such as the Canada - Belize cooperative agriculture project in Belize, C. A.

Selection of crop plants which contain phagorepellants can be used to decrease insect pests. For example, the extent of damage of pears by the scale Psylla pyricola (Hemiptera) depends on its differential preference for pear varieties based on phenolic complexes in the leaves (14). Biological control of Psylla is also possible through manipulation of the parasitoid/ predator Psylla complex (15). But extensive use of synthetic pesticides reduce the impact of such natural enemies.

Other ecological approaches to pest control which may have potential include the intercropping of repellant species such as Tagetes for insect control and the development of allelopathic crop plants for weed control. Repellant plant species have perhaps their greatest potential in reducing the substantial post-harvest losses suffered by small farmers throughout the tropics. These plants could be grown and harvested at the same time as the crop. Placed in and around storage places of grain, they could be used to discourage prevalent grain pests such as Sitophilus.

The approaches outlined above could in combination result in a beneficial integrated pest management program. There is a distinct advantage to such a program. Third World Countries would be using a local resource that could be harvested and processed relatively cheaply.

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TISSUE CULTURE
W.A. Keller

Rapporteurs' Report

B.M. Craig

Cell culture represents a new approach to plant breeding which after more than 10 years of exciting advances in the laboratory is now at the stage where there are some practical developments, many of which are applicable to problems in the SAT. An important example is the present ability to sanitize cassava and other plant material in vitro and to reproduce this material in a form which can be distributed to farmers for propagation. In some species, particularly cereals, while there have been significant advances in culture techniques, it is not yet possible to regenerate whole plants from cultured material although some recent advances in this regard have been made with maize x sorghum crosses and with cultured material of pearl millet.

There are many attractive long range possibilities such as that of producing very wide crosses (intergeneric or wider) using in vitro fertilization and embryo rescue techniques. However, in the pursuit of these possibilities, one should not overlook more short term and immediately useful application of tissue culture methods, such as:

1. Reduction of loss from plant diseases, especially in developing countries through sanitization procedures previously mentioned (especially in intensive systems such as horticulture and greenhouse culture);

2. Asexual and rapid propagation of valuable hybrid materials without returning to the parent strain;

3. Identification, selection and multiplication in vitro of naturally occurring mutants with enhanced resistance to various pathological and environmental stress;

4. Culture of haploid tissues to produce homozygous strains.

With respect to sanitization of breeding material, it was suggested that the network of banana projects supported by IDRC in the Caribbean and elsewhere could benefit greatly from the application of that technology.

PLANT TISSUE CULTURE RESEARCH ACTIVITY IN CANADA

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September 17, 1980

A. Plant Tissue Culture : Areas of Activity in Canada

Plant tissue culture techniques are currently utilized in a number of Canadian university and government laboratories as well as in privately-owned enterprises. The applications of these techniques fall into nine major areas:

(1) Basic studies in differentiation, morphogenesis, and metabolism
(2) Meristem culture for production of disease-free plants
(3) Mass propagation
(4) Germplasm preservation
(5) Haploid production and utilization
(6) Selection of novel genetic variants
(7) Synthesis of natural products
(8) Hybridization
(9) Genetic engineering with recombinant DNA

1. Basic Studies in Differentiation, Morphogenesis, and Metabolism

Plant tissue culture systems are under investigation in a number of government and university laboratories with the objective of developing greater knowledge of factors that influence the *in vitro* differentiation of specific tissue and organ types as well as the regeneration of plants. The starting material may consist of single cells or protoplasts, or multicellular structures including leaf and stem explants and callus tissue. The ability to regenerate plants from cultured cells, tissues, or organs is a prerequisite for agricultural applications of plant tissue culture. A number of laboratories whose ultimate objectives involve the genetic modification of crops have therefore also undertaken parallel fundamental studies in morphogenesis *in vitro*. Studies on morphogenesis have involved two approaches:

(a) Characterization and analysis of *in vitro* systems in species such as tobacco where plant regeneration is already possible. The knowledge acquired may also be applicable to recalcitrant species such as cereals and legumes in which little success in plant regeneration has thus far been obtained.

(b) Direct investigation of recalcitrant species with the application of novel procedures in order to stimulate plant regeneration.

The activities of laboratories involved in studies on differentiation and morphogenesis are listed in Table I.

Plant tissue culture systems are also being utilized in a number of basic metabolic studies such as ion transport, biosynthesis, virus infection, and low temperature survival. Laboratories involved in these studies are listed in Table II.

2. Meristem Culture for Production of Disease-free Plants

Tissue culture techniques can be directly utilized in freeing economically-important crop species from virus diseases. Such diseases can be especially serious in vegetatively-propagated species (e.g. potato, grapes). The technique involves culturing shoot tips, in some cases, subsequent to a heat treatment. The plant or plants which are regenerated are often virus-free and can be utilized as donors for mass propagation (discussed below) of large numbers of virus-free plants. Canadian researchers have made significant contributions to production of virus-free crop plants in cassava and various legume species. Establishments involved in meristem culture are listed in Table III.

3. Mass Propagation

In vitro culture procedures are being utilized in both public and private organizations to rapidly multiply plants with desirable features. In many cases multiplication values of one million from one donor plant can be obtained within one year. The starting tissue may include shoot tips, leaf or stem explants, or callus cultures. The regenerates are highly uniform and will be disease-free if the donor was also disease-free. The technique is especially valuable for vegetatively-propagated, cross-pollinated, high cash value material such as fruit, vegetable and ornamental species, or for lumber and pulp tree species. Research on development of methodology for propagation as well as the routine application of developed techniques are being carried out in a number of locations listed in Table IV.

4. Germplasm Preservation

Tissue culture procedures have potential for preservation of valuable germplasm. The techniques include maintaining cells, shoots or plantlets in low light and temperature conditions, immobilizing cells in alginate beads, and freezing cells or shoot tips in liquid nitrogen. Laboratories involved in these activities are listed in Table V.

5. Haploid Production and Utilization

The production of haploids of crop plants has important applications for plant improvement:

(1) Effective selection of desirable genetic recombinants can be made in haploid populations thereby greatly reducing the length of time required to produce new cultivars

(2) Pure breeding (homozygous) lines can be rapidly obtained from haploid populations. Such lines would be of value in hybrid seed production

(3) Haploids can be utilized for the initiation of haploid cell cultures from which efficient selection of novel genetic variants or mutants could be carried out (discussed in Section A.6).

Two types of *in vitro* culture techniques are utilized in Canada to achieve haploid plant production:

(1) Barley haploids are obtained through the culture of embryos produced by the hybridization of cultivated barley with a wild barley species, *Hordeum bulbosum*. The technique has been developed and refined for barley haploid production by the University of Guelph and Agriculture Canada (Ottawa). It is being utilized for barley haploid production in a number of breeding programs (Table VI). Production of wheat haploids via this technique is at a preliminary stage of development.

(2) Anthers are cultured with the aim of inducing haploid plant development directly form immature pollen. Anther culture research is being carried out in a number of Canadian laboratories. In some species such as cereals, the work is still in early stages of development, whereas in others such as rapeseed and tobacco it is well developed and haploids are undergoing field evaluation (Table VII).

6. Selection of Novel Genetic Variants (Mutants)

Since very large numbers of plant cells can be grown in flasks it is feasible to select for mutants from such culture systems. The technique is especially powerful if haploid cells are utilized since there would be no masking of recessive mutations. Genetic variability is apparently generated during the culture process but it may also be induced through the use of mutagens. Research in this area has been only recently begun in Canada and is being carried out in relatively few centres (Table VIII).

7. Synthesis of Natural Products

Plant cell cultures are being studied with the objective of analyzing and/or stimulating the production of natural products including enzymes and secondary metabolites. These studies could result in the utilization of cell cultures as fermentation systems to produce valuable pharmaceuticals. Efforts in Canada in this area,compared to work in Europe and Japan are on a small scale. Canadian research laboratories involved in this area are listed in Table IX. At present this area of activity has no direct applicability in food crop improvement.

8. Hybridization

Tissue culture techniques are being utilized to achieve interspecific plant hybridization. Both sexual and parasexual (somatic) hybrids have been produced with these techniques.

Embryo culture techniques have been used to obtain plants from interspecific sexual crosses in cereal and Nicotiana species. The institutes involved in hybrid production via embryo culture methods are listed in Table X.

Parasexual hybridization involves the fusion of plant protoplasts followed by the regeneration of hybrid plants. Theoretically, very wide crosses could be obtained with this procedure. Canadian scientists have achieved international recognition for their pioneering efforts in this area. Laboratories undertaking somatic hybridization studies are listed in Table XI.

9. Genetic Engineering with Recombinant DNA

Recent advances in genetic modification of microbes with recombinant DNA have stimulated discussion and proposals to utilize recombinant DNA in genetic improvement of crop plants. A research program involving plant genetic modification via recombinant DNA is in the process of initiation in the Prairie Regional Laboratory, National Research Council, Saskatoon. Studies in genetic engineering with recombinant DNA are being planned in Ottawa Research Station and Chemistry and Biology Research Institute (Ottawa) of Agriculture Canada. ENS Biologicals, a private company, recently established in Toronto may also become involved in the application of recombinant DNA methodology to plants. Recombinant DNA technology is currently being utilized in studies on nitrogen fixation in legumes at the Biology Department, McGill University (D. Verma) and at the Lady Davis Institute, Jewish General Hospital (H. Schulman) in Montreal.

B. Assessment of Canadian Research Activity in Plant Tissue Culture

Canada has made significant contributions to the world-wide development of plant tissue culture as a valuable tool in crop plant improvement. Possibly the most widely recognized Canadian advances include:

(1) The development of techniques to achieve somatic hybridization
(2) Production and utilization of barley haploids through embryo culture
(3) The production of rapeseed haploids through anther culture
(4) The elimination of virus diseases in cassava and legumes through meristem culture
(5) Fundamental studies on plant regeneration in a number of crop species including tobacco, tomato, carrot, alfalfa, flax, rapeseed, peas, and cereal species.

The greatest activity and potential for further development is found in three centres:

(1) Saskatoon: Prairie Regional Laboratory, National Research Council; Biology, Biochemistry, and Horticulture Departments, University of Saskatchewan, and Saskatoon Research Station, Agriculture Canada

(2) Guelph: Departments of Crop Science, Horticulture, Botany and Genetics, and Chemistry, University of Guelph

(3) Ottawa: Ottawa Research Station, Agriculture Canada; Biology Department, Carleton University, and Biological Sciences Division, National Research Council.

In all three centres the ongoing research activity involves collaboration between government laboratories and universities or between departments of a university. The research capability of Ottawa Research Station, Agriculture Canada, is undergoing significant expansion in 1980 with the employment of three research scientists (Drs. D. Brown, B. Miki, and S. Molnar) in the plant tissue culture program. Secondary centres in which several researchers are located and which probably would be able to undergo further expansion and development include:

(1) Calgary: Biology Department, University of Calgary

(2) Fredericton: Biology Department, University of New Brunswick; Fredericton Research Station, Agriculture Canada, and the Forestry Research Laboratory, Environment Canada.

Other locations in which tissue culture studies are being conducted (as listed in Tables I-XI) involve operations on a small scale. Some of these laboratores may be able to undergo expansion in the near future. Tissue culture programs focussing on the genetic modification of crop plants are being planned in the Plant Science Department, University of Manitoba (Winnipeg) and in the Alberta Research Council (Edmonton). These will be significant operations, will likely be initiated in 1981, and will involve a minimum of two professional research staff in each location.

C. Future Role of Tissue Culture in Canadian Agricultural Research

With respect to Canadian agriculture and crop improvement, it would be worthwhile to further expand and develop research in several areas involving plant tissue culture. These include:

(1) Intensification of studies on plant regeneration in recalcitrant cereal and legume species

(2) Development of reliable techniques for mass propagation and germplasm preservation in high cash value material such as fruit crop species

(3) Increased effort in the development of reliable procedures for large scale production of haploids for direct use in breeding programs and for use in initiation of haploid cell cultures

(4) Further development of methodology for selection of genetic variants in cell cultures

(5) Development of procedures for somatic hybrid cell selection and,where possible, investigation of the role of somatic hybrids in providing increased genetic variability in comparison to sexually-produced hybrids

(6) Increased emphasis on development of recombinant DNA techniques for genetic engineering of crop plants.

D. Application of Plant Tissue Culture to Crop Improvement in Underdeveloped Countries

Tissue culture techniques are applicable in crop improvement of underdeveloped regions including the semi-arid tropical regions recognized by IDRC as a priority region. The areas of tissue culture research which would be the most effective in crop improvement in tropical regions include:

(1) The development of regenerable tissue culture systems for elimination of viral diseases and rapid propagation in desirable genotypes. Such techniques would be of special value in heterozygous, vegetatively-propagated crops such as cassava, potato, sweet potato, and yams

(2) The development of procedures for producing and utilizing doubled haploids. These procedures would be applicable for rapid development of hybrid lines in heterozygous material

such as cassava. They would also be very useful in selection of desirable genotypes in cereal species such as millet and sorghum as well as in grain legumes.

(3) The development of procedures for selecting genetic variants from regenerable cultures. With effective screening procedures, selection for traits such as superior drought, salinity, or disease resistance could be carried out. Stable variants could be crossed with existing cultivars to improve the crop species.

(4) The development of procedures to achieve wide crosses with special attention paid to interspecific crosses in grain legumes and the intergeneric cross of sorghum x corn. Emphasis should be placed on sexual hybridization involving *in vitro* pollination (test tube fertilization) and/or embryo culture techniques.

Studies in the areas described above do not require sophisticated equipment. Basic tissue culture facilities including laminar flow benches (or sterile transfer rooms), incubators, culture chambers, dissecting microscopes as well as chemicals and facilities for media preparation are the basic requirements for the initiation of this research.

Canadian scientists could make a positive contribution to the application of tissue culture techniques for crop improvement in the semi-arid tropics. Cooperative programs could be established between institutes in these areas and laboratories in Canada. At present the Canadian institutions most capable of becoming involved in such collaborative work are listed in Section B of this paper. The research activity could involve a number of approaches including:

(1) the development of new technologies, procedures, etc. by Canadian scientists in Canadian institutions with the transfer of technologies occurring after their development.

(2) the development of joint research projects involving studies by graduate students and/or foreign scientists in Canadian institutes

(3) the organization of reciprocal visits by foreign and Canadian scientists

The International Research Centers could play a major role in research coordination and insuring the transfer of new techniques. The establishment of short term training programs or workshops which could be conducted in Canada or in an International Research Center should also be considered.

TABLE I. Tissue Culture Studies on Morphogenesis in Canadian Establishments

Establishment	Research Personnel	Material	Comments
Summerland Research Station Agriculture Canada Summerland, B.C.	D. Lane	apples, apricots	Shoot regeneration from mature embryos
Prairie Regional Laboratory National Research Council Saskatoon, Sask.	K. Kao K. Kartha	peas, chick peas, peanuts, alfalfa, rapeseed, *Catharanthus*	Plants have been regenerated from alfalfa protoplasts (Kao) and tissue explants and cell cultures of other species (Kartha)
Saskatoon Research Station Agriculture Canada Saskatoon, Sask.	G. Stringam	rapeseed (Canola)	Plant regeneration from stem explants and epidermal layers
Plant Science Dept. University of Manitoba Winnipeg, Man.	C. Palmer	cell cultures of potato, soybean and tobacco	Studies of factors influencing differentiation
Biology Dept. University of Windsor Windsor, Ont.	D. Thomas	cell cultures of several species	Studies on the production of volatiles *in vitro* and their relation to differentiation
Biology Dept. Western University London, Ont.	R. Greyson	corn (organs and cell cultures)	Recently-initiated study to regenerate plants from protoplasts
Crop Science Dept. and Botany and Genetics Dept. University of Guelph Guelph, Ont.	K. Kasha, D. Tomes and L. Peterson G. Seguin	barley, red clover, Bird's foot trefoil	Recently-initiated study in barley (Kasha); plants regenerated from clover and trefoil (Tomes); ultra-structructural studies on regener-ation (Peterson)
Ottawa Research Station Agriculture Canada Ottawa, Ont. and Biology Department Carleton University	W. Keller, B. Murray, C. Nakamura, J. Simmonds G. Douglas S. Gleddie G. Setterfield	broccoli, Canola, barley, *Triticale* interspecific cereal hybrids, tobacco, *Nicotiana* somatic hybrids, *Begonia* *Streptocarpus*	Plant regeneration obtained from flax stem explants (Murray), broccoli, Canola, and *Nicotiana* epidermal explants (Keller), and tobacco, cereal and eggplant callus (Douglas, Gleddie, Nakamura, Setterfield); floral induction in *Streptocarpus*, *Begonia* and tobacco cultures (Simmonds)

continued

TABLE I, cont'd.

Establishment	Research Personnel	Material	Comments
Biology Dept. University of New Brunswick Fredericton, N.B.	P. Arnison L. Dionne	tobacco wild legume species	Studies on *in vitro* floral induction in tobacco (Arnison) and plant regeneration in legumes (Dionne).
Biology Dept. University of Calgary Calgary, Alberta	T. Thorpe	tobacco	Studies on factors influencing organogenesis

TABLE II. Studies on Basic Cellular Properties Through the Use of Tissue Culture in Canadian Establishments

Establishment	Research Personnel	Material	Comments
Vancouver Research Station Agriculture Canada Vancouver, B.C.	J. Jacoli	carrot	Study of mycoplasma-related diseases
Biology Dept. University of Saskatchewan Saskatoon, Sask.	L. Fowke	cultures of several species	Studies on wall regeneration on protoplasts; studies on uptake of liposomes
Biochemistry Dept. University of Saskatchewan Saskatoon, Sask.	P. Shargool	soybean cell cultures	Studies on factors affecting regulation of biosynthetic pathways
Biology Dept. Western University London, Ont.	R. van Huystee	peanut cell cultures	Studies on peroxidase isozyme synthesis and regulation
Biology Dept. Carleton University Ottawa, Ont.	P. Lee	wheat, sow-thistle cultures	Studies on virus infection at the cellular level
Chemistry & Biology Research Institute Agriculture Canada Ottawa, Ont.	J. Singh	wheat, rye (epicotyl and leaf tissue)	Studies on survival of protoplasts under freezing stress
Biology Dept. Concordia University Montreal, P.Q.	R. Ibrahim	apple fruit, tomato fruit, flax and tobacco cultures	Studies on enzyme systems involved in production of phenolic compounds
Biology Dept. McGill University Montreal, P.Q.	R. Poole	bean and tobacco cell cultures	Studies on ion transport

TABLE III. Meristem Culture in Canadian Establishments

Establishment	Research Personnel	Plant Material	Comments
Vancouver Research Station Agriculture Canada Vancouver, B.C.	F. Mellor R. Stace-Smith N. Wright	potato	Routine procedure for elimination of several virus diseases; 140 virus-free cultivars maintained
Sidney Research Station Agriculture Canada Sidney, B.C.	R. Harris	grapes cherries	Several virus diseases eliminated. Research program recently initiated.
Prairie Regional Laboratory National Research Council Saskatoon, Sask.	K. Kartha	grapes, strawberries, grain legumes, cassava, coffee	Extensive research program on the development of reliable meristem culture techniques.
Morden Research Station Agriculture Canada Morden, Manitoba	W. Russel	potato	Production of disease-free stock
Experimental Farm Agriculture Canada La Pocatiere, P.Q.		potato	Routine procedure for elimination of several virus diseases.
Fredericton Research Station Agriculture Canada Fredericton, N.B.	W. Coleman	potato	Program initiated to eliminate spindle tuber virus

TABLE IV. Utilization of Tissue Culture for Mass Propagation in Canadian Establishments

Establishment	Research Personnel	Material	Comments
Sidney Research Station Agriculture Canada Sidney, B.C.	R. Harris	grapes, cherries saskatoons, blueberries, asparagus, ornamental species	20 varieties of grapes have been propagated; research on other species in developmental stage
Dept. of Plant Science Univ. of B.C. Vancouver, B.C.	N. Senn	ornamental species	
Summerland Research Station Agriculture Canada Summerland, B.C.	D. Lane	pear, cherries, apples, apricots	Plants have been regenerated from meristem cultures
Kelowna Nurseries Ltd. Kelowna, B.C.	D. Dunstan	apples, cherries, grapes, crabapples, pears, ornamental species	Program in active stages of development; plants have been regenerated from shoot-tips; commercial operation
Le Noble Orchids Richmond, B.C.		orchids	Commercial operation
Clay's Nursery Langley, B.C.		*Rhododendron*	Commercial operation
Biology Dept. University of Calgary Calgary, Alta.	T. Thorpe	spruce and pine species	Program under development for mass propagation of coniferous species
Horticulture Dept. Univ. of Saskatchewan Saskatoon, Sask.	E. Maginnes	tomato	Studies on mass propagation of several varieties
Horticulture Dept. University of Guelph Guelph, Ont.	P. Harney	asparagus, rose, woody ornamentals	Plants regenerated from meristems; asparagus program is well developed

...continued

TABLE IV, continued

Establishment	Research Personnel	Material	Comments
H. and A. Farms Ltd. R.R. #1, Harrow, Ont. and Harrow Research Station Agriculture Canada	T. Klassen	apples, *Prunus* species	Evaluation of *in vitro* propagation in commercial orchard operations
Epp's Greenhouses Ltd. Huttonville, Ont.		*Streptocarpus*, African violet	Commercial operation
Ottawa Research Station Agriculture Canada Ottawa, Ont.	J. Simmonds	lily cell cultures	Multiple regeneration has been achieved
Pilansky Gardens Ltd. 7076 Niven Rd. Campbellville, Ont.		*Begonia*	Commercial operation
Plant Science Dept. Macdonald College Ste. Anne de Bellevue Que.	C. Chong	apples, blueberries	Studies on propagation from meristems (for commercial application)
Biology Dept. University of Montreal Montreal, P.Q.	M. Cailloux	apples, ornamental species	Plants regenerated from meristems. (Development of methodology for commercial application)
Biology Dept. McGill University Montreal, P.Q.	W. Boll	coniferous species	Program in early stages of initiation
St. Jean Research Stn. Agriculture Canada St. Jean, P.A.	D. Rousselle	apples	Plants regenerated from meristems
Serres A. M. Dion Ltee. 125 Cote Cachee Boisbriand, P.Q.	A. Dion	apples, ornamentals	Commercial operation

...continued

TABLE IV, continued

Establishment	Research Personnel	Material	Comments
Pierre Noreau Oka, P.Q.	P. Noreau	apple	Commercial operation in early stages of development
Biology Dept. University of New Brunswick Fredericton, N.B.	B. Cumming J. Seabrook	peony, lily, daffodil	Plants regenerated from callus and meristems
Fredericton Research Station Agriculture Canada Fredericton, N.B.	W. Coleman	potato	Program in early stages of development
Forestry Research Laboratory Environment Canada Fredericton, N.B.	J. Bonga	pine and other coniferous species	Research program on induction of plant regeneration from tissue explants and callus
Kentville Research Station Agriculture Canada Kentville, N.S.	N. Nickerson	blueberries	Program under development

TABLE V. Germplasm Preservation Through *in vitro* Culture Procedures in Canadian Establishments

Establishment	Research Personnel	Material	Comments
Sidney Research Station Agriculture Canada Sidney, B.C.	R. Harris	grapes	Shoot tip cultures maintained at 8°C for up to 16 months
Prairie Regional Laboratory National Research Council Saskatoon, Sask.	K. Kartha	peas, chick peas, cassava, strawberries	Extensive research program to develop procedures for long term cryopreservation of meristem cultures.
Dept. of Crop Science University of Guelph Guelph, Ontario	D. Tomes	Bird's foot trefoil	Shoot cultures maintained under low temperature and light conditions
Biological Science Division National Research Council Ottawa, Ont.	I. Veliky	cell cultures of several species	A newly-initiated program to develop techniques for long term maintenance of cells immobilized in alginate

TABLE VI. Cereal Haploid Production via Embryo Culture in Canadian Establishments

Establishment	Research Personnel	Material	Comments
Dept. of Genetics University of Alberta Edmonton, Alta.	R. Sadasivaiah	barley	Generation of large numbers of haploids for breeding programs
Brandon Research Station Agriculture Canada Brandon, Man.	K. Campbell	barley	Evaluation of the potential haploids in breeding malting barley
Dept.of Crop Science University of Guelph Guelph, Ont.	K. Kasha	barley	Evaluation of the potential of barley haploids in breeding.
	K. Kasha	wheat	Feasibility of haploid production under evaluation.
Ciba-Geigy Seeds, Ltd. Ailsa-Craig, Ont.	K. Ho	barley	Barley haploids utilized in large scale breeding program; new cultivar developed from haploid-derived material

TABLE VII. Haploid Production via Anther Culture in Canadian Establishments

Establishment	Research Personnel	Material	Comments
Saskatoon Research Station Agriculture Canada Saskatoon, Sask.	G. Stringam	rapeseed (Canola)	Evaluation of anther-derived haploids in field plots
Prairie Regional Laboratory National Research Council Saskatoon	K. N. Kao	barley, wheat, <u>Triticale</u>	Recently-initiated program in cooperation with visiting scientists from People's Republic of China
Delhi Research Station Agriculture Canada Delhi, Ont.	R. Pandeya	tobacco	Evaluation of anther-derived haploids in field plots
London Research Centre Agriculture Canada London, Ontario	T. Lee T. Ho	winter wheat	Program in early stages of development
Crop Science Dept. University of Guelph Guelph, Ont.	K. Kasha	barley	Program in early stages of development
Horticulture Dept. University of Guelph Guelph, Ont.	V. Machado M. Ali	rutabaga	Recently-initiated program to produce pure lines for hybrid cultivar development
Ottawa Research Station Agriculture Canada Ottawa, Ont.	I. Craig	wheat	Program to increase the frequency of haploid production
	W. Keller	rapeseed (Canola), broccoli	Program well developed with potential for high frequency haploid production
Biology Dept. Laval University Quebec, P.Q.	C. St. Pierre	barley	Program in preliminary stages of development
Fredericton Research Station Agriculture Canada Fredericton, N.B.	W. Coleman	potato	Program in preliminary stages of development

TABLE VIII. Studies on Selection of Genetic Variants (Mutants) in Tissue Cultures in Canadian Establishments

Establishment	Research Personnel	Material	Comments
Summerland Research Station Agriculture Canada Summerland, B.C.	D. Lane	apples, pears, and other fruit tree species	Recently-initiated program to select for resistance to disease and insects *in vitro*; also selection for dwarf types
Biology Department University of Saskatchewan Saskatoon, Sask.	J. King R. Horsch	haploid *Datura* cell cultures	Mutant lines resistant to metabolite analogues as well as auxotrophic mutants have been selected
Saskatoon Research Station Agriculture Canada Saskatoon, Sask.	G. Stringam	haploid rapeseed (Canola) stem explants	Program has been initiated to select for resistance to *Sclerotinia* based on resistance to oxalic acid
Crop Science Dept. University of Guelph Guelph, Ont.	D. Tomes E. Swanson	Bird's foot trefoil cell cultures	Program initiated to select for resistance to herbicides, and metal ions
Biology Dept. Carleton University Ottawa, Ont.	G. Setterfield D. Simmonds	haploid *Datura* and *Nicotiana* cell cultures	Program being developed to select for developmental and auxotrophic mutants
Ottawa Research Station Agriculture Canada Ottawa, Ont.	B. Murray	haploid flax cultures	Program being developed to select for agronomically-desirable mutants such as herbicide resistance

TABLE IX. Studies on Synthesis of Natural Products by Tissue Cultures in Canadian Establishments

Establishment	Research Personnel	Material	Comments
Chemistry Department University of B.C. Vancouver, B.C.	J. Kutney	cell cultures of several species	Studies on production of pharmaceuticals including anti-tumour drugs
Food Science Dept. University of B.C. Vancouver, B.C.	P. Townsley	coffee, tea cell cultures	Studies on synthesis of caffeine and flavor compounds
Prairie Regional Laboratory National Research Council Saskatoon, Sask.	F. Constabel W. Kurz	poppy, *Catharanthus* and other species	Program in early developmental stage; evidence for production of pharmaceutical compounds *in vitro*
Chemistry Department Trent University Peterborough, Ont.	S. Brown	*Ruta graveolens*	Studies on biosynthesis of coumarin and other phenolic compounds
Chemistry Department University of Guelph Guelph, Ont.	B. Ellis	cell cultures of several species	Studies on production of secondary metabolites

TABLE X. Production of Interspecific Sexual Hybrids via Embryo Culture in Canadian Establishments

Establishment	Research Personnel	Material	Comments
Plant Science Department University of Manitoba Winnipeg, Man.	P. Kaltsikes	wheat x rye hybrids (*Triticale*)	Routine procedure for hybrid production
Ottawa Research Station Agriculture Canada Ottawa, Ontario	G. Fedak	Interspecific cereal hybrids (wheat, rye, barley, and wild species)	Extensive hybridization program involving routine embryo culture procedures
Biology Department Carleton University Ottawa, Ontario and Ottawa Research Station Agriculture Canada Ottawa, Ont.	G. Douglas G. Setterfield W. Keller	tobacco and other *Nicotiana* species	Development of embryo culture methodology to obtain high yields of interspecific hybrids
Ste. Foy Research Station Agriculture Canada St. Foy, P.Q.	A. Comeau	wheat x *Agropyron* hybrids	Routine procedure for hybrid production

TABLE XI. Somatic Hybridization Studies in Canadian Establishments

Establishment	Research Personnel	Material	Comments
Prairie Regional Laboratory National Research Council Saskatoon, Sask.	K. N. Kao	several species including legumes and *Nicotiana*	Extensive studies on protoplast fusion techniques; characterization of hybrids at the cellular and whole plant level
	L. R. Wetter	several somatic hybrids including soybean + tobacco hybrid cells	Characterization of hybrids through analysis of isoenzymes and chloroplast proteins
Saskatoon Research Station Agriculture Canada Saskatoon, Sask.	G. Stringam	rapeseed (Canola) + mustard combination	Program in preliminary stages of development; presumptive hybrid cells isolated
Biology Dept. University of Saskatchewan Saskatoon, Sask.	L. Fowke	cells of various somatic hybrids	Light and electron microscopic analysis of protoplast fusion products
Biology Dept. Carleton University Ottawa, Ont. and Ottawa Research Station Agriculture Canada Ottawa, Ontario	G. Douglas S. Gleddie G. Setterfield W. Keller	various *Nicotiana* species including tobacco and other solanaceous species such as potato, tomato, eggplant, and petunia	Hybrids of *N. tabacum* + *N. rustica* have been produced and characterized; studies on other species combinations are in progress
Biology Dept. Dalhousie University Halifax, N.S.	R. Lee	*Nicotiana* species	Program on cytoplasmic properties of somatic hybrids is in preliminary stages of development

CRITERIA OF GRAIN QUALITY
Paper by R. Reichert

Rapporteurs' Report
R.S. Forrest and S. Vogel

The paper was limited to consideration of sorghum and millets as these supply 90% of the food energy for the rural population of the Sahelian region. In addition to the usual quality factors of colour, protein, fibre content, etc. attention should be focussed on ease of dehulling, particularly when developing new varieties. In this connection there is need for rapid laboratory-scale dehulling devices such as the one developed at the Prairie Regional Laboratory. There is considerable Canadian competence in the determination of quality of certain grains and the relevant methodologies can be transferred. Sorghum and millet are almost always dehulled prior to consumption: therefore, both assessment of dehulling characteristics and development of equipment to end laborious hand dehulling are priorities. Storage quality and dehulling quality are often in conflict; hence the need for laboratory dehulling equipment in any breeding program.

Many developing countries are attempting to reduce the importation of grain by substituting processed locally produced grains. However, in certain countries the consumption of sorghum and millet is associated with poverty; hence the need to develop industrial capacity to produce processed foods made from mixtures of sorghum and/or millet with other grains.

Other priority areas include the development of methodologies for determining flour quality in sorghum and millets and for determining cooking quality and factors affecting it in legumes.

FOOD QUALITY OF SORGHUM AND MILLET GRAINS

PREPARED FOR THE

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A. Introduction

The purpose of this paper is to review work which has been done on the sorghum and millet grains in Canada and to indicate where Canadian research in crop quality could potentially be of benefit in less developed countries.

Sorghum and millet grains are the most important food crops of the semi-arid tropics. Table 1 outlines the production areas of these grains in various parts of the world. Whereas in economically developed countries sorghum and millet are used mostly as animal feed, in the developing countries they are predominantly a source of human food. About 3% of total production in developed countries goes to other uses including fermented beverages or industrial uses versus 9% for such purposes in developing countries. In the Sahelian region it is probable that 90% of the rural people rely on sorghum and millet as their main source of food energy. Typical traditional foods include thin or thick porridges, bread and a wide range of fermented beverages.

The volume of sorghum and millet improvement work done in the developed world has been small by comparison with that on rice or wheat. Most sorghum improvement work was spent studying the necessary agronomic characters of new varieties. The main efforts of plant breeders was toward yield per hectare. Quality considerations of the grain were mainly limited to considerations of nutritional quality, ie. palatibility and digestibility for livestock.

Over the past several years there has been a growing awareness that many more quality factors are important in the selection of sorghum and millet for human food. Some of these include: colour, fiber content, hardness, ease of dehulling and grinding, endosperm structure, aroma and flavour. These are the quality characteristics which I am mainly concerned about today. It is safe to say that breeding exclusively for higher yields is not enough. In the future, plant breeders will have to insure that their new varieties also possess desirable food quality characteristics. To quote Dr. Hugh Doggett, "People will eat poor quality food only when they are under the stress of hunger: but they will only cultivate with enthusiasm the cereals which they want to eat themselves because they like them and because the market price is attractive."

Research on the aesthetic and product quality factors in these grains has only recently begun. The majority of this work has been done in the USA. The Agency for International Development (AID) in the USA. has received extensive funding from congress through a program known as TITLE 12. AID has in turn been funding several universities in the USA. One of the major intents of this multi-million dollar program is to "help the small farmer to help himself". Most of the millet quality work is being done at Kansas State University under the terms of a 3 year $770,000.00 contract. Sorghum quality work has recently started at Texas A & M University. The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) has also been involved in quality from both nutritional and product quality aspects. ICRISAT has an active program in breeding for high lysine sorghum varieties. About 3 years ago work on sorghum food quality was also started.

B. Sorghum and Millet Work in Canada

The level of work in all areas on the sorghum and millet grains has been very low in Canada mainly because their production is uncommon here. Indeed in some parts of Canada it is impossible to get the grains to mature. The IDRC has been one of the main instigators of work on these grains and Table 2 outlines the projects which they have funded.

To support the applied sorghum and millet improvement projects in the developing countries IDRC has encouraged some basic research in well-equiped Canadian laboratories to attempt to solve some of the more fundamental problems limiting production. The Plant Science Dept. at Laval University and the Crop Development Center at the University of Saskatchewan have been studying drought tolerance of these crops since one of the major constraints in semi-arid areas is a low water supply.

In the project at Laval, methods of screening large quantities of breeding material for drought tolerance at an early age were investigated in collaboration with a sorghum-breeding project in Senegal.

At the University of Saskatchewan a more fundamental approach was used by studying the various plant hormones involved in the drought tolerance mechanism and their balance and interactions within the plant. In this very complex research area, the project succeeded in identifying and quantifying various hormones and in doing so developed a methodology that could perhaps be used for screening breeding material to determine its degree of drought tolerance. The methods have potential for application to other species of crop plants since the investigators have shown that the genetic variability in drought tolerance in sorghum is correlated with variability in hormone profiles.

The third project in Table 2 was conducted at NRC in Saskatoon and involved preliminary work in exploring the possibilities of making a cross between sorghum and maize using modern tissue culture techniques. The long term objective was to combine some of the best characters of both sorghum and maize. For instance if the drought tolerance, hardiness and disease resistance of sorghum could be combined with the high-yield, desirable grain characteristics of maize, the result might be a very valuable new crop.

The last four projects in Table 2 involve grain milling and food quality and they are highly dependent on desirable quality characteristics of the grain. One of the major problems in the utilization of sorghum or millet is the efficient dehulling of the grain. Both grains are covered with a tightly adhering pericarp layer and sorghum grain also frequently bears a heavily pigmented testa layer.

The project at the University of Guelph studied the dehulling of sorghum and millet with a recently developed attrition-type mill. In laboratory trials they found that the mill worked reasonably well and subsequently two of the dehullers were installed in Nigeria. On site, however, the mill proved ineffective and it was at this point that NRC in Saskatoon (PRL) was approached to study the problem.

Initial work at PRL involved evaluating, comparing and modifying dehulling equipment. Eventually a simple abrasive thresher was identified and subsequently modified until it effectively dehulled sorghum, millet and a variety of legume grains. Several models of the dehuller utilizing carborundum stones have been built and successfully field tested in many developing countries. In the use of the mill in Nigeria it was discovered that millet flour produced by the mechanical method did not meet the approval of the consumer simply because they were not accustomed to the gray-green colour of the flour. Research at PRL demonstrated that the traditional process indeed produced whiter flour due to a bleaching process which rendered pH-sensitive pigments colourless. A simple acid decolourizing treatment was subsequently developed to enable the production of mechanically processed white millet flour. The most recent work at PRL has involved development of a laboratory dehulling device which plant breeders can use to predict grain milling quality. This instrument can test 8 samples at one time and requires only 10 g of grain. This technology is nearly ready to be incorporated into actual plant breeding programs.

One of the primary objectives of the last two projects (Table 2) was to develop technologies which might permit significant replacements of wheat flour by sorghum, millet, maize or other flours. This would have the effect of reducing the quantity of imported wheat in some developing countries.

In the project at the College of Home Economics at the University of Saskatchewan studies showed that good quality Nigerian-type bread can be made from composite flour consisting of 80% wheat and 20% sorghum. Good quality composite flour bread was also produced from 80:20 wheat/maize and 80:20 wheat/millet flour using the same methods. This project also developed high-protein foods such as noodles and snacks made from cowpea-sorghum and cowpea-millet mixtures.

In the project at the University of Manitoba a mechanical dough development process for non-wheat flours was developed. In this process dough "ripening" was replaced by repeated sheeting of the dough between hand-propelled sheeting rollers. It was shown that this method was an effective and practical method of producing acceptable bread from composite flours. The non-wheat flours included: sorghum, millet, cassava, maize, faba beans, and triticale. Satisfactory bread but of diminished loaf volume, was obtained from composite flours containing up to 30% non-wheat flour.

Besides IDRC supported projects there are several Canadian groups which are working on sorghum as a potential Canadian crop (Table 3). King

Grain Ltd. in Chatham, Ontario and the Agriculture Canada research station in Lethbridge are breeding for varieties which are suitable for growth in Ontario and southern areas of Alberta, Saskatchewan and British Columbia. According to Agriculture Canada, sorghum has good potential for the hot, dry southern areas of these provinces and it is projected that there could be several hundred thousand acres of grain sorghum on Alberta dryland alone within the next 15 to 20 years. Presently the acreage devoted to sorghum in Canada is relatively small; about 1,000,000 lbs are produced annually in Alberta and Ontario. The Alberta Corn Committee and Agriculture Canada have recently established a $97,000.00 program to study problems of establishing sorghum stands, production and processing. The nutritive value of Alberta-grown sorghum for monogastric animals, such as hogs will also be assessed. In conjunction with Palliser Distillers, sorghum will also be tested as a substrate for alcohol production. Interest in this entire project has been high since Alberta has been unable to produce enough corn for its own use and therefore must rely on corn imported either from the U.S.A. or from Manitoba.

C. Available Expertise in Grain Quality

From the preceding section it is evident that few Canadian scientists have had experience with sorghum or millet grains. Even fewer have had experience or are aware of the problems involved in assessing their grain quality characteristics.

Canada does, however, have considerable expertise in the area of grain quality of wheat and other grains which are indigenous to Canada. It is possible that this expertise could be utilized in solving some of the problems involved in sorghum and millet grain quality.

Every year for the last 64 years NRC and Agriculture Canada has sponsored a meeting which brings together individuals interested in grain quality. Three subcommittees within the "Expert Committee on Grain Quality" meet annually; the subcommittee on a) wheat, b) barley and c) oilseeds and special crops. The subcommittees are charged with the responsibility of evaluating the intrinsic quality of new cultivars of the principle cereals and oilseeds grown in Canada in co-operative tests operated by the Agriculture Canada research branch. Normally, potential new varieties will be rated as equal to, better than, or inferior to certain standard varieties which may in some cases be reference varieties in the official grade schedules of the Canada Grain Act. Testing methods for determination of intrinsic quality of the various cereals and oilseeds are continually reviewed by the subcommittees and by the "Expert Committee on Grain Quality" with the objective of making them as relevant as possible to end use criteria employed by domestic and overseas consumers. Encouragement and guidance are given to aid in the development of more effective testing methods. Research in crop quality is reviewed annually and these research reports are incorporated into the yearly report of the Expert Committee.

The main research teams which have contributed to these yearly reports are listed in Table 4. This list is only complete with respect to the major teams involved in crop quality research. In addition, other Agriculture Canada research stations and some university departments are doing crop quality work.

The quality criterion for Canadian grains have taken these committees decades to develop and many of the tests are still being re-analyzed and modified. To give you an idea of the complexity involved in the licensing of a new wheat variety, Table 5 gives an example of the quality indices which are measured for every potential bread wheat and durum wheat variety. All of the quality tests can be fairly rapidly measured and this is one of the major requirements for any test that a plant breeder must use.

D. Future Directions

The type of information that was given in Table 5 for Canadian wheats is needed for sorghum and millet grains. Rapid analytical methods are required to help select from over 15,000 sorghum varieties and over 7,000 millet (Pennisetum americanum) varieties available in the ICRISAT collection. In the future, quality criterion will also be required for the other species of millet such as the proso millet, little millet, finger millet, ditch millet, browntop millet, hungry rice millet and others.

Canadian institutions, who have expertise in the area of crop quality, can play a role in this work by the application of the knowledge and methodologies developed in solving our own crop quality problems. In the application of methodologies, however, considerable care will be required. Many of the tests used on bread wheats, for example, cannot be directly applied to sorghum or millet. An example from my own experience illustrates this point. Bread wheats are always milled on roller milling equipment and therefore milling quality tests are normally done on a laboratory roller mill (Buhler laboratory mill). Sorghum and millet grains, however, are usually processed in carborundum stone type dehullers or other abrasive equipment. Therefore, it was necessary for us to design a completely different type of laboratory mill which could be used to predict the milling quality of these grains.

In summary, I can say that only limited progress has been made in defining quality characteristics of sorghum or millet grains. It is safe to say that many years of work by many individuals all over the world will be required before they are established.

TABLE 1

PRODUCTION AREAS OF SORGHUM AND MILLET

(IN THOUSANDS OF HECTARES)

	Sorghum	Millets
Africa	13810	16360
Asia	18320	45730
North and Central America	7460	
South America	3260	250
World	43650	65450

Source: FAO Production Yearbook 1977

TABLE 2

IDRC-SUPPORTED SORGHUM/MILLET PROJECTS IN CANADA

Project	Project Leader	Address
Drought tolerance (1973-77)	Dr. P.M. Saint-Clair	Plant Science Dept. Laval University Quebec City, Quebec
Drought tolerance (1974-80)	Dr. G.M. Simpson	Crop Development Centre University of Sask. Saskatoon, Sask.
Sorghum X Maize hybrid (1975-78)	Dr. O.L. Gamborg	Prairie Regional Lab. NRC, 110 Gymnasium Road Saskatoon, Sask.
Grain milling (1972-73)	Dr. J.M. Deman	Dept. of Food Science University of Guelph Guelph, Ontario
Grain milling (1973-80)	Dr. C.G. Youngs	Prairie Regional Lab. NRC, 110 Gymnasium Road Saskatoon, Sask.
Composite flours - Legume utilization (1973-75)	Prof. A.K. Sumner	College of Home Economics University of Sask. Saskatoon, Sask.
Composite flours (1971-74)	Dr. W. Bushuk	Faculty of Agriculture University of Manitoba Winnipeg, Manitoba

TABLE 3

OTHER SORGHUM PROJECTS IN CANADA

Project	Project Coordinator(s)	Address
Grain breeding	Dr. F. Scott-Pearse	King Grain Ltd. Chatham, Ontario
Grain breeding	Dr. D.J. Major	Research Station Agriculture Canada Lethbridge, Alberta
Management, production, processing	Alberta Corn Committee Agriculture Canada	Alberta

TABLE 4

CANADIAN INSTITUTIONS WITH ACTIVE

RESEARCH TEAMS IN CROP QUALITY.

Institution	Area of Expertise
*1. Grain Research Laboratory Canadian Grain Commission Winnipeg, Manitoba	wheat, barley, rapeseed
*2. Dept. of Plant Science The University of Manitoba Winnipeg, Manitoba	wheat, also wild rice, rye, rapeseed
*3. Dept. of Crop Science and the Crop Development Centre University of Saskatchewan Saskatoon, Sask.	wheat, rapeseed, legumes, barley, sorghum, sunflower
*4. Prairie Regional Laboratory National Research Council Saskatoon, Sask.	legumes, also sorghum, millet, barley
*5. Food Research Institute Agriculture Canada Ottawa, Ontario	oats, rapeseed
*6. Research Station Agriculture Canada Ottawa, Ontario	wheat, oats, rapeseed
*7. Research Station Agriculture Canada Winnipeg, Manitoba	wheat, barley

* Active participants of the Expert Committee on Grain Quality (Agriculture Canada)

TABLE 5

CANADIAN QUALITY TESTS FOR BREAD WHEATS AND DURUM WHEATS

A. Bread Wheat Quality Tests

Wheat Data	Milling Data	Flour Analytical Data	α-amylase Activity Data	Water Absorption Data	Dough Testing Data	Baking Data
Grade	Flour yield	Protein content	Falling number	Farinogram	Farinogram	Loaf volume using
Test weight	Flour ash	Protein loss on	Flour amylograph	Baking using	Baking strength	-AACC-MPB
1000 Kernel weight	Flour colour	milling	viscosity	-Remix-MPB	index	-Remix-MPB
Protein content	Starch damage	Wet gluten	Flour gassing power	formula	Chorleywood	-Chorleywood
Ash content		Pigment content	α-amylase activity	-Chorleywood	parameters	-Remix-MPB
SDS sedimentation			-wheat		Extensigram	formula
			-flour		parameters	

B. Amber Durum Wheat Quality Tests

Wheat Data	Semolina Data	Spaghetti Data	Gluten and Cooking Quality
Grade	Yield	Colour	Sedimentation
Test weight	Ash content	-brightness	volume
1000 Kernel weight	Protein content	-purity	Brownness
Vitreous kernels	Wet gluten	-dominant	Compressibility
Ash content	Pigment content	wavelength	Recovery
Protein content		Pigment	Tenderness
Pigment content		content	
Kernel size distribution		Pigment	
		loss	

FOREST RESEARCH PRIORITIES
Paper by J. Cayford

Rapporteurs' Report
L.G. Lessard

The major problems requiring forestry research in the SAT include the following:

1) Land rehabilitation and reclamation and the arresting of desertification with tree planting;

2) Maintenance and enhancement of environmental quality and in particular water conservation;

3) Forest products utilization and processing technologies;

4) Mechanization of tree planting operations, especially in the many situations where there is a shortage of labour or where there are seasonal labour conflicts between forestry and agriculture;

5) Development of agroforestry and silvipastoral research methodologies, especially with respect to forage production in dry areas.

The first two of the above are perhaps of highest priority. With respect to cooperative research between Canadian and developing country or international institutions, the most promising areas are in basic research which can be done in the greenhouse or laboratory. Specific aspects include:

a) tree physiology, especially propogation techniques for useful leguminous and non-leguminous nitrogen fixing species;

b) seed production technology and direct seeding techniques;

c) symbiotic relations of tree roots and microorganisms including Rhizobia, Mycorrhizae and Frankia (recent Canadian work with <u>Alnus crispa</u> which is reaching an industrial stage has important implications for other species of this genus, for example in Latin America and in Nepal);

d) planting technology, especially the use of container grown trees;

e) application of integrated pest management techniques to forestry, particularly monitoring methodologies and the use of pheromone traps and other such devices;

f) forest fire monitoring methods and control technologies such as the Canadian Forest Fire Behaviour System; and,

g) development of energy technologies based on forest biomass with due regard for socioeconomic considerations of such technologies in developing economies.

REPORT OF THE WORKING GROUP ON FOREST RESEARCH

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INTRODUCTION

Members of the ad-hoc Forestry Working Group met in Ottawa on October 7, 1980 to discuss forest research activities which might be undertaken in Canada for the benefit of developing countries.

The meeting was called by L.G. Lessard, Associate Director, Forest Science, International Development Research Centre. It was a follow-up to the United Nations Conference on Science and Technology for Development (UNCSTD) held in Vienna in August 1979, at which time the Government of Canada announced the adoption of a policy to encourage the application of Canada's domestic research and development capabilities to the solution of problems in the developing countries. It is Canada's intention that direct linkage should be established between the research and development systems of developed and developing countries through co-operative arrangements.

The purpose of the Working Group meeting was to discuss the preparation of a background paper on Canadian research work and expertise in the forestry sector which could be applicable to the developing countries. More specifically the Working Group was:

1. To identify priority research areas that could be undertaken at Canadian institutions and which would be applicable to the developing countries with particular reference to the semi-arid tropics; and

2. To assess the present Canadian capability and suggest appropriate locations for particular research projects.

At the October meeting a number of research areas were identified and individual members of the Working Group accepted responsibility for preparing brief statements. I agreed to collate these statements and to make the presentation to this gathering. The report should be considered as a very preliminary document which should be updated after this meeting.

Six priority research areas have been tentatively identified. These areas are as follows: (1) Wood Utilization (2) Energy from Biomass (3) Forest Protection (4) Regeneration and Afforestation (5) Forest Land Classification and Inventory (6) Tree Nutrition and Physiology.

WOOD UTILIZATION

There is an unending list of utilization studies that should be undertaken including species identification, and characterization and development of appropriate technologies for both primary and secondary conversion of tropical hardwoods. Also, there is an immediate need for research on affordable housing based on low cost domestic products. In addition, in many developing countries only a few preferred species are being exploited resulting in massive waste and damage to the forest. The properties of underused and unused species must be identified and directed to specialized uses or to substitution for higher value species. In countries which lack sufficient forest resources, consideration should be given for the utilization of agricultural residues from sugarcane, rice, oil palm, etc. for the production of forest products. Last but not the least, is the urgent need for education and training of workers at all levels i.e., professional, technical and operating.

ENERGY FROM BIOMASS

Canada could undertake a good deal of useful work and develop appropriate technologies in this broad area for transfer to the developing countries. Nearly one-half of all timber cut in the world is used for fuel. In the tropics about 80% of the annual cut is firewood and 90% of the population rely on it for their domestic needs. But in much of the semi-arid tropical regions population growth is outstripping forest growth. This increase in population coupled with rising (imported) oil costs is putting considerable pressure on the forests for the supply of fuel wood in both urban and rural areas.

Research should be aimed at the development of efficient systems of burning wood directly (eg. better wood stoves, etc.) for domestic use or to generate power (eg. densified biomass) and at converting wood into more versatile fuels - charcoal, alcohol and gas. Some work has been done on charcoal research in the tropics but much more is needed on the production and use of all these fuels as well as fuel wood sources (suitable species, energy plantations, etc.) and utilization of waste material including agricultural residues.

FOREST PROTECTION

Canadian institutions have considerable expertise in the fields of forest fire science, forest entomology and forest pathology. They have the potential to advise, guide and train workers in these fields and to conduct collaborative studies. Canada has relatively little experience in forestry problems caused by birds and animals and should not be relied on for help in this area.

Research and development of forest fire hazard measurement and application would be suitable for immediate work. The Canadian Forest Fire Behavior System is amenable for transfer to other countries following refinement to suit local conditions. Spain, Venezuela, Argentina and Portugal are presently trying out existing tables with considerable success and Mexico is planning to test the System. Guidance can be provided to permit the required refinements for specific fuel types and the development of local fuel and hazard classifications.

In view of the quarantine requirements for importing insects and pathogens into this country and the necessity for field observations in many aspects of insect and disease research, it may not be practical to undertake research in these fields in Canada. Collaboration and guidance can be provided and some of the more fundamental laboratory studies can be undertaken on serious pests e.g. taxonomy and mycology, toxicological screening, pheromone analysis, virology, bacteriology, etc. (some of the latter may have to be done under quarantine conditions).

REGENERATION AND AFFORESTATION

Rehabilitation of degraded forest land is an urgent problem in arid, semi-arid, and tropical areas of the world. About 1,000 million hectares of once-forested land have been turned into semi-desert in recorded history. Dry seasons are long and in most of these regions annual rainfall is less than 700 mm.

Overcutting the forest and brushland for fuel and burning the grassland to create better pastures destroys vegetation on millions of hectares annually. However, with appropriate planting and good management much of these wastelands can be made to produce good crops. Every twig produced is of value to people starved for fuel and desperate for building materials.

Drought is particularly significant in regions where "desertification" of vast areas is having disastrous effects on both man and the environment. Research is needed in the introduction of drought- and disease- resistant tree species, on proper management techniques for stabilizing the environment, and particularly on methods for dune fixation. To increase yields, research is also needed to improve afforestation techniques using genetically improved stock, in combination with appropriate tending and thinning regimes. Research could be conducted in Canada on evaluating tree characteristics to determine the suitability of various species for afforestation projects.

FOREST LAND CLASSIFICATION AND INVENTORY

There are few issues or problems in developing countries that do not involve the land and the natural resources. Good management decisions and good political decisions are dependent upon an adequate data base. Multistaged inventories can provide information at reasonable costs. Approaches utilizing satellite imagery, aerial photography and ground sampling have been pioneered in Canada.

Concomitant with large data bases, there is a need for development of improved data handling capability and the use of computers by forest managers. Considerable efficiencies can be achieved by the use of mini and micro computers in a distributed data processing network, making the inputting and outputting of information more accessible than previously possible with large computing systems. Data entry and editing may now be done at the location where the information is generated. This makes it possible to utilize local knowledge for editing of input information and maintains more personal interest in the data base. In addition, managers have not used computer data bases as much as may be desirable for efficient decision-making. This has mainly been a problem because of limited accessibility to the data base and lack of software development (computer programs) to make information readily available to them. With greatly decreased costs for intelligent terminals there are new possibilities for distributed data processing and data base management systems. With this approach, there is the possibility to use remotely located computing devices as if they were local and to share information for efficient use of the data base for improved management of forest resources.

TREE NUTRITION AND PHYSIOLOGY

Two areas of tree physiology are considered to have high priority. The first area concerns mineral nutrition and particularly the matter of nitrogen fixation. The general principles outlined by Dr. R.W. Miller are equally applicable to forestry as they are to agriculture. The role of mycorrhizae symbiosis could be explored and the relationships between mycorrhizal plants and mineral absorption, resistance to pathogens and resistance to drought investigated. The question of mycorrhizae may be especially relevant in considering the afforestation of degraded forest lands. There may also be opportunities for genetics research to select for low nutrition-demanding species. The second priority area is that of vegetative reproduction. Physiological studies of vegetative reproduction may be very important in connection with the growing of shrub species for fuelwood production.

CANADIAN INSTITUTIONS

The second objective of the Working Group was to assess Canadian capability in forestry research and development and to identify possible locations for research projects. As with the research areas, this listing must be considered preliminary and could, I believe, be expanded if desired following this meeting:

UNIVERSITY FORESTRY DEPARTMENTS

British Columbia	-	Reforestation and afforestation
	-	Introduction of exotic tree species -plantation research for semi-arid country
Laval	-	Forest fire research
New Brunswick	-	Forest fire research

Alberta	- Role of fire and grazing on forest productivity
Lakehead	- Growth and yield of plantations - Forest resource planning
Toronto	- Forest pathology, Eucalyptus - Occurrence of forest fires - Physiology of arid and vegetative regeneration

CANADIAN FORESTRY SERVICE

Newfoundland Forest Research Centre	- Reforestation and afforestation - Genetic improvement of native trees and trials of exotic species - Energy from forest biomass
Maritimes Forest Research Centre	- Tree improvement research; tree nutrition and physiology - Forest entomology and pathology
Laurentian Forest Research Centre	- Forest stand inventory - Forest entomology and pathology - Forest biomass for energy
Great Lakes Forest Research Centre	- Forest regeneration and entomology - Tree nutrition and physiology - Forest fire research
Northern Forest Research Centre	- Forest inventory, computer mapping, data base management systems - Forest hydrology - Forest fire research
Pacific Forest Research Centre	- Forest entomology and pathology - Remote sensing for forest inventory - Energy from Biomass - Forest fire research
Forest Pest Management Institute	- Forest insect pest management
Petawawa National Forest Institute	- Regeneration and afforestation - Forest inventory and sampling design - Forest fire research - Forest genetics

OTHERS

FORINTEK Canada Corporation	- Forest products utilization, except for pulp and paper

	-	Energy from forest biomass, chemicals and adhesives, animal fodder, composite wood products.
Forest Engineering Research Institute of Canada	-	Forest harvesting.

CONCLUSION

In conclusion, I would suggest that these discussions concerning our research and development capability are just one part of a much larger international forestry interface. There are other forestry initiatives that might be undertaken including a centre for international forestry which would possibly be located at one of our university forestry faculties.

AQUACULTURE
Paper by G.I. Pritchard

REPRODUCTIVE STUDIES IN FISH
Paper by P.J. Heald

Rapporteurs' Report
W.H. Allsopp and F.B. Davy

Discussion

Interest was expressed in the quick production of fish from the tropical environment, the concomittant problems of insects and water-borne vectors of disease, the multiple use of water for irrigation and fish culture, and the need for using indigenous species. The urgency of food supplies was emphasized and a quick answer posed a dilemma to many countries where entrepreneurs offered "package deals with exotic species".

The merits of using tilapias, local carps, mulluscs, and other species indigenous to the region if not autochthonous to the locality, were emphasized.

The problems of pesticide residues, fish kills, and productivity in irrigation waters were also mentioned. The discussion emphasized the need to maximize water use in the semi-arid tropics, using to best advantage the numerous irrigation reservoirs, canals and man-made lakes by the simplest low-cost production systems such as floating cages or fixed enclosures giving maximum yields of fish. The need was stressed for collaborative programs for the transfer of such technology adapted to the ecological and cultural needs of particular countries. The lack of access to relevant information for countries of the region was emphasized.

The Nova Scotia Technical University made a presentation indicating the range of activities and services which its new facilities were capable of undertaking and suggested some specific areas of need in processing equipment designed to reduce post-harvest losses and facilitate product development. It was indicated that refrigeration presented an opportunity for fish preservation but was also energy intensive and costly in most tropical countries.

The use of meat and bone separators for processing small and unusual fish species as good products for human consumption was indicated to be a highly desirable technology which can be readily applied with suitable testing and modifications.

It was also indicated that there has been considerable liaison and inputs from various Canadian federal laboratories which have been pivotal in the successful results of very effective programs in fish breeding, oysterculture and fish product development in all the developing continents (Latin America, Africa and Asia).

Disciplinary Areas of Canadian Competence

The subject areas which seemed to be most relevant in response to the known needs of the semi-arid tropics were as follows:

1. Fish reproduction, juvenile rearing and seed supply;
2. Mariculture systems for molluscs and macro-algae;
3. Post-harvest processing technology and product development;
4. Fish health (disease/vaccines, nutrition);
5. Supportive literature (Canadian SDI literature, monitoring capability).

The above subject areas were deemed to be most significant from the viewpoint of food impact, institutional liaison between Canada and the LDCs, and from the priorities of LDCs expressed and well described in many published assessments.

These disciplines seemed to reside in a number of institutions across Canada but many key centres worked in collaboration in an interface of research/development capabilities technically shared by government, industry and universities. In this regard therefore, it may be premature to identify a lead institution and/or program leaders in each case. However, in view of past and current activities and available facilities, it was felt that the geographic locations may be indicated as follows:

a)	Fish reproduction systems	British Columbian/Newfoundland institutions
b)	Processing and product development	Atlantic Province institutions
c)	Mariculture systems for mulluscs and seaweeds	Atlantic Province institutions
d)	Literature support	Cdn. SDI and institution to be identified
e)	Fish health (nutrition, disease vaccines)	Ontario laboratories

It was felt that though the priority ratings were as indicated above, the needed organizational arrangements may well result in certain program areas preceeding others. It is urged that these should be planned as three-year focussed programs which will permit at least three substantive programs of needed underpinning research as well as the building of relevant institutional competence by mutual exchanges, and training of research leaders, with phased medium term and longer term linkages.

Further activities are necessary in order to match better the priority research areas identified and specific Canadian capability.

Research and Experimental Development in support of Aquaculture in the Semi-Arid Tropics[1]

G. I. Pritchard

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Ottawa, Ontario

K1A 0E6

1) Paper presented at Symposium on Canadian Agricultural Research Priorities, International Development Research Centre, Ottawa, November 6-7, 1980.

The Government of Canada has announced a policy of encouraging the application of Canada's domestic research and development capabilities to the solution of problems of the developing world. Food production poses the most acute of these problems, particularly in areas where water, the most essential nutrient for man and the keystone to all food production systems, is limited. Thus, in the semi-arid tropics[1] where national policies and programs give priority attention to the management and conservation of water, the intensive culture and husbandry of aquatic plants and animals is but one further dimension of such activities. This paper undertakes to identify Canadian expertise with capabilities to respond to such opportunities and the growing number of aquaculture applications. It results from no special survey or study, and is limited by the author's inability to identify all such Canadian expertise.

Defining the need

Aquaculture is best viewed within the context of "holistic" use of land, freshwater and coastal marine resources. Programs that relate to water must embrace diverse categories of basic research, running the full gamut of natural sciences through bacteriology, biology, chemistry, geology, physics, engineering as well as a substantial range of specialties within the socio-economic and planning fields. Water-use planning includes flood-forecasting, emergency planning, river basin planning and management, water quality control, as well as weather forecasting.

Within the semi-arid tropics, fish production is regularly tied to water impoundments, reservoirs, irrigation systems, as well as to a few natural water systems. In countries that border on sea coasts, culture in brackish or inshore waters may also be involved, and "sea-run" systems may occasionally be possible for anadromous or catadromous fish. When used, aquaculture provides alternative protein sources and diversity for human diets, often with a minimum of additional infrastructures.

Important biological, technical and economic factors influencing the development of aquaculture are identified in Figure 1. Numerous models (e.g. Pillay, 1977; Pritchard, 1976)

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1) e.g. North-Central Africa, Western and Central Asia, Mexico, North-East Brazil, Peru, Chile, etc.

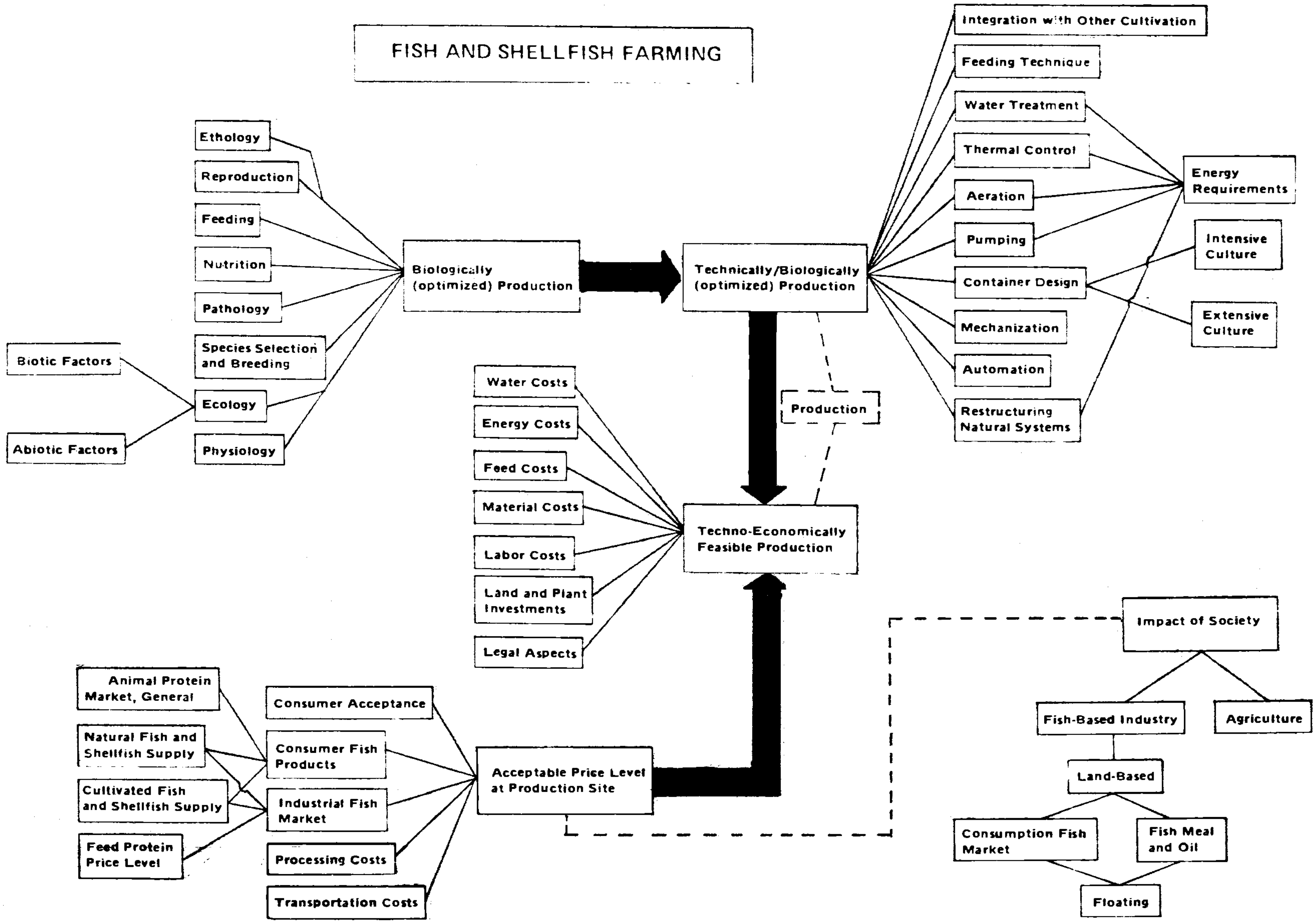

Figure 1. Important biological, technical and economic factors influencing the development of aquaculture.
Redrawn from Ackefors, H. and C. G. Rosen, 1980.

exist for analyzing aquaculture requirements, this model was selected because it separates quite clearly the inputs required to optimize biological productivity from the technology, economic feasibility and business concerns that tend to be more site specific. Thus the series of blocks (ethology, reproduction, feeding, nutrition, pathology, species selection and breeding, ecology, and physiology) in the upper left of the figure point to the leading scientific areas within which knowledge might most readily be transferred from Canada to developing countries. Other areas (e.g. life support technology and engineering development, design and evaluation of production systems, legal/ institutional/strategic planning, food storage and consumer acceptability, production economics, and marketing) may be equally important to a successful aquaculture system and have a requirement for inputs from Canadians, but frequently are done best near the problem site.

Although the need to stimulate the indigenous capabilities and opportunities for its extension is well recognized, there remains much need for international assistance to aquaculture development in many countries. Recently, an Ad Hoc Consultation (FAO, 1980) gave special attention to international support to research in aquaculture. Having been called at the suggestion of the Technical Advisory Committee (TAC) of the Consultative Group on International Agriculture Research (CGIAR) its recommendations are of interest to all agencies. The Consultation concluded, among other things, that additional international research effort was needed for the rapid development of aquaculture and recommended that particular emphasis be given to research on tilapias, carps, mullets, and milkfish. This emphasis should be balanced between:

(a) in-depth research on seed, health, feed and genetic improvement, in that order, and
(b) applied research on total culture systems.

These subject areas were broadly interpreted by the Consultation: research on seed was considered to include research on reproductive physiology, research on regulation and control of gonad maturation and spawning, research on fry and fingerling production, and in short all that is needed to produce seed reliably and cheaply. The other fields, health, feed, and genetic improvement, were similarly considered in a broad sense. Specific details on these concepts can be obtained from other planning documents (e.g. UNDP/FAO, 1975; 1978).

In focussing on the semi-arid tropics, the elements of inland aquaculture must accommodate several limiting factors. Unlike in Canada where heat and not water is often the controlling factor, approaches must intensify fish production to maximize use of limited water reserves. Moreover, most water impoundments are man-made, thus seldom possessing indigenous fish suitable for culture. Remoteness, costs, and distance from other industries, dictate an assiduous use of fertilization and food supplementation. Basic research priorities in these circumstances must address the careful selection of improved stocks for introductions, control of fish health, ecological impacts, together with the bio-energetics and dynamics of ponds. Transferability and appropriateness of production technologies, control over the full life cycle of stocks, as well as the development of indigenous species for local use and for use elsewhere should be addressed when warranted. Likely candidate species include tilapias,carp, catfish and freshwater prawns that have well developed technologies, some of which are suitable in polycultures. Emphasis will be placed upon "plankton-eaters" and in some cases herbivores, and an increased use of cages and of ponds of a size that are manageable is foreseen.

The basis for these perspectives come from looking at specific cases in Africa. E. R. Broughton (1980) who recently assessed the potential for the inland fisheries industry in Northern Region of Ghana which is spread over 70,000 square kilometers. The most northern reaches of Lake Volta are located in the southern part of the Region. Three water reservoirs ranging from 550,000 to 1,230,000 m^3 storage are already established, which could be used for year-round fish culture and juvenile fish rearing. Four others are in the planning stages. Other smaller dams and dug-outs exist in the Region, estimated to be 85 in number. Still this region is less advanced than the Upper Region of Ghana where records indicate 300 odd dams and dug-outs having surface areas ranging from 2.5 ha to 1860 ha. Plans exist for construction of an additional 120 earth dams each with a minimum capacity of 12000 m^3 of which a selected number will be equipped with 10-½ ha fish ponds below the dam. Most of the small dam reservoirs and dug-outs dry up during the dry season, however this would not prohibit fish culture activities on a planned seasonal basis. Such aquaculture schemes will play a key role in rural development of fish farming. He noted that costs of reservoirs were justified as a result of multi-uses, and identified a significant role for small floating cages. Several species of tilapia, carp, catfish and Nile perch may be bred in captivity and are culturable under such circumstances.

In contrast, Cross (1980) notes that aquaculture has a long history in Egypt among the peasant farmers of the northern Nile Delta. The principal system in operation uses ponds of less than 30cm depth to rear the mullet as an annual crop, obtaining the fry from wild stocks on the Mediterranean coast. No feed or fertilizers are used, and yields average 325 kg/ha in well managed ponds. While the fish farms are adequately productive, the main purpose of many of these farms is the reclamation of the huge areas of saline-alkaline lands in the northern Delta region. Some are derelict agricultural areas whilst others are permanent intermittent wetlands or even lake margins which are flooded to a depth of up to 0.7m. Gross and net yields from reclamation aquaculture are higher than those from traditional agriculture. From recent studies it is clear that up to 50,000 ha of derelict saline-alkaline soils and intermittent wetlands around the northern Delta could be developed, with potential yields of up to 650 kg/ha of mullet if fertilization and feeds were used.

In areas such as in the Sudan coastal areas of Mexico and Brazil where marine or brackish water cultures are applicable, other problems emerge. Here, greater emphasis must be placed upon conflicts in coastal zone management and inventories of indigenous species. Molluscs, including both oysters and mussels together with clams, seaweeds and crustaceans emerge as candidates for development. Some species, such as mullet may be grown in both salt and freshwater. As with inland culture systems, greater mobility of stocks is desirable, requiring inputs of science on selection, disease control, and juvenile rearing. Support is also needed in areas such as toxicology, environmental physiology, and biological oceanography related to nutrition. Coastal fisheries also have a greater need for product storage and transport posing special problems in food technology. All aquaculture also requires support in information transfers, data processing as well as in the design and evaluation of experimentation.

The degree of success obtainable with various fish and invertebrate production systems is summarized in Table 1. These production figures compare with yields of 30-60 kg/ha of marine fisheries on continental shelves, and as low as 3-5 kg/ha from northern lakes in Canada. A more comprehensive overview of aquaculture development is presented by Pillay and Dill (1979). Greater attention probably should be paid in the future to indigenous species in the developing countries, of which much less is known.

On the other side of the coin, Robinson (1980) reports that the overall state of world fishery resources is not good. The slow growth rate - essentially a continuation of the trend in the 1970's - results from conventional marine finfish, which account for about 75% of the total production of living aquatic organisms, offering relatively poor prospects for increased catches. The situation is relatively more favourable in the developing countries where lightly exploited resources are somewhat more abundant than in the developed countries where technological innovation has led to the earlier heavy exploitation of stocks in adjacent waters. Even within the developing countries, however, given a projected rate of population increase of over 2%, the rate of growth of production will be inadequate on average to maintain per capita levels of supply, notwithstanding the possibilities of diverting to direct human consumption some of the

TABLE 1: THE PRODUCTION OF FISH AND INVERTEBRATES

SPECIES	COUNTRY	TECHNIQUE/SITE	PRODUCTION kg/ha	TYPE OF CULTIVATION	REMARKS
<u>Finfish</u>					
Carp	India	Pond	max 110	Extensive, Polyculture	
Carp	India	Pond	300-900	Semi-intensive, Polyculture	
Carp	India	Pond	max 2,800	Semi-intensive, Polyculture	Feeding
Carp	China	Lake	300	Extensive, Polyculture	Stocking of seed only
Carp	China	Pond	3,500-4,500 (max 15,000)	Semi-intensive, Polyculture	Manure
Catfish	USA	Cage(Pond)	5,400	Intensive, Monoculture	Feeding
Tilapia	UAR	Lake	136-678	Semi-intensive, Polyculture	Feeding; together with mullets and eel
Tilapia	Cameroon	Pond	980-3,225	Semi-intensive, Monoculture	Feeding
Mullet	Taiwan	Pond	2,500-3,500	Semi-intensive, Monoculture	Feeding
Milkfish	The Philippines	Pond	300-1,000	Semi-intensive, Monoculture	Feeding, Fertilizer
Milkfish	Taiwan	Pond	1,800-1,900 (max 3,000)	Semi-intensive, Monoculture	Feeding, Fertilizer
Eel	Taiwan	Pond	3,500	Semi-intensive, Polyculture	Feeding
Rainbow trout	Taiwan	Pond	100-200	Extensive, Monoculture	
Rainbow trout	Taiwan	Pond	150,000-300,000	Intensive, Monoculture	Feeding
Rainbow trout	USA	Silo	max 6,500,000	Intensive, Monoculture	Recirculating systems, Feeding
Yellowtail	Japan	Cage	max 280,000	Intensive, Monoculture	Feeding

TABLE 1: THE PRODUCTION OF FISH AND INVERTEBRATES (Cont'd)

SPECIES	COUNTRY	TECHNIQUE/SITE	PRODUCTION kg/ha	TYPE OF CULTIVATION	REMARKS
Molluscs					
Oyster	USA	Ponds, Bays, Rafts, Beds	10-1,000 (max 5,000)	Semi-intensive	Planting of seed oysters. Predator control
Oyster	Japan	Buoy, long lines	53,000 (meat)	Semi-intensive	Planting of seed oysters
Blue mussel	China	Buoy, long lines	50,000	Semi-intensive	Natural settling of seeds
Blue mussel	France	Poles	4,500	Semi-intensive	Natural settling of seeds
Blue mussel	Spain	Rafts	600,000	Semi-intensive	Natural settling of seeds
Crustaceans					
Shrimps	The Philippines	Pond	250-900	Semi-intensive	Feeding
Shrimps	Japan	Tank	2,000-6,000	Intensive	Feeding
Shrimps	China	Pond	1,500	Semi-intensive	Feeding
Prawns	Hawaii	Pond	4,000	Semi-intensive	Feeding

Sources: J.E. Bardach, J.H. Ryther and W.O. McLarney, Aquaculture - The Farming and Husbandry of Fresh Water and Marine Organisms, Wiley-Interscience, New York 1972.

H. Ackefors et al., Aquaculture in People's Republic of China, Royal Swedish Academy of Engineering Sciences, Stockholm, 1977 (mimeograph in Swedish).

M. Huet, Textbook of Fish Culture, Fishing New Books Ltd., London, 1970.

Redrawn from Ackefors, H. and C. G. Rosen, 1980.

catches now used for reduction to meal and oil. Countries where significant declines in per capita consumption could occur include some of the least developed countries (LDCs), eg. Mali and Chad, which depend on heavily or moderately heavily exploited flood plain fisheries and where the expansion of aquaculture is likely to do little more than offset the effect of possible interference with the aquatic environment. Also, in Uganda and Burundi the lake fisheries are already fairly heavily exploited and the prospects for significant growth are not good. Others will view Robinson's outlook as overly pessimistic when compared with aquaculture accomplishments from countries such as China that have pursued intensive and integrated land/water use approaches (Pritchard, 1980). However, within the traditional fisheries sector, the largest volume of scientific efforts are still devoted toward inventoring wild fish resources for the purpose of curbing over-exploitation and with little innovation. Moreover, technological advances frequently were made with high energy costs, thus alternatives must be sought. It is significant to note that even in developed countries, many such entrenched attitudes are changing, as characterized by U.S. President Carter signing the "National Aquaculture Act" on September 27th of this year.

Degrees of intensification, of course, frequently relate to levels of fertilization of ponds and to external feeding. Supply and quality of feedstuffs in local supply are a major determinent of success in many systems of intensive culture. Thus, there is growing emphasis upon the culture of species that feed on lower forms of aquatic plankton, and upon herbivors.

Unlike in agriculture where plant production has attracted a large share of research efforts, the fisheries sector historically has been concerned mostly with the higher trophic levels. A shift in this focus is overdue, and expertise will likely be sought from other sectors. Canadians are already recognized as leaders in the subject of marine plants.

Canadian relevance

In an effort to match Canadian expertise to these and similar challenges, lists of expertise are shown in Annexes I to IV, and the expertise is displayed in Tables II-V against the priorities identified earlier. Available inventories (Canadian Committee on Oceanography, 1979; DFO, 1980; Emery and Emery, 1980; and NSERC, 1980) were used. More than twenty (20) universities in the country teach aspects of freshwater and marine fisheries, and have research capabilities; there are also two marine laboratories operated by consortia of universities. Federal laboratories have extensive resources, once reserved almost exclusively for national problems but with growing interests in "contracting-in" of research and experimental development applicable to a wide range of needs. Provincial research councils and commercial firms also have laboratory facilities and consulting expertise which could be tapped.

Reviewing the various scientific areas, one notes numerous imbalances. In the area of ethology systematics and plankton sorting, several centres (e.g. UBC, ROM, HML, etc.) stand out, and their expertise is sought regularly in international circles. Likewise, in areas of reproduction, physiology and endocrinology, Canadians like Drs. Hoar, Idler and Donaldson have provided outstanding leadership, and commercial developments have followed that include efforts to transfer the technology to developing countries. However, the areas of feeding and nutrition were long neglected, but this lag to a large part has been overcome with new and creative nutrition programs at Guelph, Halifax and West Vancouver. Feed manufacturers have followed, and now export both formulated feeds that standup to specifications. Expertise in processing technology is also being supplied.

Canadians within the last decade have made significant strides in the area that relate to fish health and the control of infectious diseases, so that even developed countries like Japan and West Germany turn regularly to us for advice. Also, there is good balance between universities, governments, and industry. A recent

TABLE II: Analysis of university expertise in Canada in support of aquaculture

	University (See Annex I)																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1. Ethology, systematics and plankton sorting		X		X						X															
2. Reproduction, physiology and endocrinology		X								X													X		
3. Feeding, feedstuffs evaluation					X					X															
4. Nutrition, nutrient requirements and diet formulations					X																	X			
5. Pathology, disease control and immunology	X		X		X			X				X			X				X				X		
6. Species selection and breeding				X	X					X			X												
7. Ecology, including contamination	X	X		X	X	X	X		X	X		X	X	X		X	X	X		X		X	X	X	X
8. Physiology of growth, juvenile rearing, etc.		X		X	X				X	X	X				X		X						X		
9. Life support technology and engineering development		X		X	X					X													X		
10. Design and evaluation of production systems					X					X															
11. Legal/institutional/strategic planning				X																					
12. Food storage and consumer acceptability																					X				
13. Production economics																				X					
14. Marketing																									

TABLE III: Analysis of commercial and non-profit laboratories and experimental facilities with a capability in aquaculture

Laboratories and Experimental Facilities (See Annex II)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33
1. Ethology, systematics and plankton sorting				X								X			X										X						X		X
2. Reproduction, physiology and endocrinology																																	
3. Feeding, feedstuffs evaluation		X																					X	X									
4. Nutrition, nutrient requirements and diet formulations																							X	X									
5. Pathology, disease control and immunology							X		X			X																				X	
6. Species selection and breeding															X	X	X																
7. Ecology, including contamination				X		X				X				X				X	X														
8. Physiology of growth, juvenile rearing, etc.				X										X												X							
9. Life support technology and engineering development	X				X	X						X						X									X	X	X				
10. Design and evaluation of production systems	X	X	X					X			X		X			X	X		X	X	X	X				X		X		X			
11. Legal/institutional/ strategic planning																																	
12. Food storage and consumer acceptability											X																		X				
13. Production economics																																	
14. Marketing																																	

TABLE IV: Analysis of consulting firms with expertise on aquaculture

Consulting Firms (See Annex III)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1. Ethology, systematics and plankton sorting							X								X						
2. Reproduction, physiology and endocrinology																					
3. Feeding, feedstuffs evaluation																					
4. Nutrition, nutrient requirements and diet formulations																					
5. Pathology, disease control and immunology																					
6. Species selection and breeding																					
7. Ecology, including contamination				X							X			X	X		X	X			X
8. Physiology of growth, juvenile rearing, etc.																		X			
9. Life support technology and engineering development					X			X										X	X	X	X
10. Design and evaluation of production systems		X	X		X			X	X	X	X		X						X	X	
11. Legal/institutional/ strategic planning	X				X	X					X	X				X				X	
12. Food storage and consumer acceptability																X					
13. Production economics																					
14. Marketing										X						X					

TABLE V: Analysis of Federal/Provincial research centres with a capability in aquaculture

	Research Centres (See Annex IV)																		
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1. Ethology, systematics and plankton sorting							X									X			
2. Reproduction, physiology and endocrinology					X														
3. Feeding, feedstuffs evaluation					X						X								
4. Nutrition, nutrient requirements and diet formulations	X				X						X								X
5. Pathology, disease control and immunology			X				X				X		X						
6. Species selection and breeding			X				X			X									X
7. Ecology, including contamination		X	X	X			X	X	X	X		X							
8. Physiology of growth, juvenile rearing, etc.		X	X				X			X					X				
9. Life support technology and engineering development			X				X			X	X	X			X				
10. Design and evaluation of production systems		X	X			X				X			X				X	X	X
11. Legal/institutional/strategic planning		X									X			X					
12. Food storage and consumer acceptability											X								
13. Production economics														X					
14. Marketing														X					

addition to this area is Connaught Laboratories which has undertaken an agressive vaccine development program with the potential of serving world markets. Efforts to develop experimental genetic programs (both for the selection of high-performance strains and for establishing methodologies for preserving genetic diversity and endangered strains) have moved more slowly. Innovative programs are however underway at centres such as the North American Salmon Research Centre in St. Andrews, Dalhousie University (oysters) and the NRC laboratory in Halifax (marine plants) in Ontario at Maple and Guelph, and in Winnipeg (trout).

Any survey of aquatic research shows a heavy concern for ecological studies, in part a hang-over from priorities in the mid-1960's and the concern for preserving the quality of the environment. However, there are specific areas of primary productivity and habitat quality that are particularly applicable to both fresh-water and marine aquaculture toward which Canadian expertise might be applied, although some reorientation may be required. Directly related are problems such as bioenergetics and growth, particularly in juvenile forms that often have peculiar feeding requirements.

A growing number of Canadian centres have become interested in the life-support technology for aquatic species and the associated engineering developments. Much of this work is conducted with a view toward commercial applications, although Canadian developments have tended to emphasize natural resource features. In general, the Europeans and the Japanese are further advanced in this field, although Canadian efforts could match the Americans in diversity and quality. Once carried through to design and evaluation stages, production systems tend to find themselves under some form of industrial umbrella, in part related to Canadian policies to move such research within industry. There are, here too, inconsistencies across the country, as heavy government expenditures on applications of aquaculture technologies such as salmonid enhancement tend to discourage the private sector.

Another factor is the lack of well defined legal definition and strategic plans.

Successful and reliable product development from aquaculture often requires inputs on food technology, together with economics and marketing. The Technical University of Nova Scotia is developing a new laboratory to service needs for fisheries technology, however little attention has yet been paid to resource economics and marketing. More expertise might be attracted to these problems if adequate encouragement were provided.

Regardless of the expertise in any one area, culture systems must ultimately be viewed within the context of applied systems approaches. There are many interfaces. Aquaculture should not be characterized by traditional disciplines and outlooks, but requires planned transdisciplinary approaches. In consideration of the overall expertise in all sectors, five regions of Canada emerge as having the mix of expertise desirable. There are:

(1) Halifax/St. Andrews
(2) Guelph/Toronto
(3) Vancouver/Nanaimo/Victoria
(4) St. John's, Nfld.
(5) Winnipeg

All have certain constraints. Wet laboratories are available, but not necessarily with desired temperature controls. Introduction of species exotic to Canada pose certain threats. Two regions do not have access to natural saltwater, and the latter two are centered mainly on one laboratory without the same range of industrial support and infrastructures in their immediate proximities.

Focussing attention on R & D relevant to aquaculture in developing countries of the world in any or all of these points should stimulate beneficial responses and more coordinated efforts. There may need to be specific institutional changes to improve flexibility of people, particularly so that they can work for periods of time in the developing world without a loss of security at home. All would benefit from having at least one specialist or professorship identified with international food production.

Conclusions

Aquaculture, or the farming of aquatic animals and plants in fresh, brackish and marine waters, is admittedly an age-old practice in many countries, but the very important role it can play in meeting the animal protein requirements of the world's expanding human populations has come to be realized only in recent years. Until recently, many people thought of "food from the sea" as a solution to the world's food problems. It has, however, become very apparent now that the contribution that the capture fisheries of marine and inland waters can make to food production is finite and the limit may not be too far off. On the other hand, there is clear evidence that aquaculture can produce substantial quantities of readily acceptable food of high nutrient value, at remarkably high rates of yield per unit area. The yields will largely be governed by the state of technology, levels of scientific inputs, and skill of the farmer, rather than the productivity of the environment and natural processes.

Canada has much credible scientific expertise of relevance to aquaculture in developing countries which, if so deployed, could bring benefits to all parties.

As to specific scientific approaches, refinements will be needed as production systems are targeted. Thus, considerable flexibility should be maintained. However, emphasis should be placed on the experimental as opposed to descriptive approaches, and many applications can be drawn from experiences in the agricultural sector with some qualification. Nevertheless, the following lists likely action areas:

(i) Beyond some early identification of behaviour patterns and production characteristics of fish to be cultured, including species indigenous to developing countries, the efforts on species identification and interrelationships should shift to larval and plankton studies, as indices of natural food supplies, pond dynamics, and water quality. Canadian expertise on functional properties of marine seaweeds will continue to be sought.

(ii) Emphasis upon use of artificially induced spawnings likely will continue, but attention should shift to such problems as sex-reversal, control of early sex maturation, and cryogenic preservation of sperm and eggs.

(iii) Feedstuffs evaluations will require analytical services and improved techniques for conducting performance evaluations. Special attention will be needed on supplemental foods.

(iv) Complete diet formulations will continue to be handicapped by inadequate background information on nutritive requirements, thus emphasis will likely continue practical feed formulations. Basic physiological work on nutrition would be most useful.

(v) Easy diagnosis of infectious disease organisms and knowledge of etiology of pertinent diseases will continue to be required. Attention on vaccine production should continue, including delivery and testing systems. Basic work on the immune mechanism of fish is needed to support this development.

(vi) Species selection and breeding requires the development of practical breeding systems. Quantitative genetics requires new experimental designs that cope with the wide ranging biological conditions of aquatic organisms.

(vii) Ecological disruptions caused by substances such as pesticides, heavy metals, etc. will need to be controlled, requiring a range of analytical expertise. Furthermore, aquaculture technologies should be applied toward the preservation of ecological balances, including control of vegetation in natural and man-made impoundments and waterways, and for the preservation of genetic and biological diversities.

(viii) Physiology associated with survival and growth of juvenile fishes presents many challenges to research and innovation, and principles that underlie many of these problems could be established and readily applied.

(ix) Food quality, storage, and consumer acceptability must be built into production systems, thus problems of food technology need priority attention.

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ANNEX I: Universities with research activities related to aquaculture

UNIVERSITY	TOPIC
1. University of Alberta, Edmonton, Alberta (Drs. T. Yamamoto, J. S. Nelson, etc.)	Fisheries ecology, bacteriology, virology
2. University of British Columbia, Vancouver, B.C. (Drs. R. F. Scagel, H. F. Stich, D. J. Randal, P. Larkin, R. J. Anderson, J. Zahradnik, etc.)	Algal physiology, fish physiology tumors, population assessments, marine microbiology, ethology, engineering
3. University of Calgary, Calgary, Alberta (Dr. R. D. Macdonald)	Virology
4. Dalhousie University, Halifax, N.S. (Drs. K. H. Mann, A. R. O. Chapman, L. E. Haley, R. W. Doyle, B. Wildsmith, C. J. R. Garrett, M. L. Cross)	Algal ecology, oyster genetics, law, coastal oceanography, economics
5. University of Guelph, Guelph, Ontario (Drs. S. Slinger, J. B. Sprague, K. Ronald, H. R. MacCrimmon, G. W. Friars, B. J. Holub, F. W. H. Beamish, J. R. Geraci, H. Ferguson, R. M. W. Stevenson, R. A. Johnston, R. D. Moccia, etc.)	Nutrition, genetics, pathology, toxicology, limnology, bio-energetics
6. Université Laval, Québec, P.Q. (Drs. J. J. Dobson, J. C. Terriault, etc.)	Littoral population dynamics of estuaries
7. McGill University, Montréal, Que. (Dr. W. C. Leggett, etc.)	Multispecies interactions
8. McMaster University, Hamilton, Ont. (Dr. R. Sonstegard)	Pathology
9. University of Manitoba, Winnipeg, Man. (Dr. F. J. Ward, N. E. R. Campbell, T. A. Dick, etc.)	Water impoundment ecology, microbial ecology, fish growth
10. Memorial University of Newfoundland, St. John's, Nfld. (Drs. D. R. Idler, G. L. Fletcher, R. J. Thompson, A. Sutterlin, D. H. Steele, etc.)	Fish reproduction and endocrinology, inshore marine, finfish and scallop culture, etc.
11. Université de Moncton, Moncton, N.B. (Dr. B. P. Vezina)	Juvenile lobsters
12. Université de Montréal (including Ecole de médecine vétérinaire, Saint-Hyacinthe), Montréal, Que. (Drs. R. Lallier, G. Cousineau, M. Elazhary, M. Fontaine, M. J. Fréchette, etc.)	Pathology, microbiology and immunology
13. University of New Brunswick (Saint John Campus), Saint John, N.B. (Drs. M. Thomas, C. Schom)	Brackish water and coastal ecology, genetics
14. Université d'Ottawa, Ottawa, Ontario (Drs. P. Weinberger, S. U. Quadri, etc.)	Experimental ecosystems
15. University of Prince Edward Island, Charlottetown, P.E.I. (pending)	Fisheries biology, pathology proposed
16. Queen's University, Kingston, Ontario (Dr. G. W. Van Loon)	Environmental contaminants
17. Université de Québec à Rimouski Rimouski, Que. (Dr. R. El-Sabh)	Physical and biological oceanography, larvae fish, etc.

ANNEX I: (cont'd.)

UNIVERSITY	TOPIC
18. Royal Roades Military College Victoria, B.C.	Coastal oceanography
19. University of Saskatchewan Saskatoon, Sask. (Dr. G. Wobeser)	Pathology, life support systems
20. Simon Fraser University Burnaby, B.C. (Drs. G. H. Geen, P. Copes, etc.)	Toxicology, aquatic ecosystems, fisheries economics
21. Technical University of Nova Scotia Halifax, N.S. (Drs. E. G. Bligh, R. Ackman, J.H. Merritt, T. Gill, etc.)	Food technology
22. University of Toronto (including Scarborough College), Toronto, Ont. (Drs. A. H. Weatherly, H. H. Harvey, etc.)	Bioenergetics, sublethal contaminants
23. University of Victoria, Victoria, B.C. (Drs. A. T. Matheson, J. T. Buckley, T. J. Trust, D. V. Ellis, M. J. Ashwood-Smith, etc.)	Toxicology in marine environment, physiology, immunology, egg and sperm preservation, etc.
24. University of Winnipeg, Winnipeg, Man. (Dr. G. E. E. Moodie)	Benthos-forage-fish interactions
25. University of Waterloo, Waterloo, Ont.	Limnology

ANNEX II: Commercial and Non-Profit Laboratories and Experimental Facilities with a capability in aquaculture

FIRM	TOPIC
1. Algas Resources Ltd., Calgary, Alta.	Use of heated effluents, systems development
2. Apex Bio-Resources Ltd., Duncan, B.C.	Salmon farming, feed technology
3. Aquafarms Canada Ltd., Feversham, Ont.	Trout farming systems
4. Bamfield Marine Station, Bamfield, B.C.	Inshore marine sciences
5. Research Council, Vancouver, B.C. (C. C. Waldon, etc.)	Systems engineering
6. Canadian Benthic Ltd., Bamfield, B.C.	Mariculture, abalone culture
7. Canadian Veterinary Biologics Ltd. Smith Falls, Ontario (Dr. P. H. Langer)	Biologics
8. Cape Breton Marine Farming Ltd., Baddeck, N.S.	Oyster and trout rearing systems
9. Connaught Laboratories, Willowdale, Ont.	Fish vaccines
10. Envirocon, Vancouver, B.C.	Habitat assessment
11. Fisheries Resource Development Ltd., Halifax, N.S. (Dr. J. F. Maloney)	Food technology and resource use planning
12. Fundy Isles Marine Enterprises, St. Andrews, N.B. (Dr. C. Frantsi)	Fish health, culture systems, plankton identification
13. Genu Products Ltd., Dartmouth, N.S.	Marine plants
14. Groupe Interuniversitaire de Recherches Oceanographiques du Québec (GIROQ), Quebec, P.Q.	Estuarine ecology
15. Huntsman Marine Laboratory, St. Andrews, N.B.	Systematics
16. IMA Aquatic Farming, Glenwood, N.S.	Salmonid genetics, culture systems
17. International Atlantic Salmon Foundation, St. Andrews, N.B.	Salmonid culture
18. Limnos Ltd., Toronto, Ontario (John H. Neil)	Heated effluent uses, limnology
19. Institute of Man and Resources, Charlottetown, PEI	Solar aquaculture
20. Marine Colloids Ltd., Halifax, N.S.	Marine plant culture
21. Marine Lobster Farms Ltd., Charlottetown, PEI	Crustacean culture
22. Marine Resource Associates, St. Andrews, N.B.	Sea-pen farming
23. Martin Feeds Ltd., Elmira, Ont.	Feed technology
24. Maritime Feed Co-op, Moncton, N.B.	Feed technology
25. Montreal Aquarium, Montreal, P.Q.	Ethology
26. Myticulture International Inc., Ottawa, Ont.	Mussel culture
27. Nova Scotia Research Council, Halifax, N.S.	Systems engineering
28. Plansearch Marine Division (formerly MacLaren Marex) Dartmouth, N.S.	Ocean engineering, site assessments, mariculture

ANNEX II: (cont'd.)

FIRM	TOPIC
29. Research Productivity Council, Fredericton, N.B.	Food technology, systems engineering
30. Redonda Sea Farms Ltd., Vancouver, B.C.	Oyster culture
31. Royal Ontario Museum, Toronto, Ont.	Systematics
32. Syndel Laboratories, Vancouver, B.C.	Fish medicines
33. Vancouver Aquarium, Vancouver, B.C.	Ethology

ANNEX III: Consultants with aquaculture expertise

	FIRM	TOPIC
1.	Anderson and Associates Consultants, St. Andrews, N.B.	Planning and training
2.	Aquafarms Consultants Ltd., Nanaimo, B.C. (Drs. T. D. D. Groves, W. Kennedy, etc.)	Business planning and designs
3.	G. C. Armstrong Enterprises, Agincourt, Ont.	Hatchery management
4.	Beak Consultants, Vancouver, B.C. (R. E. McLaren, etc.)	Habitat quality, limnology and biological oceanography
5.	E. R. Broughton Associates Ltd., Toronto, Ont.	Facilities and strategic planning
6.	B. M. Resource Management Inc. Ottawa, Ont. (Dr. Blair McGugan)	Resource use planning and evaluation
7.	E.V.S. Consultants, North Vancouver, B.C.	Plankton identification
8.	D.P.A. Consultants Ltd., Fredericton, N.B. (A. Robertson)	Aquacultural engineering
9.	J. P. Cuerrier, Vanier, Ont.	Fish culture
10.	S. J. Ettman, Glen Margaret, N.S.	Tuna culture, marketing
11.	Faunaquatics Canada Ltd., Guelph, Ont. (Dr. H. R. MacCrimmon, etc.)	Fish culture, habitat management
12.	Robert Fletcher and Associates Ltd., Ottawa, Ont.	Strategic planning, education
13.	D. B. Lister and Associates Ltd., North Vancouver, B.C.	Hatchery biology
14.	Lombar North Group, Calgary, Alberta	Environmental assessment
15.	P. McCart Consultants, Nanaimo, B.C.	Ethology, environmental assessment
16.	Fisheries Development Consultants Canada Ottawa, Ont.	Project and strategic planning and evaluation
17.	Monenco Consultants Ltd., Calgary, Alberta (Dr. P. Neame)	Fisheries biology
18.	Montreal Engineering Ltd., Montreal, Que.-Halifax, N.S. (P. Ruggles)	Environmental assessments
19.	W. P. Truch, Calgary, Alberta	Hatchery engineering
20.	Underwood McLellan Ltd., Vancouver, B.C. - Rexdale, Ont. (D. Sinclair, D. Reid, etc.)	Hatchery engineering, culture systems
21.	W. L. Wardrop Associates Ltd. Winnipeg, Man.	Water resource planning and engineering, environmental assessment

ANNEX IV: Federal/Provincial Research Centres with a capability in aquaculture

CENTRE	TOPIC
1. Agriculture Canada Ottawa, Ontario	Feedstuffs, biologics
2. B.C. Ministry of Environment Marine Resources Branch and Fish and Wildlife Branch (R. A. H. Sparrow, G. Halsey, etc.)	Hatchery operations, oyster biology, etc.
3. Department of Fisheries and Oceans Pacific Biological Station Nanaimo, B.C.	Infectious diseases, immunology, bioenergetics and growth, finfish and shellfish culture systems
4. Department of Fisheries and Oceans Institute of Ocean Sciences, Sidney, B.C.	Physical and chemical oceanography, benthic organisms
5. Department of Fisheries and Oceans West Vancouver Laboratory, Vancouver, B.C.	Fish reproduction and endocrinology, feedstuffs evaluation and diet preparation
6. Department of Fisheries and Oceans Pacific Salmon Enhancement Project Vancouver, B.C.	Salmonid culture systems
7. Department of Fisheries and Oceans Freshwater Institute, Winnipeg, Man.	Limnology, disease control, contaminants, culture technologies
8. Department of Fisheries and Oceans CCIW, Burlington, Ontario	Water quality
9. Department of Fisheries and Oceans Quebec Region, Quebec, P.Q.	Estuarine ecology
10. Department of Fisheries and Oceans Biological Station, St. Andrews, N.B.	Salmonid genetics and biology, invertebrate culture
11. Department of Fisheries and Oceans Halifax, Nova Scotia	Fish health and nutrition economics, food technology
12. Department of Fisheries and Oceans Bedford Institute of Oceanography, Dartmouth, Nova Scotia	Ocean engineering, coastal oceanography, marine productivity
13. Department of Fisheries and Oceans Northwest Atlantic Fisheries Centre St. John's, Nfld.	Scallop culture, salmonid culture
14. N.R.C. Atlantic Regional Laboratory Halifax, N.S.	Marine plants
15. National Museum of Natural Sciences Ottawa, Ontario	Systematics, larval fishes
16. New Brunswick Fisheries Department Fredericton, N.B.	Heated effluents, finfish culture
17. Nova Scotia Fisheries Department Halifax, N.S.	Mussel culture
18. Ontario Ministry of Natural Resources Research Centre, Maple and Guelph, Ont. (P. Ihssen, Y. Cho, etc.)	Nutrition, genetics, culture systems

REPRODUCTIVE STUDIES IN FISH

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INTRODUCTION

The following general survey must be read as one aspect of approaches to the optimization, by biological means, of the production of fish. In this sense it is akin to similar studies and approaches to the optimization of the production and stock improvement of other farm animals, such as cattle, sheep and pigs, and of birds such as the domestic fowl and the turkey. The general position with respect to detailed knowledge of reproduction in fish is behind that of the above names species, partly because relatively little research has been undertaken and partly because, at least in the Western world, interest has centered largely on sport fish, i.e. salmon and trout, and not on controlled aquaculture as a means of providing an additional or alternative food source. There has been and still is a considerable amount of basic descriptive work relating to histological change in the pituitary and the gonads of various species at various stages of the reproductive cycle. This type of study, which seeks to relate changes in the pituitary to reproductive function, is similar to that carried out some decades earlier in terrestrial mammals and is basic to the understanding of the processes of reproductive change, for example, in relation to environmental change or to exposure to toxic materials. From such basic studies some clear points are emerging of which the necessity of knowing and understanding the ovulatory and spermatogenic cycles of the various species and the factors influencing these is an area of critical importance to successful breeding of fish under conditions of intensive artificial culture. It must continue to be supported to develop the information base in this area.

Several types of reproductive cycles have been identified in teleosts. Gametogenesis may start 1) in late spring or early summer and finish in the autumn with spawning in winter or early spring (salmonids, pike), ii) in the summer or autumn, stop in the winter, and recommence in the spring followed by spawning in spring or early summer (carp, roach) or iii) occur entirely in the spring with spawning in spring or early summer (tench).

In the oviparous female teleosts reproduction comprises two phases of specific interest. (a) Vitellogenesis and (b) Oocyte maturation and ovulation. Vitellogenesis is the process by which the liver forms the yolk lipophosphoprotein precursor (vitellogenin). This process is stimulated by oestrogens produced by ovarian tissue under the influence of pituitary gonadotrophins. Vitellogenin is then incorporated into the yolk and is detectable in the plasma during ovarian development. When vitellogenesis is completed the oocyte continues its maturation and is then ovulated, again under the influence of pituitary gonadotrophic hormones.

In terms of specific manipulation and control of the reproductive process, studies have been and are concentrated on two main areas. (a) Control of gonadal development and spawning and (b) Preservation of gametes. The control of the development of the gametes can be achieved in two ways: (a) by hormonal treatment and (b) by modification of the environment.

HORMONAL TREATMENT

Mammalian gonadotrophins are regarded either as being largely ineffective or, at the best, variable in their actions when used alone in fish. Some stimulation of ovarian growth by pregnant mare serum gonadotrophin (PMS) occurs in salmonids, such as the brown trout, and human chorionic gonadotrophin has been widely used in inducing spawning in Indian and Chinese carp and in the gray mullet. In many instances, however, this treatment requires supplementation with pituitary extracts. As a consequence most major studies and practical application using gonadotrophins have involved the use of whole fish pituitaries or pituitary preparations and extracts.

There is some evidence that a fairly high degree of specificity of response exists. For example, pituitary from the winter flounder does not stimulate gonadal growth in salmonids and a salmon gonadotrophic preparation was reported to be only one-sixteenth as active as carp gonadotrophin in a biological assay with immature trout ovaries. Preparations of gonadotrophins have been made from carp, salmon and rainbow trout. Preparations from salmon have been studied by two Canadian groups, D. R. Idler _et al_., St. John's, and E. M. Donaldson _et al_., Department of Fisheries and Oceans, Vancouver. A commercial preparation is available from Syndel Laboratories, Ltd., Vancouver.

Idler's group has concentrated on studying the basis of vitellogenesis and the identity of the pituitary gonadotrophins and factors controlling their release. They have isolated two fractions from the pituitaries of several teleosts, chum salmon, carp, American plaice, and winter flounder. One fraction stimulated the incorporation of vitellogenin but had no measurable gonadotrophic activity. The other fraction stimulated oocyte maturation and is considered to be a gonadotrophin. Distinction between these two fractions is made by failure of the vitellogenic hormone to cross react with anti sera to the gonadotrophic hormone and also by its failure to stimulate cyclic A.M.P. production in immature trout gonads or the uptake of radioactive phosphate by chick testes. Both these activities are stimulated by gonadotrophins. The gonadotrophin fraction is termed "The maturational fraction" since it induces maturation of oocytes. There is some evidence both from the St. John's group and from the Vancouver group that there are two maturational factors though they have not been identified. The maturational hormone stimulates the steroidogenesis, particularly the production of 11-ketotestosterone and testosterone in male fish. The 11-ketosteroid induces spermiation and spermatoza formation. Certain other steriods also induce maturation in fish, the most effective being either 11 deoxicorticosterone or progestagens. In the trout, 17-α 20-β dihydroxy progesterone is the most effective maturational hormone and was initially isolated from the plasma of the salmon. 17-α hydroxy progesterone, which was also identified, has maturational activity and has been reported to induce oocyte maturation in the winter flounder.

The extent to which these various components interact in the process of maturation and ovulation remains to be determined. Certainly in the cultured common carp, which does not ovulate spontaneously, it has been reported that though ovulation can be induced by injection of carp pituitary, this is only 50% effective and can be much improved by the use of 17-α 20-β progesterone.

Gonadotrophin release is controlled via the hypothalamus. In mammals, the gonadotrophin releasing factor is a small peptide and is responsible for the release of both the follicle stimulating hormones (FSH) and luteinizing (ovulating) hormone (LH). A similar peptide may occur in fish but has yet to be identified.

A very large number of agonists and antagonists to the mammalian releasing factor have been synthesized. Some agonists have been reported to be effective on injection in the grayling by Stein and Wintersperger in Germany and in the rainbow trout by Crimm at St. John's. Crimm's group appears to be the main Canadian group engaged in studying the nature of teleost gonadotrophin releasing factors and have developed an *in vitro* assay for fractions obtained from the hypothalumus. R. E. Peters and colleagues in the Department of Zoology at Edmonton have also undertaken a study of neurophysiological control of gonadotrophin release in the goldfish in collaboration with Billards group at Jouay-en-josas. Work in this area is much in its infancy. Synthetic releasing factors have been considered as being useful provided suitable means of control of administration and release could be devised. Conversely antagonists might be equally useful in promoting sterilization of both male and female fish.

Caution and a good deal more experimentation is needed here since it is becoming apparent in mammalian work with the rat that the releasing factor itself and pituitary long acting agonists have an extra pituitary action and are inhibitary of gonadal development and ovulation if given in continuing doses. The inhibition may involve a reduction in LH receptors in the testes and ovaries. On the other hand, such compounds may prove of value in the development of techniques of sterilization of the fish.

At the present time, control of spawning by the use of hormonal preparations or releasing factors, would appear to be limited both in operation and in potential to situations where the value of the species and product is sufficient to justify the cost and the risk. An additional limitation may arise from species requiring specific gonadotrophin preparations. The cost of production of species specific gonadotrophins is likely to result in a product too highly priced for general farm use, particularly in developing countries and a more practical approach would appear to be continuation of investigations of the use of synthetic agents.

MODIFICATION OF THE ENVIRONMENT

Study of the reproductive cycles in many species has led to the recognition that variations in environmental cues, such as photoperiod and temperature can accelerate or retard the cycle.

In autumn spawning fish gonadal maturation is induced by decreasing light periods whilst for spring spawning fish maturation is induced by increasing photoperiods. In brook trout shortened photoperiods or acceleration of the cycle of change of increasing or decreasing photoperiods induces gonadal maturation. Similarly, in the rainbow trout, at a constant temperature of 8°C, compression of the annual photoperiodicity to 6 months induced spawning 12 weeks earlier than normal. The process is accelerated further by increasing the temperature to 16°C. In the carp, a constant temperature of 20°C stimulated gonadal maturation but hormonal treatment was required to induce ovulation. Ovarian maturation in the gray mullet has been induced out of season by manipulation of photoperiod and temperature.

In relation to environment, the potential effect on reproductive capacity of sublethal amounts of a wide range of pollutants ranging from heavy metals to polychlorinated hydrocarbons may be a serious concern in many localities. The subject has been ably reviewed by Waldichuk (Vancouver). Several of these studies have been combined with measurement of circulating gonadotrophins which reach a maximal level in the plasma at the time of spawning or spermiation.

Temperature and photoperiodicity are, however,only two of the environmental cues which stimulate spawning and spermiation and the relationship of these processes to additional behavioural patterns has not been systematically investigated. The extent to which pheromones may be involved is not clear and could be worth some systematic study.

PRESERVATION OF GAMETES

In vivo, gametes remain stored in the gonads or genital tract for a period during which fertilizing ability of the sperm decreases slowly, as determined in the trout and sea bass. In the female there is considerable variation in the duration of survival of the ovum once it is shed. In the trout, survival with normal viability, is stated to be approximately one to two weeks, in the pike two days and in the carp a few hours. Since fertilization is external in teleost species, artificial insemination is a simple matter and, at its most primitive, consists of mixing eggs and sperm with water added subsequently.

As with mammalian and avian farm stock, the potential for improvement of fish husbandry in aquaculture by the introduction of methods of long term preservation, can be combined with the reliable methods of induction of ovulation. Advantages include; (a) ready transport and distribution of gametes from desired stock, (b) maximum use of a number of males, (c) availability of sperm and ova which are mature at the same time, (d) development of cross breeding, particularly of species which mature at different seasons of the year, (e) potential for hatchery production throughout the year and (f) development of disease free stock.

SPERM PRESERVATION

The use of extenders and the ability to preserve semen for several hours in advance of stripping the female is of considerable practical importance in the management of a breeding program. Short term preservation of sperm for a few hours can be achieved at low ambient temperatures i.e. 2^o - 10^oC and in the presence of oxygen. However, the small volumes of ejaculate permit one male to be used for three to four females only and make it profitable to use an extender. The majority of work has been concentrated on semen of salmon species, principally because the bulk of the studies have been developed and reported in North America where such species are of high commercial value and Government and private hatcheries provide opportunity for study. Similar developments are taking place in West Germany in Holtz's group.

Early attemps made use of single saline extenders but increasing attention to factors such as pH, osmotic pressure, and temperature has led to the development of various diluents which permit the maintenance of viability for several hours (up to nine days at 5^oC is claimed for brown and rainbow trout sperm).

Major efforts have been made to develop cryopreservation since Blackster (1953) reported 80% fertility of sperm maintained in sectioned testes of March run Atlantic herring preserved in glycerol and seawater at -79^oC for six to seven months.

Subsequently several attempts at cryopreservation were made, patterned on techniques of preserving bull semen, with many failures or in which sperm survived with low fertility only. Considerable improvements were made with the introduction of dimethylsulphoxide (DMSO) and ethylene glycol as cryoprotective agents in place of glycerol. The subject was reviewed by Horton and Ott in 1976 at which time fertility rates of 50% to 70% for cryopreserved sperm was sometimes obtained. The most effective diluents to date appear to be those described by Mohnib (1978) and Erdahl and Graham (1980), both of whom have paid particular attention to the composition of the diluent and its relation to semen constituents. Mounib, working in Halifax, obtained 80% fertility from Atlantic salmon sperm and 60% fertility from cod sperm frozen at -196°C (liquid nitrogen), for a year, in a medium containing DMSO sucrose reduced gluthathione and potassium bicarbonate. Erdahl and Graham, using a diluent based on seminal plasma composition, claim storage of brown trout semen for up to two years at -196°C with retention of fertilizing capacity. Though it has been stated that in general the viability of sperm so preserved is poor and large amounts are needed to obtain fertility, the results of Erdahl and Graham would suggest that this is not the case.

OVUM PRESERVATION

There is little work being conducted in this area. Experiments with cryogenic preservation of fertilized sea urchin and oyster eqqs have been unsuccessful (compare Horton and Ott in 1976). Herring ova have been claimed to withstand short exposure to -10°C and trout eggs to -20°C. Erdahl and Graham (1980) report that fertilized brown trout eggs can be frozen to -20°C in the presence of ethylene glycol and remain 90% fertile. Freezing to -25°C or lower resulted in very low fertility, probably owing to severe membrane damage. Similar studies have been commenced with the rainbow trout and Northern pike. Species difference appears to exist since the eggs of pink and Chinook salmon appear very sensitive to even low levels of cryoprotective agents.

At present there is no indication that a viable technique exists for the preservation of fish embryos and no record of Canadian work has appeared. In summary, there appears to be the likelihood that suitable means for medium to long term sperm preservation will be reached in the relatively near future, provided the present limited studies are expanded. The preservation of ova is a neglected and difficult area but in view of the success attaining efforts of preservation of mammalian ova and the potential value, it would be highly desirable to undertake a systematic study of the problem.

CONTROLLED SEX DIFFERENTIATION

The ability to produce a predominantly female stock could permit rapid propagation and stock improvement if linked to a successful cryopreservation program. Equally, the production of sterile fish could assist more rapid weight gains and/or an increase in marketable weight.

Work on this topic is being conducted mainly in the Department of Fisheries and Oceans Laboratory in New Brunswick and at West Vancouver. Techniques generally involve the use of steriods, such as 17-α testosterone and 17-β oestradiol, the steroids being added to solutions containing the eyed egg and alevins and being fed in the diet either for periods immediately post swim-up or at the early parr stage. Treatment with 17-β oestradiol results generally in the production of female fish but not if the steriod is given at the early parr stage. Androgen treated fish resulted in males or sterile fish, but again, not if treated at the early parr stage. There is some evidence that continuous treatment with steriods (oestrogens) may lead to a decrease in growth weight which is reversed rapidly when treatment ceases. The use, on a substantial scale, of highly potent physiologically active agents which can affect reproduction in animals and man, will undoubtedly require careful control and the appropriate toxicological clearance. It may be that the degree of public acceptance of such products would be low.

The problems and position with respect to reproductive control in fish are thus seen to be similar to those of reproductive problems in other farm species. If aquaculture is to be developed as a part of an integrated farming system, then optimization of control of reproduction of fish and subsequent feeding of the neonate will need to be accorded as much attention as that of animals such as the cow, pig and sheep.

LOW ENERGY METHODS OF FISH PRESERVATION

Other than the traditional and much decreased procedures of sun drying salted split fish, there is no work being conducted in Canada that can be classed specifically as low energy technology in relation to fish preservation. Current trends in energy conservation processes are directed towards improving trawler design and equipment to reduce energy consumption. In the outports in Newfoundland, improvement in fish landing techniques for inshore fishermen and for storage and transportation aimed at improving quality, has been introduced via the use of a low powered system on the wharf but cannot really be classed as low.

Attempts at energy conservation include devices which make use of heat pumps. The humid air from the drying fish is de-humidified by refrigeration and the heat output from the refrigerator is then used to heat the air passing into the drying chamber. This process has been linked with experimental fluidized bed system of salt or salt and ice by the Department of Fisheries and Oceans in St. John's. This system, though affecting an economy, still requires substantial electrical power. Attempts to apply technology appropriate to one region or country directly to another region or country is not likely to be the best solution to the problem. In considerations, such as social structure, economy and expertise available in each region requires evaluation before appropriate technology can be suggested. There is little doubt that one of the greatest improvements that could be made in fish treatment lies in reduction of loss through better handling, for example, by rapid icing and dealing with the products in controlled conditions. In this area considerable attention also requires to be given to post harvest treatment of the fish, particularly in terms of post harvest physiology, mechanical means of handling and preservation and efficient integration of the use of fish wastes into the farming system. In this connection, literature surveys show that the majority of countries are already well aware of these problems, have active institutes examining them and that there is considerable use of appropriate technology occurring. Such assistance as might be provided from Canadian sources would probably be best provided by seconding of advisors or the provision of exchange between specific institutes and localities.

SUMMARY OF RECOMMENDATIONS

Recommended areas for study are:

A. Fish Reproduction and Breeding

(i) Control of ovulation and spermatogenesis

Recommended

(a) That continuing attention be paid to the effects of environmental modification on gonadal maturation and development.

(b) That a systematic study be undertaken of the effects of continuing exposure to environmental pollutants of low concentrations.

(c) That the study of the effectiveness of agonists and antagonists of gonadotrophin releasing factors be continued.

(ii) Preservation of Gametes

Recommended

(a) That work on the preservation of spermatoza be continued with particular emphasis on cryopreservation.

(b) That a systematic program of ovum preservation be initiated.

(iii) Control of Sex and Sterilization

Recommended

(a) That examination of the effects and use of steroids or steroid like substances to produce sex changes or sterilization be continued.

(b) That attention be given to the potential use of agonists and antagonists of gonadotrophin releasing factors for sterilization.

(c) That the use of steroidal of other chemical agents in regulating the reproductive process be accompanied by the appropriate toxicological investigations and the development of safeguards as an essential factor in their use.

B. Preservation and processing of fish and fish products which include

(i) Post harvest physiological change.

(ii) Use of a number of species not at present considered as human food.

(iii) Effect and efficient means of mechanical processing and drying.

(iv) Mechanisms of effective utilization of fish wastes in the agricultural system.

MAIN CANADIAN LABORATORIES ENGAGED IN THE STUDY OF REPRODUCTIVE PHYSIOLOGY IN FISH

1. D.F.O., West Vancouver Laboratories

   Development of techniques of induced ovulation in salmon using pituitary preparations, releasing hormones, anti-estrogens, etc. Development of hormonal techniques for controlled sex differentiation in salmon. Sex control through gynogenesis, cryopreservation of gametes. Technology transfer to Syndel Laboratories Limited to commercially produce natural and synthetic substances which induce final maturation and ovulation in fish.

2. D.F.O., St. Andrew's Biological Station

   Use of steroids for sex reversal and control of age at maturity. Effects of low pH and cadmium on hatching of salmon eggs and on alevins.

3. Marine Science Research Laboratories, St. John's, Nfld.

   Pituitary hormones in fish reproduction, metabolism of steroidal hormones, neuroendocrinology and neorophysiology of reproduction.

4. Department of Zoology, University of Alberta (Dr. R. E. Petery)

   Spawning behaviour in the goldfish. Effect of prostaglandins on gonadotrophins. Changes in plasma cortisol in the rainbow trout. Effect of sex steroids on plasma lipids and fatty acids. Neuroendocrine regulation of ovulation in the goldfish.

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Additional information was generously supplied by Dr. R. H. Cook, Director, D.F.O., St. Andrew's Biological Station; Dr. M. Waldichuk and Dr. E. M. Donaldson, D.F.O., West Vancouver Laboratory, and Dr. R. E. Peter, Department of Zoology, University of Alberta, Edmonton.

In addition to a literature search over the five years, the following reviews were consulted.

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2. (Effects of Pollutants) Review of the problems. Waldichuk, M. (1979) Phil. Trans. Roy. Soc. Long. B, 286, 399-424
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    (b) Reproduction and artificial insemination of teleost fish. Billard, R., 327-337.
    (c) Pituitary gonadotrophins of bony fish. Isolation and biological action. Idler, D. R. & Ng, Tzi Bun, 339-345.
    (d) Preservation of gametes of freshwater fish. Erdahl, D. A. & Graham, E. F., 317-326.
4. The Theory and Practice of Induced Breeding in Fish. Harvey, B. J. & Hoar, W. S. (1979) IDRC - TS21e.

ANIMAL DISEASES
Paper by D.G. Howell

Rapporteurs' Report
B.L. Nestel and G. Losos

The session had a somewhat restricted focus dealing mainly with a specific proposal relating to research on trypanosomiasis. This is the most important disease constraining livestock production in tropical Africa.

Fundamental work on trypanosomiasis, supported by IDRC, has been carried out at Guelph since the early 1970s. The program was developed in partnership with laboratories in East Africa. Its objective was to gain a detailed understanding of the disease process in infected animals.

Some important progress has been made towards achieving this goal during the past decade. A proposal has been put forward for the continuation of the Canadian component of this work using an interdisciplinary team based at Guelph. The three primary objectives of the continuing work are:

a) to conduct a systematic study of the toxic factors produced by the trypanosome;

b) to gain a better understanding of the parasites predilection for certain tissues and body systems, particularly the cerebrovascular endothelium; and

c) to study the nature of the pathophysiological process which culminates in disease and death.

An additional aspect of trypanosomiasis research which might warrant consideration for Canadian support in the future is the biological control of the tsetse fly. It is likely that the control of trypanosomiasis will, in the long run, be effected through a program of integrated disease management which may well embrace biological control of the vector, chemotherapy, vaccination and bush clearance.

The past Canadian inputs to trypanosomiasis research have been carried out in partnership with several laboratories of the Kenya Government's veterinary department. The working relationships already established could serve as a productive basis for future activities.

Past Canadian inputs have been based on very sophisticated technology using experienced personnel to solve difficult problems relating to improving the research methodology through the development of new techniques. The results of such work have had an immediate and applicable impact on the African-based field program. Manpower development has also been a prominent feature of the program with a number of African scientists receiving post-graduate training through the Canadian component of the overall program.

A second Canadian activity in the animal health field in East Africa has involved an examination of the interrelationships between domestic and wild animal diseases. This program has shown that wildlife represent much less of a danger to domestic ruminants than was thought hitherto. It appears that many thousands of game animals have been slaughtered unnecessarily in the past. The research findings have been incorporated in a total systems approach which includes epidemiological, ecological and socioeconomic studies. The systems approach has made it possible to put together a rational strategy for land use in rangeland areas used by both domestic and wild ruminants. The use of this approach and the findings from the work in East Africa could both have some relevance in range areas elsewhere in the world including those in Canada.

The session discussion focused on diseases of ruminants in East Africa where it was possible to quote specific examples of past successes arising from Canadian research inputs and to use these examples to propose further involvements. Note was, however, taken of the likelihood of new disease problems occurring to an increasing extent in developing countries in which the livestock industry was continuously undergoing a process of intensification. Canadian inputs based on past experiences in intensification of the Canadian livestock industry could have a role to play in helping to overcome these problems in the LDCs.

It was noted in the discussion that the Guelph work on trypanosomiasis is certainly not the only case where Canadian expertise in animal diseases might be engaged in a cooperative program with developing country institutions. However, in as much as the Guelph activity involved close liaison with researchers in a developing country, the use in Canada of research facilities not available in that country and the making available of training facilities, it therefore serves as one possible model for future cooperative programs.

Trypanosomias Research

State of the Art

This document should be read in conjunction with that dated 11 June 1980 entitled Research into African Trypanosomiasis. In that document three areas of research were proposed and here follows a brief review of the state of the art in relation to these three proposals. A note is also included concerning the matter of biological control of the tse-tse fly; the vector of African trypanosomiasis.

Toxic factors produced by trypanosomes

Trypanosomes fail to produce, in either humans or domestic animals, gross lesions which could be considered to be obviously lethal. As a result, it is not known why animals die. One explanation for this is that the diseases may be caused by toxins. However, as recently as 1974 there was little or no evidence that trypanosomes produced toxins. Since 1975 however, a number of research workers, most notably at the University of Guelph have isolated and have begun to characterise several biologically active factors derived from pathogenic trypanosomes. The importance of these factors is not yet firmly established, yet their properties are such that, when acting together they could account for the clinical features of the trypanosomiases and for the deaths of infected individuals and animals.

The factors so far identified fall into several groups. The first group consists of hydrolytic enzymes which probably cause tissue damage. These include phospholipases and collagenases. The level of phospholipases in pathogenic trypanosomes has been shown to be extraordinarily high - indeed the highest recorded from non bacterial sources. In addition a good correlation exists between the level of trypanosome phospholipase and their pathogenicity. The situation with respect to the collagenases is less clear but they could contribute to the disease process especially when acting in conjunction with the phospholipases.

The second group of toxins include several tryptophan metabolites with potent anesthetic activity. These metabolites are produced mainly by T. gambiense and may be the cause of the lethargy and coma associated with this organism.

The third group of factors are less well defined. These factors influence the immune system of infected animals. Some factors are immunostimulating while others are immunosuppressive. The immunostimulating factors can cause immunosuppression by secondary immune exhaustion. Since most animals and many humans suffering from trypanosomiasis die from secondary infection it is clear that these factors are of major significance. Studies at Guelph have identified two major immunosuppressive factors and an immunoenhancing factor in trypanosome extracts and encouraging results are being obtained in characterising these.

The identification and characterisation of these factors is of importance insofar as it may be possible to devise therapy and prophylactive measures to specifically counteract the disease producing process.

Tissue affinity

Trypanosoma congolense do not distribute evenly within the blood vascular system of cattle and because of this, the level of parasitemia cannot be taken as a reliable indicator of the total numbers of parasites present. Although *T. congolense* is an obligate intravascular organism, it demonstrates marked specificity for adherence to the vascular endothelium in the brain and skeletal muscle. Studies with radio labelled trypanosomes have shown that this adherence phenomena is a result of the immune response and is not operative until around the tenth day of infection. Cerebral vascular endothelium differs from that of other organs in having a higher level of mitochondria. It is therefore possible that the trypanosomes find the brain endothelia more "fertile ground" because of their own energy requirements. Further, it is likely that in the nonimmune animal the uninhibited parasites circulate freely and do not seek a preferred vascular site. With the adherence of antibody to the parasitic membrane, their energy transfer may be impaired, and they then adhere to endothelium with a higher metabolic rate. We propose to study the mechanisms by which *T. congolense* adhere to endothelium in the brain and to determine if the adherence can be prevented by immunizing agents which cause a thickening of endothelial membranes.

The pathophysiological process

The lesions in cattle dying from T. congolense are well documented and consist of anemia with interstitial thickening in the lung and widespread focal myocarditis with reactive or degenerative changes in the lymphatic and hemopoietic organs. The actual cause of death has not been determined and appears to reside in circulatory failure as the common factor. It is likely that a variety of cardiovascular mediators are operative in the pathophysiology of death due to trypanosomiasis. We propose to study the immunopharmacologic release of vasoactive amines from leukocytes and to do serial kinin studies on young calves in extremis because of infection with T. congolense. By these studies we wish to determine which of the normal body responses are inhibitory to the organism and which appear to be self-destructive to the animal. These studies will be carried out in conjunction with a variety of receptor blocking agents to determine if the pathophysiology of infection can be altered in favour of the host.

Biological control of the tse-tse fly

IDRC might wish to consider the desireability of reviving an interest in the possibilities of controlling tse-tse flies by biological methods. IDRC publication 077 (e) edited by Marshall Laird is highly relevant and deals extensively with the subject. It is to be noted that WHO and UNESCO/ICRO/UNEP advisory microbiology panel on which the author is a member and chairman elect have identified "the biological control of pests and vectors" as a priority item for forward research. By biological control we do of course mean the deliberate use of insect predators and parasites to bring about the demise of the undesireable pest or vector and not autocidal or genetic control or the highly questionably methods of wild life disposal or brush clearance. The literature on the subject is well reviewed in the publication referred to above and in bringing the matter forward the author is most concious of the possible limitations of the method particularly in the case of the tse-tse fly. Target specificity and of course host density are matters which would need careful assessment.

25 September, 1980

D.G. Howell

Research into African Trypanosomiasis

Introduction

Between 1975 and 1978 the IDRC was able to fund a highly productive research program in trypanosomiasis which was carried out as a joint project in Kenya and Guelph. At Guelph the main thrust was directed to a better understanding of the haematology and immunology of the disease. A number of highly significant publications emerged, a list of which is attached as Appendix A.

In the opinion of the contemporary workers in trypanosomiasis the Guelph contribution to the problem was outstanding and it was a matter of great disappointment when for various reasons the program had to end.

This program represented the kind of activity, which is now being planned as an ongoing matter, namely that research which has a direct bearing on the problems of third world countries and which can be appropriately and often better carried out by a Canadian university should be funded as part of Canada's contribution to overseas aid.

This paper which will be followed by a detailed research proposal from the University of Guelph if the principle is accepted has been prepared against the foregoing background and as a result of the discussion which took place at the IDRC workshop on 23 May under the auspices of the Commission on the application of Science to Agriculture, Forestry and Aquaculture (CASAFA).

The African trypanosomies are, a group of parasitic protozoa of man and animals and which constitute a major problem to livestock rearing in a vast area of that continent, in fact virtually in all of it which lies between the 16th parallel north and the 10th parallel south. The area is significantly a high rainfall area and therefore has a very high potential for forage production and range grazing, in consequence, if freed, from the effects of the disease could make an enormous contribution to food production. The organism causes disease and death with measureable abnormalities consisting of haemolytic anaemia, pyrexia, debility, pooling of enteric fluid and cerebrovascular microthrombosis. The earlier studies at Guelph suggested that these tissue and system changes probably came about as a result of certain factors produced by the infecting microorganism.

Should it be found possible to neutralise these factors by laboratory procedures then a method of control might clearly present itself.

General Proposal

If funding is agreed in principle a detailed research proposal should be invited from the University of Guelph but essentially it would cover the following points

(a) A systematic study of the toxic factors produced by the organism -- this would require a microbiological, biochemical and immunological approach

(b) The mechanisms whereby the parasite appears to have a predeliction for certain tissues and body systems particularly the cerebrovascular endothelium

(c) The nature of the pathophysiological process which culminates in disease and death

The work could be essentially carried out using the present facilities at the Ontario Veterinary College. Suitable accommodation approved by Agriculture Canada exists at Guelph for the housing of infected animals. Funding would be required to provide for ancillary workers, post doctoral fellows, graduate students and research assistants, supplies, equipment and animal costs. The salary for a senior researcher with African experience in trypanosomiasis would be included. The work would be essentially multidisciplinary and be developed as a team approach.

Appendix A

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