Food from Land

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Food from Land

I Animal protein

II Nonanimal protein

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I Animal protein

OVERVIEW

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ANIMAL PRODUCTION IN THE CANADIAN ECONOMY

The production of animal products—meat, milk, and eggs—in Canada represents a major part of the agricultural economy. Nearly 5000 million dollars of farm cash receipts arose from the animal segment in 1976, more than the total of all other farm cash receipts combined (Table 1). Animal production is a means of converting crops and otherwise waste materials to readily marketable commodities, utilizing farm labor on a continuing basis, and spreading income throughout the year.

In addition to the income accruing to primary producers, animal agriculture provides a market for many inputs, including manufactured feeds, machinery, building materials, fertilizers, energy sources, and pest and weed control products. Animal agriculture is also the basic supplier to the dairy processing industry, which converts raw milk to dairy products such as ice cream and cheeses, and prepares milk for consumer consumption. The poultry processing and meat packing industries are obviously also entirely dependent on animal products, as are the egg grading and processing establishments.

Animal products form the major source of farm income in Canada and support several important manufacturing areas. This is a significant part of our economy.

CONVERTING FEED TO FOOD

Animals are converters of feeds to foods. They convert grass, corn silage, grains, oilseed meals, hay crops, food processing by-products, cereal straws, urea, and other nonprotein nitrogen sources to meat, milk, and eggs.

The efficiency of the conversion process is the central theme in much of animal science research. To produce more with the same input or to produce the same amount with less input is the most frequent aim of research on animals. This may be broadened to include new uses or modifications of existing sources of nutrients. For example, cereal straws can be greatly improved in available energy and in protein equivalent by treatment with anhydrous ammonia.

TABLE 1. Farm cash receipts, 1969-73 to 1977, Canada, in $1000

	Average 1969-73	1974	1975	1976 projection	1977 forecast
Wheat and C.W.B. payments*	796 811	2 054 533	2 538 035	2 018 453	
Oats and C.W.B. payments*	32 407	55 307	88 476	84 773	
Barley and C.W.B. payments*	199 270	564 635	620 796	538 251	
Advances and deferments	-71 656	-309 149	-83 533	190 550	
Rye	11 183	24 923	26 675	28 479	
Flaxseed	69 287	135 435	80 217	84 687	
Rapeseed	137 735	337 896	259 485	211 885	
Soybeans	30 885	78 511	44 925	71 054	
Corn	61 631	164 156	152 979	148 648	
Sugar beets	18 493	43 799	39 919	26 210	
Potatoes	93 283	211 475	164 805	207 468	
Fruits	102 452	140 232	137 363	125 920	
Vegetables	134 852	191 677	242 804	202 052	
Tobacco	145 582	207 681	198 188	189 316	
Other crops	146 341	225 868	247 324	249 740	
Total crops	1 908 556	4 126 979	4 758 458	4 377 486	3 916 311
Cattle and calves	1 137 442	1 677 340	1 817 975	1 971 447	
Hogs	553 064	778 092	886 471	814 803	
Sheep and lambs	8 718	12 867	13 467	14 018	
Dairy products	737 931	1 095 903	1 348 411	1 336 759	
Poultry	302 331	472 150	412 532	457 087	
Eggs	183 920	269 095	258 358	286 614	
Other livestock and products	53 166	74 887	76 687	83 871	
Total livestock and products	2 976 572	4 380 334	4 813 901	4 964 599	4 857 549
Other cash receipts†	184 689	371 387	404 810	403 311	486 448
Total cash receipts	5 069 818	8 878 700	9 977 169	9 745 396	9 260 308

Source: Boyko 1976.
*Anderson 1976.
†Clark 1976.

FACTORS AFFECTING EFFICIENCY

Efficiency of conversion of feeds to food depends on type and age of animal, nature of material being converted, the product, and the environment in which the animals are kept.

Type of animal and nature of material being converted

Farm livestock is divided into two basic classes: ruminant animals, such as cattle and sheep, which are able to use large proportions of forage in their diet; and monogastrics, such as swine and poultry, which have a single stomach and thus a limited ability to utilize forages. Unfortunately, the distinction is not always so clear cut; the rabbit, for example, is a monogastric animal but is able to utilize large quantities of roughage because of a well-developed lower intestinal tract or cecum. Similarly geese, although considered to be monogastric, as are most poultry, have the ability to use large quantities of roughage. However, for the bulk of animal production in Canada, the separation into ruminant and monogastric animals is acceptable.

All systems involving conversion of forages to foods rely on beef or dairy cattle and, to a limited extent, on sheep. Forages have highly variable contents of available nutrients, and their more efficient utilization represents a challenge to scientists and livestock producers. A few days delay in cutting forages, for example, can greatly decrease protein content and the availability of protein and energy to ruminants.

Nutrients from roughages are in general less available, even to ruminant animals, than are nutrients from concentrate feeds. Some roughages, such as straw, are of such low value that they will not support life if fed alone, but can make up a portion of the diet for certain classes of livestock; thus it is inefficient to convert straw by itself to food.

Grains can be fed to all classes of farm livestock. Even ruminant animals can utilize grains as their entire diet. However, because beef cattle, for example, are less efficient in converting high energy grains to food than are pigs and poultry, it is only when feed grain prices are markedly depressed that cattle can be economically fed in this way.

Within types of grain, each species has its own value, and with proper supplementation is used by producers to provide suitable rations for animals. Similarly, food processing by-products such as wheat bran, brewers' grains, tallow, and corn gluten meal are nutritionally defined and are used in conjunction with other feedstuffs to produce suitable animal diets. For the same reason that ruminants can utilize forages, that is, the presence of fermentative bacteria in the rumen, they can also use poor quality protein and even nitrogen as a protein source. Nonprotein nitrogen substrates such as urea and other nitrogen sources are utilized by rumen flora to produce bacterial protein that is available to the ruminant animal for conversion to animal tissues. Thus it is conceivable that with proper emphasis on forage quality, milk products and beef could be produced with no input of materials directly consumable by humans or monogastric animals.

Special attention is being given to the processing of unusual feedstuffs for livestock. Examples include processed wood, dehydrated poultry manure, and single-cell protein. This work is still partially in the development stage. Single-cell protein has had considerable technological influence and can be produced on a large scale, but costs are high (Winter 1975).

Age of animal

Young, rapidly growing animals are primarily producing muscle and bone but as they mature they tend to fatten. Advantage has been taken of this phenomenon by selecting animals and poultry that grow rapidly during the early part of their lives, thus avoiding the high energy costs caused by fat deposits. Fat is not only costly to produce but it isn't wanted—thus there is a double advantage in using younger animals. Selection, plus improved nutrition to allow maximum growth rates by young animals, has resulted in younger animals being marketed, particularly poultry meat birds and swine, and consequently in markedly improved efficiency.

Product

Poultry can produce either eggs or meat and the efficiencies of these two products differ. Similarly, cattle are used to produce both milk and beef with markedly different efficiencies. Even the so-called dairy breeds are estimated to provide approximately 30% of the total beef produced in Canada. However, the most efficient production occurs when a species is selected for a particular purpose; thus egg-laying strains of poultry are considerably more efficient at producing eggs than are the meat strains and birds selected for meat production are more efficient when used for this purpose than are egg-laying strains.

Environment

There is a growing trend toward housing all farm livestock in one environment for their entire lifetime. Poultry are raised exclusively in ventilated, closed buildings and swine producers are following this trend. Dairy cattle, in large herds, are tending toward year-round confinement, although there are still many herds following the traditional system of winter housing with summer pasture. Beef cattle have moved least toward year-round confinement because, apparently, the returns to the industry are such that it is difficult to meet the capital cost. However, it has long been recognized that the natural environment has a detrimental effect on the efficiency of production by farm livestock and, indeed, some classes of livestock cannot survive the Canadian winter without adequate shelter.

Animal health

Obviously, heavy mortality in livestock is a serious matter and causes severe financial losses to the livestock industry. Producers anticipate these losses and can estimate their cost. However, the greatest financial loss is probably caused by diseases, which cause reduction in feed intake and rate of growth and therefore substantially increase costs of production and efficiency of feed conversion. As the industry has intensified, producers have become much more concerned about both hidden and obvious costs of diseases and are taking extraordinary precautions to avoid introducing disease to their stock. As herds and flocks increase in size and are housed more intensively, a disease outbreak becomes more serious and can cause failure of the enterprise. Poultry producers are becoming more and more averse to allowing visitors onto their premises and swine producers continue to establish herds with a minimal disease level. It is expected that this trend will extend to the ruminant species.

COMPETITION BETWEEN ANIMALS AND HUMANS FOR SOURCES OF NUTRIENTS

As Winter (1975) pointed out, there seem to be two opposing schools of thought on the question of competition between animals and humans for sources of food. One view is that animals are consumers of grains and oilseed meals, which could be used to sustain human life but are instead used to produce limited quantities of meat, eggs, and milk for the well-to-do. Many people sympathize with this opinion and feel strongly that it is not acceptable to process food suitable for human consumption through animals in order to provide animal products. Dr. Borgstrom of Michigan State University stressed this opinion in his seminar on World Food Supply presented to research scientists at Agriculture Canada.

There is, however, the alternative view—that man relies on animals to provide foods of high nutritional value and high acceptability produced from materials that cannot be readily used directly for human consumption. Milk, poultry, meat, eggs, beef, and pork are commodities readily accepted by most Canadians and provide a highly nutritious diet with excellent protein quality.

Anderson (1976) has discussed these opposing viewpoints in detail and has provided data showing that the competition for food between animals and humans, who could utilize it directly, is much less than has been proposed by some authors and that the dairy cow, for instance, produces more protein in milk than it consumes from feeds that could be used by humans. Similarly, the much-maligned beef animal is nearly 50% efficient in providing protein for human consumption from feedstuffs that could be utilized directly by humans. It hardly seems relevant to include protein from grass or hay, as some authors have done, when estimating the efficiency of protein conversion by beef, dairy cattle, and sheep. The laying hen and broiler chicken require only 2.2 to 2.5 kg of corn–soybean protein to produce a kilogram of edible protein. The hog provides 1 kg of edible protein for every 5 kg of protein consumed from foodstuffs that could be utilized by humans. Even here, however, one must consider the types of materials that swine can utilize, such as food manufacturing by-products, garbage, and grass eaten by mature sows, to realize that there will probably continue to be a place for swine in providing food for humans in Canada.

Moreover, these quantitative comparisons do not take into account the additional quality of the protein produced from livestock, which complements protein from nonanimal sources (Anderson 1976).

OPPORTUNITY FOR INCREASED ANIMAL PRODUCTION

Animal production is dependent on crop production and cannot be separated from crops and soils. Some very intensive units have been set up that have attempted to be independent of farming *per se*. However, such enterprises are subject to rapid changes in market prices and can become uneconomic. In addition, some very mundane problems occur, such as the disposal of manure on limited areas.

Dr. Clark, Director of the Land Resource Research Institute of Agriculture Canada, has recently summarized the opportunities for increased crop production in Canada (Clark 1976). He has pointed out that only 13% of the total land area has potential for agriculture and, of this, 40% can be used effectively only for pasture, leaving only 8% of the total for cropping. Most of the tillable land is in Western Canada; Ontario and Quebec have only 16% of the total. He has pointed out that there is a potential reserve of 20–25 million hectares suitable for agriculture but much of this is marginal for field crops or is too dispersed for efficient agricultural production. It is clear, therefore, that even though Canada is an extremely large country, its resources in terms of land suitable for agriculture are very limited.

Taking into account land in Canada now productive and those areas that could be used for agriculture, Dr. Clark has estimated that on the basis of the present food and feed requirements, Canada could support a population of approximately 50 million people. He estimates that Canada should face no problem in feeding its projected population by the year 2000 unless there are extreme productivity constraints.

SCIENTIFIC PERSONNEL AND FACILITIES FOR IMPROVING ANIMAL PRODUCTION

Canada has a solid base of scientific and technical competence to support animal production and to develop new and more efficient methods. Agriculture Canada carries out research oriented toward animal production at 14 locations, involving 138 professional person years. These 14 establishments are part of the Research Branch of the Department and provide new technology for provincial livestock specialists and extension agents from coast to coast. In addition, the Health of Animals Branch of the Department of Agriculture has 67 scientists working on disease problems that face Canadian animal producers. The two largest Agriculture Canada research institutes serving animal production are the Animal Research Institute and the Animal Disease Research Institute, which share a block of land in the Greenbelt. These two institutes have been under development for 12 years and when finally completed will represent facilities for animal production and animal disease research equivalent to the best in the world.

The second major source of research in support of animal production is at the universities, of which there are nine with major programs oriented to animal diseases or animal production. The combined university animal and poultry science departments comprise 100 professional person years and the three veterinary science faculties provide 183 professional person years in teaching and research (Commonwealth Agricultural Bureaux 1975).

Given adequate support, Canadian universities and the research-oriented branches of Agriculture Canada can continue to provide the technological expertise for Canadian livestock producers to be highly efficient in the conversion of feed to food.

SHEEP AND LAMB PRODUCTION

Although farm cash income from sheep and lambs increased up to 1976, this was a result of rising prices rather than increased production. In fact, lamb production has been decreasing for many years, and is close to becoming a lost agricultural enterprise in Canada. The reasons for this are numerous but include such major problems as lack of predator control, seasonal production, prevalence of internal parasites, low financial returns, and availability of imports from New Zealand. In fact, 80% of the lamb consumed in Canada is imported but could be produced here.

In terms of land and crop resources, Canadian producers could easily meet the requirements for lamb production even if this should increase several times. It seems just as desirable to produce our own lamb in Canada as it is to produce our own milk, eggs, beef, and poultry; in fact it is in Canada's best interest to have all our meat produced here.

As mentioned when discussing feed sources and ruminant animals, sheep can utilize the same feedstuffs as beef cattle, including nonprotein nitrogen sources, and could be an alternate source of meat that would not compete for feeds that could be considered as food for direct human consumption. In addition, sheep are at least equivalent to beef cattle in their efficiency of conversion of protein in feeds to foods and probably more so because of their higher reproductive rate. Sheep also provide wool, a natural fiber, which is independent of nonrenewable resources.

Although traditional systems of sheep production have resulted in a near disappearance of the sheep industry in Canada, a significant research program has been undertaken by the Animal Research Institute to try to develop a system, compatible with the Canadian climate and feed supplies, that will increase efficiency to the point where sheep production in Canada will become a viable proposition.

SUMMARY

- Animal production is a major contributor to the Canadian economy.
- Animal production has as its aim the efficient conversion of feeds to food.
- The efficiency of converting feeds to food depends on many factors.
- Animals and poultry can in fact convert feed protein to food protein efficiently and do not have to compete in a detrimental way for sources of nutrients capable of being utilized by humans directly.
- Given our current levels of agricultural productivity and the make-up of the human diet, Canadian land resources could support a population of approximately 50 million people.
- Canada has a strong base of professional people and adequate facilities to continue to provide the technology for efficient livestock production.
- The sheep industry in Canada has been decreasing and needs major technological input if it is to survive.

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ROLE OF BEEF CATTLE

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I wish to commend the Parliamentary and Scientific Committee for its concern in this area and for its solicitation of views directly from people in the animal industry.

I believe that my role is to discuss the contribution that beef cattle makes to the food supply, with emphasis on protein.

CONCEPTIONS

To start with, I think some background may be useful. Reading the public mood and interpreting current conceptions, I have formed three impressions:

1. That much public concern exists about the adequacy of the present and future supply and price of food. This issue is related to the concern about a loss of prime agricultural land to nonagricultural uses.
2. That there is a popular and widespread conception that livestock are inherently inefficient converters of feed into human food and that livestock production is therefore wasteful.
3. That the morality of beef production is in question, predicated on the simplistic assumption that grain consumed by cattle could be fed directly to needy and often hungry humans. As a result of this "morality" issue, increasing numbers of people are being encouraged to feel guilty about consuming animal products.

REALITIES

In juxtaposition to the previous conceptions, I should like to list a few realities:

1. As an agricultural nation, Canada is capable of vastly exceeding domestic food production requirements and of exporting huge quantities of agricultural commodities.
2. Although no one can challenge the need for far-sighted land-use planning, there is not now, nor is there likely to be, any shortage of agricultural land. Indeed, the most persistent and least soluble of agricultural problems since the advent of modern farming technology has been to contend with surpluses.

3. Food in Canada is now more abundant on a per capita basis than it has ever been before; it contains a higher proportion of foods of animal origin than ever before, and yet is cheaper in terms of disposable incomes than ever before.

A case can simply not be made for concern about the adequacy or price of the food supply in Canada. There are, and will be again, sudden deviations from trend, which will be misinterpreted by those who forget that biological forces and the weather can greatly affect the food supply in the short run.

WHAT ABOUT THE WORLD?

Having stated the case insofar as Canada is concerned, I must now acknowledge the hungry half of the world and concede that their food supply outlook is not so good. Again, we must identify some conceptions and some realities. The dominant conception about livestock production is that the grain fed to cattle and hogs in Canada could sustain the lives of hundreds of thousands in the underdeveloped nations.

When painted graphically, this is a compelling picture. Hence arises the question of morality. Winter[1] creates an image of starving children, kept out by a fence as cattle feed on grain. Because not one of us would tolerate such a scene if it confronted us, let us look at that fence that separates "starving children" from "gluttonous cattle" more carefully.

- Are the children denied food because cattle consume grain? I think this describes the type of superficial moralistic and uninformed view that has gained some unwarranted credibility of late.
- Before we worry about feeding grain to cattle, or worse still, consuming grain in the production of alcohol, let us ponder a few other things.
- We have not solved the political and economic problems that attend the transfer of grain from Canada to the hungry world.
- We have not discovered how to extend food aid without damaging the incentives needed to stimulate agricultural production in poorer nations.
- We have learned, however, that food aid is a stopgap emergency measure and not a long-term or continuous one.
- Too few of us have the courage to recognize the fundamental problem, which is runaway population growth. Too many think it is inhumane to speak of population control as a prerequisite to adequate global nutrition.

Too few of us realize that Malthus was right in proposing that fecundity would ultimately outrun our best efforts and our greatest technological advances in food production. Can we not see that to forsake livestock production in order to make more food available is essentially an empty gesture? When population reaches the point that we can no longer produce livestock, it would only be a matter of time before we could not produce enough grain to feed an exploding population. Our great reluctance to look at the population side of the equation inevitably dooms our efforts to failure.

[1]Winter, George R. Protein efficiency in Canada. Montreal, Que.: Can. Livestock Feed Board; 1975.

A common question asked is, "will we be able to feed the 7000 million people projected for the world in the year 2000?" The answer is very simple. Yes, we will or they won't be here.

That may appear to be a brutal reply, but the reality is even more brutal. We are well past the flex point in the population curve. The reality is that either we limit population growth in a humane and intelligent way or nature will take brutal steps to do it for us. The steps that nature chooses are well known and include mass starvation, endemic disease, debilitating malnutrition, and in addition, man contributes murderous wars.

There is no virtue in maximizing the human population of this planet, and there is even less in turning away from the issue because it offends our sensitivities, or our traditions, or our religious convictions.

My simple question is "why cannot mankind order its affairs so that an optimum global population can enjoy the abundance of the world's resources in a happy balance that preserves the environment and husbands her distinctly finite resources for generations yet unborn?"

My argument, which I believe is rational, is that a population pressure that still allows a diet based on a balance between foods of plant and animal origin makes more sense than a population so great that there is a forced dependency on a simplified plant-based diet. Let me explain.

Animals represent a vast, living, flexible reservoir of food, and have performed this function since they were first domesticated. They enrich and improve the quality of our food supply. In times of temporary food shortage, livestock can be slaughtered in larger numbers, while breeding stock is retained for future increase. In cases of extreme or prolonged shortage, the level of the livestock population can be reduced, thereby permitting more direct forms of human food consumption. The safety or flexibility factor thus provided is extremely valuable. How many of us have thought of the powerful buffer that livestock provides as a storable, living, reproducing reservoir of food. To abandon livestock production in favor of human population removes this buffer and thus diminishes the margin of safety we enjoy in our food supply.

CATTLE COMPETITIVE OR COMPLEMENTARY?

The production of cattle may be regarded as either competitive with the human demand for food or complementary to the human food supply, depending on the combination of circumstances.

1. Because it is a source of high quality protein, beef can be complementary in supplying protein.
2. When cattle are on land suitable only for grazing, they are always complementary. However, when they are raised on land that is capable of crop production for more direct forms of consumption, the cattle may be competitive but could still be complementary. Which they are depends on the adequacy of the food supply, on its protein and energy content, and on incomes being sufficient to support a diet containing

both animal and plant products. However, it is possible that income, rather than the level of supply, is a limiting factor in regard to people's diet. When incomes are low and food supplies are adequate, prices of both plant and animal products inevitably decline. When incomes are low and food supplies are inadequate, livestock can be extremely competitive. This situation occurs in India, where a huge food reserve exists in the form of cattle but is inaccessible because of religious belief. The cattle further compound the problem by consuming food that might otherwise be available for human consumption.

The possible combinations of protein and food energy supply, land base, and income levels are shown in Appendix 1. I should like to make some observations on these data because all of the combinations do not exist in reality in any one country.

1. There is no area in the world at present where the protein supply is deficient on a country-wide basis.
2. There is no area in the world at present where the food energy supply is deficient on a country-wide basis.

These statements do not, however, mean that the total population of each country receives adequate protein and food energy. This problem is clearly related to income distribution and social structure, and is not the result of cattle consuming the protein or energy supply.

In addition, although total protein and energy levels are at present adequate, there is no assurance that supplies will continue to be adequate in the face of rising human population. Thus, the combinations in Appendix 1 that do not exist at present (nos. 7–24) are all theoretically possible, and within these 18 combinations cattle may play a distinctly complementary role in at least 10 and a competitive role in 8. If incomes can be improved, the livestock will be competitive only where the energy content of the diet is inadequate and the land base suitable for direct human food production is given over to livestock production. In these circumstances, unlimited population growth and livestock production may be judged equally immoral. Tables 1 and 2 give further support to my argument.

THE INEFFICIENCY OF LIVESTOCK PRODUCTION

Livestock are acknowledged to be inefficient converters of plant food into human food. The energy efficiency of the cow–calf operation is less than 3% and that of cattle-feeding operations about 10%. I have had to derive a protein efficiency estimate. In 1972, the world beef cattle herd consumed some 1.9×10^9 kg of protein and yielded an estimated 0.45×10^9 kg of meat protein for an implicit efficiency of 24%. The protein was, however, upgraded significantly in the process by the addition of some essential amino acids not readily available in foods of plant origin.

In addition, in the case of both energy and protein content, cattle, being ruminants, convert massive quantities of otherwise unusable foodstuffs into

TABLE 1. Per capita food requirements for humans

	Daily energy requirements (kJ)	Reference* protein (g/day)
N. America, W. Europe, and Japan	10 694	39.2
E. Europe, and USSR	10 757	40.0
Latin America	9 974	37.7
Near East	10 280	45.5
Africa	9 773	41.5
S.E. Asia	9 304	36.6
World	9 664	38.7

Source: Abbott, derived from FAO/WHO Expert Committee on Nutrition 1971. Cited by G. R. Winter, Protein efficiency in Canada. Montreal, Que.: Can. Livestock Feed Board; 1975.

*Reference protein has a net protein utilization value of 100.

TABLE 2. Estimated available protein supply and requirements by region

Region	Daily available supply in 1970 (g/person)		Total daily protein requirements FAO/WHO (g/person)	Supply/requirements ratio
	Total protein	Total animal protein		
World	66.8	21.7	38.7	1.73
Economic Class I	89.5	52.7	39.2	2.28
North America	96.6	69.4	39.7	2.43
Western Europe	88.6	48.7	40.0	2.22
Oceania	100.2	69.4	38.9	2.58
Other developed	78.2	32.6	36.3	2.15
Economic Class II	56.4	11.4	38.4	1.47
Africa	58.6	9.5	41.5	1.41
Latin America	64.9	24.7	37.7	1.72
Near East	66.8	13.4	45.5	1.47
Asia and Far East	51.7	7.9	36.6	1.41
Economic Class III	68.3	18.2	38.8	1.76
USSR and Eastern Europe	92.9	40.9	40.0	2.32
Asian centrally planned economies	58.7	9.2	38.3	1.53

Source: FAO, from G. R. Winter, Protein efficiency in Canada. Montreal, Que.: Can. Livestock Feed Board; 1975.

high quality meat products. These foodstuffs may be residues from cropping land, thus adding an element of complementarity.

HOW MUCH GRAIN DO CATTLE EAT?

I think I have dealt adequately with the misconception that cattle production is more generally competitive with the human food supply than complementary to it. However, there is also a general misconception about the amount of grain actually consumed by cattle in the beef production process. I have therefore attempted to quantify grain usage in the beef production process (Appendix 2). This analysis is necessarily imperfect, but I doubt that the error can be greater than 10%. The data illustrate that approximately 4 kg of grain were consumed per kilogram of carcass beef produced in 1976. Because this estimate also suggests that beef cattle consumed about 20% of the grain consumed by the livestock industry in 1976, I am further assured that the estimate is reasonably reliable.

This type of analysis does not explain the proportion of beef supply that was produced on land that could have been used for more direct food production. The point is, however, academic because the food supply in Canada is surplus to requirements.

VALUE OF MANURE

Often unconsidered is the ecological balance maintained by the return of animal wastes to the soil. Such a process restores to the soil important quantities of plant nutrients in the form of nitrogen, phosphorus, and potassium. Perhaps more importantly, manure also restores organic matter to the soil, thus improving and maintaining soil structure. My expertise does not permit me to comment further, except to draw attention to this often forgotten benefit.

SUMMARY

There is a serious public misconception about the role of livestock in the food production process. Livestock are frequently regarded as competitors with humans for the available food supply. The reality, however, is that in most cases livestock play a strong complementary role in a variety of ways.

- The ruminant utilizes vast tracts of otherwise unusable range lands and also consumes masses of crop residues. This process improves the quality of the food supply, particularly the protein quality.
- Livestock are not competitive in situations where the food supply is adequate.
- Livestock serve as a vast reservoir of high quality food.

- Animal wastes are important in maintaining soil fertility and soil structure.
- The amount of grain consumed by cattle is grossly overstated. Although cattle consume as much as 7 kg of grain per kilogram of body weight gain, this occurs only in the brief finishing process. A more realistic rate of usage is 4 kg of grain per kilogram of carcass weight.

Little purpose is served by indicting livestock production in the debate about the adequacy of Canada's or the world's food supply. Such an indictment has no basis in fact, except in areas where livestock are reared on a land base suitable for direct human food production and where the food supply is inadequate.

APPENDIX 1. Cattle competitive or complementary? Some common situations

	Protein S-Sufficient D-Deficient	Energy S-Sufficient D-Deficient	Land G-Grazing C-Crops	Incomes H-Supports meat consump. L-Supports veg. consump. P-Poverty	Cattle ++ Strongly complementary + Complementary 0 Neutral – Competitive –– Strongly competitive
1.	S	S	G	H	++
2.	S	S	G	L	+
3.	S	S	G	P	+
4.	S	S	C	H	++
5.	S	S	C	L	–
6.	S	S	C	P	––
7.	S	D	G	H	+
8.	S	D	G	L	+
9.	S	D	G	P	+
10.	S	D	C	H	–
11.	S	D	C	L	––
12.	S	D	C	P	––
13.	D	S	G	H	++
14.	D	S	G	L	+
15.	D	S	G	P	+
16.	D	S	C	H	++
17.	D	S	C	L	–
18.	D	S	C	P	––
19.	D	D	G	H	++
20.	D	D	G	L	+
21.	D	D	G	P	+
22.	D	D	C	H	–
23.	D	D	C	L	––
24.	D	D	C	P	––

APPENDIX 2. How much grain do beef cattle consume in Canada?

In 1976 the beef supply was derived approximately as follows:

Beef from cull cows	20%
Beef from fed steers	54%
Beef from fed heifers	24%
Beef from cull bulls	2%

USAGE OF GRAIN IN BEEF PRODUCTION

1. Cows. Grain is not fed to beef cows and is fed to dairy cows solely for milk production purposes. Therefore, grain utilization for cow beef production is zero.

2. Fed steers. Birth to weaning at 200 kg—no grain utilized (Note: A negligible amount of grain is sometimes used for creep feeding.) Following weaning, steers may follow one of several feeding regimens. The two most common feeding regimens are described; quantities of grain utilized are approximate.
   (a) Full grain feeding—weaning to market. The highest level of grain that it is possible to feed a steer or heifer per day is about 2 kg per 100 kg body weight or 7 kg per kilogram of gain.
   200 kg to 500 kg = 300 kg gain
   300 × 7 kg = 2100 kg grain
   2100/500 = 4.2 kg grain per kilogram of live weight or
   7.2 kg grain per kilogram of carcass beef.
   (b) Moderate feeding route. Ration is based primarily on pasture, silage, and roughage, with heavy grain feeding confined to the last 140 days, when cattle grow from 340 to 520 kg. Cattle may consume a maximum of 9 kg of grain per day for 140 days, a total of 1260 kg. Cattle were also fed supplement at 900 g per day for 200 days (from 200 kg to 340 kg) or 180 kg.
   1440/520 = 2.77 kg grain per kilogram of live weight
   or 4.76 kg grain per kilogram of carcass weight.

3. Fed heifer. Birth to weaning—no grain.
   (a) Full grain feeding.
   180 kg to 410 kg = 230 kg gain
   230 × 7 kg = 1610 kg grain
   1610/410 = 3.9 kg per kilogram of live weight
   or 6.7 kg per kilogram of carcass weight.
   (b) Moderate feeding rates. Cattle consume 7.25 kg of grain per day for 140 days from 270 kg to 430 kg. Cattle were also fed supplement at 900 g for 150 days from 180 kg to 270 kg.
   Grain 7.25 × 140 = 1015
   0.9 × 150 = 135
   1150 kg
   1150/430 = 2.67 kg grain per kilogram live weight
   or 4.60 kg grain per kilogram carcass weight.

4. Bulls. Very little grain is fed to bulls for beef production purposes. Any minor amount can be safely disregarded.
An assumption must be made as to the proportion of fed steers and heifers produced on the "full" and "moderate" grain utilization regimes. I estimate that in 1976, 20% of the steers and heifers were produced on the full utilization regimen and 80% on the moderate regimen.

These data can be used to give the following table.

Beef source	Proportion of each 100 kg of beef produced (in kg)		Grain utilization (kg) Live basis	Grain utilization (kg) Carcass basis
Cow	20		0	0
Steer	54			
		10.8 full fed (20%)	44.71	77.00
		43.3 moderate (80%)	120.10	206.93
Heifer	24			
		4.8 full fed (20%)	18.67	32.16
		19.2 moderate (80%)	51.26	88.32
Bull	2		0	0
Total	100		234.74	404.41

Thus 2.35 kg of grain are utilized in the production of 1 kg of live beef and 4.04 kg in the production of 1 kg of carcass beef. In 1976, Canadians ate about 45 kg of domestic beef per person and thereby consumed the equivalent of 180 kg of grain.

On the basis of this analysis and on the basis of the fact that in 1976 Canada produced 1 073 000 t of carcass beef, we utilized approximately 4 340 000 t of grain. This is about 20% of the total grain fed to livestock in 1976.

THE CANADIAN PORK SYSTEM

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SCOPE

The Canadian pork system contributed about 1600 million dollars to the economy in 1976. This contribution came from 8 million pigs, generating 800 million dollars in farm receipts and accounting for 10% of farm cash income. In the process, the system utilized about 3 million metric tons of feed grain from 1.4 million hectares of land, provided Canadians with 25% of their meat supply and generated a total activity of 1600 million dollars.

STRUCTURE

The system contains five clearly defined entities:

1. Farm supply
2. Farm production
3. Farm marketing
4. Slaughtering and processing
5. Retailing

A full analysis of the industry requires an analysis of each of these segments.

LOCATION

Pigs are produced throughout Canada but are concentrated in three major and two minor regions:

Major regions	*Minor regions*
southern Ontario	eastern Saskatchewan
southern Quebec	southern Manitoba
central Alberta	

CHANGING FARM PATTERNS

Until the Second World War, pig production was usually a secondary livestock enterprise on a farm, ranking behind both beef and dairy cattle. Since the war, considerable specialization and consolidation has taken place. In 1941, for example, there were pigs on 125 000 farms in Ontario. Today, there are pigs on about 15 000 farms. The decline has been steady for 36 years. There is a high degree of concentration within the 15 000 farms; about 20% of the farms produce 80% of the pigs.

THE RISE OF MODERN UNITS

As farm production has consolidated into fewer units, unit size has increased and has shifted from units that were labor intensive, utilizing minimum technology and capital, to units that are labor efficient, with large inputs of both capital and technology. In addition, as time progresses the industry consumes new technology at ever increasing rates. A typical modern unit today may accommodate 150 sows, producing 2500 pigs annually with a capital investment of $250 000 and an operating capital of $75 000. It is the rise of these modern units, which consume both capital and technology, that makes the farm supply agribusiness component of the system particularly important, for it is the farm supply component that provides these inputs.

REGIONAL PATTERNS

Production in the Prairie Provinces fluctuates widely in direct proportion to grain surpluses. Westerners sell grain directly if markets are available. If markets are not available, the grain is fed to livestock. Pork production in Ontario has historically been more stable than in other provinces but has now declined from 40 to 30% of the Canadian total. Quebec, on the other hand, has increased its production from 20 to 30% of the Canadian total.

These cyclical and changing patterns have caused major shifts in marketing patterns. Historically the west has been a surplus area, exporting to Quebec. Quebec is now a surplus area. The west must therefore seek U.S. and offshore markets.

The highly variable production in the west has always created problems that are probably more critical today than previously because production since 1971 has declined by over 50%. This decline has left the packing industry with a greatly reduced supply of raw material and, consequently, a large overcapacity with a resulting high overhead. As a result, the packing industry in the west is in severe economic difficulties and is consolidating for survival. Pigs are now slaughtered at only three locations in the west (Winnipeg, Saskatoon, and Edmonton). An additional problem is the high labor turnover caused by a relatively buoyant employment situation.

MARKET FORCES

Price is primarily determined by the U.S. market, which is centered in Omaha. When Canada is in a surplus position, the price is that of the Omaha market minus the cost of export. When a deficiency exists in Canada the price is that of Omaha plus the cost of import.

Within Canada, the Toronto market has historically dominated the national picture, with pricing in Quebec, the Maritimes, Manitoba, and Saskatchewan having distinct ties to Toronto. Because Quebec has moved into a surplus position, however, less pork is moving west to east and the Toronto market may be decreasing in national significance.

GOVERNMENT POLICY

The agricultural economy of Western Canada is grain oriented. As a result of this, three policies have been adopted to help stabilize and develop this economy. These policies are:

1. The Crowsnest rates for movement of western grain to terminals.
2. The feed-freight assistance for movement of feed grain from the west to Quebec and the Maritimes.
3. The Western Grain Stabilization Act.

There are strong feelings that each of these policies discourages, or puts at a disadvantage, western pig production and therefore has a negative impact compared to the positive impact of the hog stabilization policy.

One of the real challenges facing legislators is the development of policies that do not interfere unduly with the interrelationships of commodities.

CURRENT MARKET SITUATION

For the past several years, Canada has been a net importer of pork. Prices of home-produced pork have therefore been strong and production has been profitable. In spite of this, Canada remains a net importer. Real expansion has occurred only in Quebec. The Quebec expansion is unique in that it has developed in a close relationship with feed suppliers (80% of Quebec production is carried out under some form of integrated or contractual arrangement).

MARKETS

There are three markets for Canadian pork: Canadian, U.S., and offshore (Japan). The USA has been the historical export market. During the 1970s, a small but significant market has developed in Japan. This market is in the form of "spot sales" and long-term contracts. It has a long-term potential but will be highly competitive. The competition will come from three sources: USA, Europe, and the Far East.

COMPETITIVE POSITION

The quality of Canadian pork is competitive on world markets and particularly so in comparison with U.S. pork. The Canadian industry is highly technical and efficient. Input costs, however, are greater than those of the USA because of our somewhat higher feed costs and the stringent animal housing needs. Our meat industry also suffers some disadvantages of scale.

MAJOR NEEDS

About 90% of the protein supplement used for Canadian pigs is imported from the USA. At times this has cost $30 per pig. The development of a Canadian source for this supplement would benefit the Canadian balance of payments.

Rapeseed meal has a real potential but its use needs additional research and development. There are also times when surplus skim milk powder might more advisedly be directed to pig-feeding than subsidized for exports.

Continued expansion and development will require capital but agriculture does not develop its own capital. Historically, the Farm Credit Corporation has been an important source of long-term capital; in an inflationary society, however, its financing limits need examination.

Support in technological development, particularly in areas unique to Canadian pig production, is required to insure continued competitiveness.

Finally, policy development that inadvertently plays one commodity against another must be avoided.

FURTHER READING

The Canadian pork industry. Mimeo publ. Agric. Can. 1976.
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The Prices Review Board reports on pork are also valuable references.

POULTRY

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Canadians consumed 469 892 metric tons of poultry meat as well as 5 082 672 000 eggs in 1976; this large amount of food is equivalent to 12.38 g of protein per capita daily. Approximately two-thirds of the protein was in the form of meat, the remainder was derived from eggs. Most of the meat was supplied by chickens (69.5%) but there were significant amounts from turkeys (22.3%) and fowl (7%); the contributions of ducks and geese were small (1.2%). The protein contribution of poultry to the Canadian diet during the years 1973 to 1976 inclusive is shown in Table 1.

In 1970 the average North American consumed 98.2 g of protein per capita daily, of which 70.7 g were derived from animal products (Abbott 1973). These data should apply reasonably well to Canada, and on this assumption it appears that the poultry industry supplies about 12.6% of our daily protein consumption or 17.5% of our animal protein consumption. These values are impressive but it is perhaps more meaningful to express our intake of poultry protein in terms of nutritional requirements. Abbott (1973) estimated the requirement for high quality protein, such as that found in eggs, to be 39.2 g per capita daily. This value must be raised as the quality of protein decreases;

TABLE 1. Poultry meat and eggs as sources of protein in the Canadian diet

	Annual consumption per capita				
Year	Meat (kg)*	No. eggs*	Protein from meat (kg)†	Protein from eggs (kg)‡	Total daily protein per capita (g)
1973	21.32	233	3.189	1.566	13.02
1974	20.64	228	3.088	1.532	12.66
1975	19.36	224	2.896	1.505	12.06
1976	20.32	220	3.040	1.478	12.38

*Poultry Market Review 1976.
†Assumes eviscerated carcass contains 34% dry matter of which 44% is protein.
‡Assumes each egg weighs 56 g and contains 12% protein.

thus for red meat and poultry it becomes 49 g, for milk 52.3 g, and for wheat 75.4 g. Winter (1975) has estimated the Canadian protein requirement to be 50 g per capita daily. If we accept his value it will be seen that the poultry industry supplies approximately 25% of our protein requirements.

The quality of a protein is determined by the absolute and relative quantities of the component amino acids absorbed from the digestive tract when the protein is eaten. A useful estimate of protein quality is net protein utilization (NPU). A series of NPU values is presented in Table 2. Egg protein, with an NPU of 100, is totally available but the proteins of red meat and poultry are of lower quality. Plant proteins generally are of inferior quality.

TABLE 2. NPU values of selected food proteins

Food	NPU
Eggs	100
Fish	83
Red meat and poultry	80
Soybean flour, defatted	72
Rice	67
Corn	56
Wheat	52

Source: Anderson 1976.

This method of describing protein quality overlooks the fact that a normal diet consists of a variety of foods and therefore of proteins. If one protein contains an excess of an amino acid, it can complement a protein deficient in that amino acid. Animal proteins are good sources of lysine and methionine, two amino acids in which many plant proteins are deficient; consequently the inclusion of animal protein in a diet can have a value substantially greater than that described by NPU or similar estimates.

Biological quality is not the only criterion by which protein should be evaluated. It is axiomatic that food has no nutritional value unless it is eaten. There are numerous factors governing food acceptability, ranging from cost to religious taboos, and it is beyond the scope of this report to deal with the subject. However, there are a few points worth mentioning. In many communities the consumption of animal protein reflects an elevated social status, thus there is a continuing demand for animal products. In Canada there is an increasing demand for convenience foods and an array of new products has been developed to meet this demand. In many instances the cost of convenience is prohibitive or nutritional value is sacrificed. The egg is highly acceptable and nutritious and can be prepared in a multiplicity of ways in a short period of time—it is truly a package of convenience. Poultry meat is also found in many convenient forms. The growth of fast-food chains selling cooked chicken attests to the popularity of chicken meat. Other examples of convenience foods are prepared soups, stews, pies, mayonnaise, and even eggnog. It should also be noted that eggs possess several functional properties that make them invaluable in the preparation of foods such as sponge cakes, noodles, and mayonnaise.

The animal industry is frequently criticized for using protein that could be diverted to feed the human population. Abbott (1973) put this in perspective when he stated "some people are critical of the large quantities of protein that are fed to livestock...we must remember the economic fact that a large part of these supplies are available precisely because of the demand for livestock feed; if this demand were not here, less would be produced." More recently Anderson (1976) wrote "livestock/plant production is a self-regulating system. Higher grain prices lead to higher livestock production costs and animal product prices, which lead to lower consumption by humans. The type of animal products produced and the types of feed used are dictated by economics." In support of his argument Anderson pointed to the decrease in the amount of grain fed to livestock in the USA in 1974 because of increased prices.

The efficiency with which an animal converts feed protein into meat or egg protein depends on a multiplicity of variables such as the age and physiological state of the animal, the nature and amount of feed available, and the rate of production. Some estimates of efficiency conveniently neglect the protein cost of maintaining a cow in order to produce a calf from which beef is obtained, or the protein intake of the hen kept to produce the eggs from which broiler chicks are hatched. Other estimates attempt to include all feed protein consumed without stressing that much of it is not useful to humans and the land on which it is produced is incapable of producing human food. For example, grass grown in the Alberta foothills is a useful source of protein for cattle, but this area is not capable of growing crops that could be directly eaten by man; feather meal and animal viscera are good sources of protein for poultry; poultry excreta has nutritional value for cattle and sheep. Many estimates of efficiency are biased to suit the hypothesis of the author; others are outdated. For example, the feed required to produce 1 kg of live broiler chicken dropped from 2.70 kg in 1954 to 2.51 kg in 1965 and to 1.98 kg in 1970. These changes, which reflect improvements in the genetic make-up of the broiler stock, nutritional improvements in the diet of the parents and broilers, and more sophisticated management, illustrate how quickly estimates of efficiency can become misleading and outdated.

Anderson (1976) has estimated the amount of feed grain and oilseed meal protein required to produce edible animal protein (Table 3). The data include allowances for breeding herds and recognize the fact that some dietary protein is derived from forages or materials unfit for human consumption. Anderson then corrected these figures to allow for the fact that the nutritional values of animal proteins are greater than those of cereals and oilseed meals. The data on beef cattle are based on the assumption that an animal, at the time of slaughter, has consumed 886 kg of corn and 59 kg of soybean meal; if more grain is fed the estimate will rise. Similarly, the estimate for dairy cow efficiency is based on milk production of 5450 kg in 305 days and intakes of 1620 kg of corn plus 180 kg of soybean meal; again, higher levels of grain will cause the estimate to rise.

TABLE 3. Conversion of plant protein to animal protein

	Feed grain* oilseed meal protein needed to produce 1 kg of animal protein (in kg)	Feed grain* oilseed meal protein needed to produce 1 kg of animal protein on basis of protein available to humans (in kg)
Beef cattle	3.0 (or less)*	2.3
Dairy cattle	1.14	0.95
Sheep	2.4	1.9
Hogs	8.0	5.5
Laying hens	3.0	2.2
Broiler chickens	3.4	2.5
Turkeys	5	4

Source: Anderson 1976.
*Does not include roughages consumed in feed ration or use of nonprotein nitrogen in diet.

Anderson's data seem to present a realistic picture of the efficient conversion of plant protein that could be consumed by humans into edible animal protein such as is found in meat, milk, and eggs. The dairy cow, using dairy cow efficiency given above, produces more protein value than it consumes (Table 3). The laying hen and broiler chicken have highly efficient conversion ratios of 2.2:1 and 2.5:1, respectively. The values are grossly different from those developed by scaremongers who would have us believe that the production of animal protein is detrimental to the nutritional wellbeing of the world population.

Even a cursory glance at protein efficiency would be incomplete without mention of the by-products of the animal industry. By-products of the poultry industry include viscera, heads, feet, bones, feathers, egg shells, and hatchery waste, all of which can be recycled as animal feed ingredients. In addition there is much evidence showing that poultry excreta can be used to supply both protein and energy in diets for cattle and sheep. Thus, in a system geared to the concept of recycling wastes, the efficiency of the poultry industry is exceedingly good.

The Canadian poultry industry has developed because of the demand for its products, but this would not have been possible without the information and techniques generated by progressive and intensive research. The industry is very efficient; moreover, it has the flexibility to respond rapidly to increases in both the supply and the demand for products. The size of the national poultry flock can be changed drastically in a few months, whereas herds of cattle, and to a lesser extent swine, are less elastic because of the lengths of their reproduction cycles and their low rates of reproduction.

Poultry research has advanced more rapidly than research on other farm animals. This is partly because it is easy to produce large numbers of uniform birds at a relatively low cost. The leading research by the poultry industry in genetics and nutrition has served as a model for research on other species. It is difficult to assess the value of this, but it is real and substantial. The data in Table 4 provide an indication of the progress made by the Canadian poultry industry.

No other animal industry can match this rate of increased productivity and efficiency.

TABLE 4. Increased efficiency in the poultry industry over 25 years

	1952	1977
Feed to produce a dozen eggs	3.0 kg	1.7 kg
Feed to produce a 1.6 kg broiler	5.9 kg	3.1 kg
Age of a 1.6 kg broiler	13 weeks	7 weeks
Feed per kilogram of turkey meat	6 kg	3 kg
Annual production of eggs per hen	180	250

Because of the advanced state of poultry production it is logical to ask if the potential exists for further substantial improvements. There is strong evidence that dollars spent on poultry research will continue to yield a very high return that will benefit both the producers and the consumers of poultry products. Poultry breeding studies conducted at the Animal Research Institute have shown that it is possible to routinely raise the egg production of the laying hen to 280 eggs per year. More important is the fact that the rate of increase during recent generations has remained high and has been accompanied by the improvement of egg size, egg shell quality, hatchability and interior egg quality; therefore it is reasonable to expect further substantial improvements in the future. Research on broiler production at the Animal Research Institute and other institutions shows that a similar trend exists. We have not yet reached the ultimate in feed conversion and in the many other aspects of an efficient poultry meat system.

Where should the research dollar go to insure maximum efficiency of edible protein production by poultry? Increased knowledge of genetics and poultry breeding are essential if products suited to new market demands are to be made available. (The chicken demanded by the "Colonel" is very different from the roasting chicken that used to scratch around the farm yard.) Also, it is through improved strains of birds that we will increase productivity and reduce feed inputs. However, although breeding provides a base from which to work it must be noted that each improvement in a bird alters its nutritional requirements, hence the nutritionist and geneticist must work closely together. Further, as the largest cost of poultry production is the feed, there must be continued emphasis on feedstuff evaluation as well as on assessments of nutrient requirements. There is a need for improvements in our research programs on management, poultry physiology, waste utilization, processing, and marketing. This work should complement the breeding and nutritional work. In fact, research in poultry production should be multidisciplinary to be fully effective.

There has been considerable adverse publicity about the cholesterol content of eggs. Unfortunately this publicity is not based on fact, and indeed, according to recent research, those who claim that the consumption of one or two eggs a day may be harmful to health are possibly wrong. It is important that this dispute be settled, and if there is no hazard, as I suspect, the market for eggs will increase. If a hazardous component is identified, research must be directed toward eliminating it.

CONCLUSION

- The Canadian poultry industry produces enough high quality protein to supply 25% of the human protein requirement.
- The quality of poultry protein is high and it is present in products that meet the current demand for convenience and ease of preparation.
- It takes 2.2 kg of nutritionally equivalent feed protein to produce 1 kg of egg protein.
- The argument that animal production robs the human food supply is fallacious.
- Poultry production is more advanced than any other form of animal production; efficiency today is almost twice as high as it was 25 years ago.
- There is every reason to believe that productivity and efficiency will continue to increase rapidly, providing there is sufficient research support.
- Research in Canada must continue at an effective level, with the greatest emphasis being placed on a "total" or multidisciplinary approach involving genetics, nutrition, physiology, disease control, and management (environment) to insure maximum progress.

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DAIRY

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Before discussing the Canadian dairy industry it is perhaps appropriate to consider milk in relation to world hunger. McMeekan (1967) has noted that soil surveys estimate that of the 3.16×10^9 ha of potential arable land in the world, 1.38×10^9 ha are cultivated. He further notes that there is good evidence that production on existing cultivated land could be doubled by the end of the century. Vandemaele (1976) has shown that two-thirds of the land suitable for agriculture is suitable only for grazing. Preston (1976) has proposed using cattle—for milk, beef, fuel, and fertilizer—for improving the level of nutrition, the economy, and the ecology of the tropics. This multipurpose use would be based on sugar cane, a relatively new feed resource for cattle. The perennial nature of sugar cane and its ability to convert solar energy into food go a long way toward eliminating the problem of animal protein deficiency among inhabitants of the tropics. It appears that alleviation of world hunger can best be achieved through the development of food production in the deficient regions.

In any food production system we are interested in the output of protein and the energy yield per unit of resource used (land, labor, fossil energy). The competition for food between man and animals is often stressed, but the ecological aspects and resource input considerations are frequently ignored. Pimental et al. (1975) have noted that forage crops are generally higher in food energy yields per fossil fuel input than are grain crops. Table 1 shows that the ratio of food energy yield to fossil energy input is 3.79 for forage crops (alfalfa, maize silage, hay) and 2.39 for grain crops (maize, wheat, oats). With the exception of alfalfa, the protein yield per hectare and the fossil energy input per unit of protein output are similar for forages and grain crops. Alfalfa is superior in terms of yield per unit of area and conversion of fossil energy. At present the energy input to extract protein for man from alfalfa is not economically feasible.

The Dairy Council Digest (1976) states that dairy cattle utilize approximately 11.7% of all grains, 16.6% of all protein supplements, and almost 20% of all roughage consumed in the USA. Dairy products, excluding butter, supply 22.0% of the protein in the U.S. diet. The dairy industry is relatively flexible with regard to energy inputs. The economics of farming has determined the ratio of grain to forages used in dairy cattle diets.

TABLE 1. Analysis of vegetable protein production per hectare for various crops in the United States

Crop	Crop yield		Energy inputs		Fossil energy input/protein output (GJ)
	In protein (kg)	In food energy (GJ)	Fossil energy (GJ)	Labor (Person hours)	
Alfalfa	710	47.6	11.3	9	4.01
Soybeans	640	31.8	22.2	15	8.61
Maize	457	74.8	27.6	22	15.17
Maize silage	393	100.7	23.0	25	14.59
Oats	276	30.9	12.5	6	11.29
Wheat	274	31.3	15.9	7	14.38
Hay	200	35.9	13.0	16	16.26

In Canada, dairy farming provides about 20% of the farm cash income. Statistics (Appendix 1) show that the dairy cow population has been reduced by about 31% over the past 25 years to 2 048 000 cows in 1976. Total milk production has been maintained by a 65% increase in production per cow. During this same period, per capita consumption of fluid milk and butter has declined and cheese consumption has increased. The overall effect has been for the annual total milk equivalent per capita consumption to decline by 25% from 459 to 342 kg of milk.

Lack of data available for study and presentation to meetings such as this is a continual frustration. It is necessary to omit information on fossil fuels from this paper because the appropriate data are not available. A major portion of the data presented here comes from the Dairy Herd Analysis Service (DHAS) files. The data are based on two-thirds of the dairy cow population in the provinces east of the Ontario border for which milk, feed, and management records are kept on a routine basis.

Dion (1967) stated that, "In Canada, much of our potential agricultural production is lost because we do not apply efficiently what we know." Canadian agricultural research and the industry have frequently operated in isolation. Over the past 25 years the average capital value of a farm unit has increased from $15 200 to $144 499 (Appendix 1). This has contributed to changing farming from a way of life to a business enterprise and has forced farmers to seek methods of developing economically viable units.

Milk-recording programs are helping to develop a link between research and the dairy industry. Since 1967, when the Dairy Farmers of Canada held their first milk-recording conference, the number of cows whose production is recorded has increased from 11.3 to 29% of the national herd. With the utilization of feed analysis, the development of technology for mass milk-composition analysis, and data processing, more and more dairymen have available herd and cow data on nutrition, reproduction, health, labor inputs, and financial statistics, as well as the traditional production information needed for management. In the reverse direction the analysis of the accumulated milk-recording data is helping to reveal what future research would be most productive.

Using the U.S. National Research Council (1971) nutrient recommendations for dairy cattle maintenance and lactation, the 1976 Canadian production levels (Apppendix 1) represent improvements of 37% in conversion of feed energy and of 25% in protein conversion over 1951 production levels. It should be noted, however, that improvement in energy and protein conversion was 55 and 36% respectively for the U.S. dairy herd over the same period.

Some appreciation of the inputs and outputs for high- and low-producing herds can be obtained if we examine data from Quebec Holstein herds on DHAS files that had annual levels of production below 4000 kg and over 6000 kg of milk (Table 2).

The data in Table 2 show production at the lower and upper ends of a population of 2882 herds. On the basis of recorded feed inputs the higher-producing herds were 18% more efficient in terms of estimated net energy input to unit of milk produced. Labor was twice as efficient in the high-producing herds. The increase in financial returns over feed costs of $17 920 (assuming a 40-cow herd) for the high-producing herds reflects the current economic significance of high production.

Obviously there are areas in the dairy industry that need improvement. These include an increase in the percentage of milk-recorded cows, a more competitive rate of improvement in the industry, and more elaborate milk-recording programs to identify specific problems that are inhibiting production improvement. In order to consider potential improvements in production efficiency in the dairy industry, it seems appropriate to consider six areas; genetic change, feed efficiency, reproductive efficiency, health, management, and product quality.

TABLE 2. Comparison of DHAS herds (Holstein) for 1976 (Moxley et al. 1977)

Trait	Under 4000 kg milk per cow	Over 6000 kg milk per cow	Difference
No. herds	419	243	
Prodn. per cow (kg)	3567	6387	+79%
Ave. cow wt. (kg)	481	546	+14%
In milk (days)	281	310	+10%
Meal fed (kg)	1035	2175	+110%
Silage (metric ton)	1.5	3.7	+147%
Hay (metric ton)	2.4	2.2	-8%
Feed cost per 100 kg ($)	9.80	8.84	-10%
Prodn. per person unit (metric ton)	85	177	+108%

Net over feed cost for 40-cow herd = $17 920

GENETIC CHANGE

Genetic change is achieved through selection and use of sires on a population basis and of females on a within-herd basis. The introduction of milk-recording programs at the turn of the century was to provide records for selection purposes. The introduction of artificial insemination in the early 1940s increased the importance of sire selection. Recently developed mathematical procedures and data processing have led to a refinement of means for measuring the genetic or breeding values of dairy sires and cows. Under present conditions research data suggest that the optimum use of selection would lead to genetic improvement in milk yield of 2% annually. About 85% of this improvement would be attributed to dairy sire selection and use.

The price of milk is based on milk volume and fat content. With our present concern about animal protein it seems ironic that protein content has been ignored. The federal subsidy on industrial milk is based on fat yield. Within the past decade equipment for mass testing of milk for protein content has been available. DHAS has been testing milk for protein since the program was initiated in 1966; however, its use has been generally limited to research studies. Without an economic incentive a dairy farmer is not likely to concern himself with increasing the protein content of milk. In a study of the genetic trends among artificially bred Holsteins in Quebec (Kennedy and Moxley 1975) a decline in the protein content of milk was noted. Under present procedures for sire selection and use, the sires that were selected for sampling in 1977 will be making their major contribution to the milking herd from 1984 onward. This means that changes in market needs must be anticipated and taken into account in genetic selection.

Our potential export markets for breeding stock, semen, and embryos are dictating our interest in protein testing. Our competitors in northwest Europe have already established milk payment procedures that take protein levels into account and protein testing is included in their milk-recording programs.

Despite the financial significance of the dairy industry and the long-term impact of genetic change, Canada has no national policy on dairy cattle genetic research. Kennedy (1977) has reviewed the areas of research covered over the past 20 years. Most studies have been concerned with the genetics of selection for milk yield and milk composition. Other studies have been concerned with conformation traits, the genetics of mastitis, genetic nutrition interactions, and biochemical characteristics. Kennedy has noted that genetic gains are only fulfilling half of the theoretical potential.

FEED EFFICIENCY

It is generally recognized that the most frequent limiting factor in milk yield is energy intake. This may be due to quantity, or quality, or both, of the feed. Reid (1973) has noted that dairy cows are capable of producing 3600 kg of milk annually on an all-roughage diet. This is equivalent to the production of the DHAS herds under 4000 kg (Table 2) that required a metric ton of meal to supplement their roughage diet. This is perhaps an unfair comparison because soil and climate conditions are not always favorable for the production of good quality forage.

Tong et al. (1976) noted in a study of over 150 000 DHAS lactation records that increases in energy intakes from silage, hay, pasture, and meal had a positive effect on milk, fat, and protein yields. On the basis of a study of 2951 herds, Moxley (1976) noted that each additional kilogram of meal intake produced an increase of 1.2 kg of milk. This was after the effects of possibly associated factors were corrected for. In present economic circumstances and following correct feed recommendations it is profitable to increase meal intake by the vast majority of the dairy cattle population.

In a study of DHAS herds with 5 or more years of milk recording, the level of nutritional intake contributed more to the rate of improvement in production than did genetic change, reproductive efficiency, or level of mastitis. This was regardless of whether the herd was at a high or low level of production when it started on DHAS (Moxley et al. 1977). This suggests that some intensive nutritional field studies could provide direct benefits to the industry. Corley (1970) has suggested that reducing forage losses from 25 to 5% and improving the digestibility of forages from 50 to 70% would be worth 750 million dollars to the U.S. dairy industry.

Under practical conditions nutrient requirements, other than energy, are usually met by supplementation, usually in a meal mixture. Services for feed analysis and the formulation of rations are available from a number of sources. The extent of the use and application of these services is not known.

Metabolic disturbances and feed contamination are problems in dairy cattle nutrition. The increased use of corn silage and high moisture corn has alleviated these problems. Weather conditions during the fall can favor the development of molds on corn, which will result in the production of aflatoxin. This can seriously affect the health of the dairy herd.

From general observations, when a dairy herd starts on a complete milk-recording service the most frequent immediate benefits are derived from an improvement in the feeding program.

REPRODUCTIVE EFFICIENCY

The development of artificial insemination (AI) has been a major contribution to the genetic improvement of dairy cattle. Fifty per cent of the dairy cattle are bred by AI. Embryo transfer has been a more spectacular development. However, the knowledge gained in developing embryo transfer procedures may be of more value than the procedure itself.

Sterility or poor reproductive efficiency is a costly problem to the dairy farmer. Its cause is complex and can result in extended calving intervals, thus reducing annual yield per cow, or it can result in losses through necessary culling. Table 3 shows that 35.7% of the cows removed were culled because of reproduction problems. The total culling level of 25.2% in Nova Scotia in 1976 is similar to the levels observed elsewhere.

TABLE 3. Removal of cows from Nova Scotia dairy herds

Cause	No. of cows	% of cows removed
Breeding problems	390	35.7
Low production	337	30.9
Mastitis	108	9.9
Calving problems	32	2.9
Conformation	141	12.9
Other	83	7.9

Source: Nova Scotia Dairy Herd Analysis Service 1976.

Research has been carried out to establish methods to detect estrus and to confirm pregnancy. The British Milk Marketing Board provides a routine service, based on milk analysis, to confirm pregnancy during the 4th week following breeding. No services of this nature exist for Canadian dairymen. There is need for coordination of efforts on the part of AI units and milk-recording services. This could lead to more accurate measures of conception rates, more accurate identification of offspring got by sires, the effect of a sire on calving difficulties, and calf weight, and would also improve the chances of early detection of sires that are carriers of abnormalities.

Field research could go a long way toward identifying the causes of low reproductive efficiency. Research on improved embryo transfer techniques and the sexing of embryos requires more basic laboratory research.

HEALTH

Mastitis is defined as an inflammatory change of the mammary gland which, along with physical, chemical, and microbiological changes, is characterized by an increase of somatic cells, especially leucocytes, in the milk, and by pathological changes in the mammary tissue.

Mastitis is a major problem in the dairy industry. It is believed that 50% of all cows in North America are affected by various forms of mastitis. The incidence of the disease can be reduced by maintaining milk equipment properly and using it correctly, maintaining good sanitation practices, and by identifying and treating, or culling, infected animals.

Most methods of detection are based on somatic cell counts. DHAS has carried out research with a Danish-manufactured somatic cell counter (Fossomatic). Since February 1977 individual cows in about 600 herds have been tested monthly. The relationship between somatic cell counts on a herd basis and milk yield in herds that have been on test over 5 years is given in Table 4.

The average somatic cell count of herds in Canada is not known. There is a suggestion that it might be about 700 000 somatic cells per millilitre of milk.

TABLE 4. Average milk yield in DHAS herds associated with different levels of somatic cell counts during 1977

Somatic cell count (thousands per millilitre)	No. herds	% of herds	Annual production per cow (kg)
<200	27	7.6	5572
200–299	75	21.1	5518
300–399	100	28.2	5454
400–499	81	22.8	5475
500–599	37	10.4	5373
600–699	19	5.3	5305
700–799	5	1.4	5234
>800	10	2.8	5180

Source: Downey et al. 1977.

If this is the case, mastitis may cause the loss of 100 million dollars worth of milk per year. This ignores cost of treatment, milk losses following treatment, and culling or death of cows due to failure of treatment. With the introduction of routine somatic cell counting and the utilization of these records in cooperation with the veterinarian, the dairy farmer should be able to reduce losses from mastitis.

MANAGEMENT

In recent years there has been considerable research into the use of complete rations in the USA. Coppock (1977), Spahr (1977), and Britt (1977) have reviewed research in this area. There is evidence that the combination of group feeding and complete rations can improve feed conversion efficiency, reduce the incidence of metabolic diseases, and improve efficiency of reproduction.

Basic information has been developed to the stage where it would be desirable to study the economics of group feeding with complete rations. This is the type of research that can be carried out in a field study with an innovative dairyman.

PRODUCT QUALITY

Despite the importance of milk, market demands for quality are minimal because of the lack of suitable equipment for analysis. Presumably we should be primarily concerned with the content and quality of protein, the presence of bacteria, and the absence of contaminants, particularly antibiotics used in mastitis control.

Webb et al. (1974) give the average protein content of milk as 3.5%, consisting of 2.9% casein and 0.6% whey proteins. Dawson and Rook (1972) have observed a positive relationship between energy intake levels and protein content of milk. A review by Schultz (1977) shows that mastitis does not change total protein but reduces the casein and increases the whey protein components. Milk is valued because of its high quality protein, which enhances the value of cereal protein in the human diet. It is obvious that research on milk protein is needed and that ways to include protein in the milk pricing system should be found.

The responsible dairy farmer would respect strict controls on bacteria content and the presence of contaminants, including antibiotics, in milk. For human health and the good of the dairy industry, development and implementation of the appropriate testing procedures need attention.

Lactose has come to the attention of the public because of digestive upsets caused by milk in children who have been on a no-milk diet since weaning. The problem is associated with a lactase deficiency. The Protein Advisory Group of the United Nations feels that because of this problem efforts must continue to encourage increased milk consumption in developing areas. Lactose is important in milk not only for its energy value but also because it increases the utilization of calcium and other minerals.

In this era of processed foods, fast foods, and junk foods, milk appears to be a necessary component in our diet in order to maintain health. Milk is the product most frequently used by the Montreal Diet Dispensary to correct dietary deficiencies in pregnant mothers. Milk is important not only for its own nutritional content but also for its enhancement of other nutrients in the diet. Jonas et al. (1976) have reviewed U.S. milk consumption changes and have proposed product research to meet consumer needs, nutrition research to promote consumer health, and marketing research to explore consumer motivation.

SUMMARY

- Over the past 25 years milk production has continued to use a declining share of the plant protein and energy resources while maintaining total production yield.
- Protein, in spite of its importance, is ignored in the milk-pricing system. With limited protein testing in milk-recording programs, protein is also virtually ignored in existing genetic improvement programs. On the basis of published results, milk protein research in Canada is very limited.
- The reviews of genetics, nutrition, reproduction efficiency, and some aspects of health and management suggest that there is ample opportunity to improve efficiency in the industry. For immediate benefits to the industry and the population in general, emphasis should be placed on the development of production research. This type of research is likely to be most successful if it is carried on *with* the industry rather than *for* the industry.

• There is need to consider the effects on human health of declining milk consumption. For a product that is apparently supplying 25% of our protein requirements and 80% of our calcium requirements, as well as other nutrients, milk research deserves more serious attention.

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APPENDIX 1. Selected statistics, 1951-76

		1951	1956	1961	1966	1971	1976
Canadian agriculture							
Ave. capital value per farm*	($)	15 200		27 389	44 307	65 927	144 499
Dairy statistics†							
No. of dairy cows	(1000)	2 973	3 160	2 987	2 674	2 255	2 048
Milk production	(1000 t)	6 749	7 669	8 318	8 334	7 924	7 685
Annual production per cow	(kg)	2 268	2 427	2 785	3 116	3 515	3 751
Milk consumption in Canada							
per capita disappearance							
fluid milk	(kg)	174	182	151	142	123	119‡
butter	(kg)	8.7	8.8	7.2	7.9	7.1	5.4‡
cheese§	(kg)	2.6	2.9	3.4	4.2	5.7	7.1‡
Total milk equivalents	(kg)	459	465	393	400	374	342
U.S. agriculture							
Dairy statistics[ll]							
No. of dairy cows	(1000)	21 505	21 501	17 243	14 071	11 842	11 049
Milk production	(1000 t)	52 018	56 635	57 020	54 391	53 765	54 593
Annual production per cow	(kg)	2 419	2 762	3 307	3 866	4 540	4 941
Per capita disappearance$^{\pi}$ milk equivalents	(kg)	336	320	291	274	253	

*Selected Agric. Statistics for Canada, no. 77/10; June 1977.
†Dairy Statistics Canada, 23-201.
‡1975 data.
§Does not include cottage cheese.
[ll]Dairy Herd Improvement Letter, USDA, ARS 60-9 Vol. 53 no. 2; Sept. 1977.
$^{\pi}$Dairy Situation USDA DS 343.

FOOD RESEARCH AND DEVELOPMENT

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I wish to outline the principal concerns that face the food industry and the many people involved in research and development activities in food science and technology. These concerns should be and are, in the main, the bases for the choice, the planning, and the conduct of R & D programs in this very broad and diverse field. The researchers referred to are located in federal and provincial laboratories, in universities, and in the commercial enterprises of the private sector.

In addition, I hope to show how the conduct of R & D programs and the provision of scientific and technical services are contributing to the resolution of these major concerns, thereby assisting in the optimum utilization of the sources of foods available to Canada, and in provision of the quantity, quality, and variety of foods demanded by both our domestic and export markets.

The principal concerns facing those engaged in both business and R & D activities in food include:

1. insuring adequate production capacity;
2. insuring adequate distribution methods;
3. insuring adequate nutritional content;
4. insuring capability to provide acceptable foods for consumption;
5. providing adequate means to assess food safety;
6. providing means to maintain price of food compatible with the economic condition of the population.

These concerns serve as the goals to which R & D activities are directed. The very nature of foods, being so diverse in kind and so complex in composition and properties, demands an interdisciplinary approach in our endeavors to determine and understand the many factors that affect our ability to produce sources of foods, to assess and control quality, to insure safety and nutritive value, to develop new or expanded uses of food components, and to maximize the efficiency and effectiveness of the processing technology required to maintain the food supply.

Among the forces at work in our society that lend emphasis to these concerns are:

1. the continuing widening of the gap between supply of food and population growth in most of the underdeveloped countries of the world;

2. the world-wide projection of energy shortages in the next 25 years;
3. the vocal and demanding consumer movement stressing safety and nutritive value of the food supply.

Each of these forces, generally recognized as universal, has its effects on the R & D activities within each country, particularly within those recognized as the lands of greatest potential for the supply of food to countries not capable of producing their own.

Canada is a country considered capable of producing some foods in quantities far in excess of its own domestic needs. Hence I feel that the results of many of the R & D activities here could serve as examples worthy of international application, recognizing the modifications in approach and interpretation required by the particular agronomic and socio-economic situations that exist elsewhere. Therefore, I shall indicate the directions I see developing in food research activities in Canada and extrapolate how these may affect international concerns.

Some of the major trends developing in food science and technology in Canada are:

1. an increasing tendency to look at food supply and use in the context of a system;
2. an increasing determination to identify more specifically the objectives of research projects and programs being carried out in all sectors;
3. an increasing and improving interaction between the public and private sectors in the pursuit of R & D goals in food science;
4. an increasing interest and involvement of all scientists in the complexities of experimentation with foods and food components.

I should like to elaborate on these trends.

FOOD SYSTEMS APPROACH

Our work with food must begin with the material—the seed, or the stock—made available to the original producer, the farmer. From this point on the food system relies on the expertise brought to bear on the growth, harvesting and collection, processing, and distribution to the ultimate consumer. At each step in the process there are particular questions that need to be answered. At each step, too, there are important compromises to be made, compromises between quality and yield, between energy costs and availability of supply, between choices of equipment in processing and value of end-use. Such detailed questions and compromises can only be resolved successfully by an effective interdisciplinary approach, and it is in our favor that we are recognizing this and using this approach to aid our R & D programs.

Governmental programs such as Agricultural Marketing Assistance Program (AGMAP), Grains and Oilseeds Market Incentives (GOMI), Industrial Research Assistance Program (IRAP), Crop Development, and Program for the Advancement of Industrial Technology (PAIT), are now, more and more, serving to support R & D in broad areas including all phases of the systems approach. Similarly, the Contract Research Programs of the government—the "buy" alternative in "make-or-buy" R & D—is being utilized to support studies that are complementary to laboratory or pilot plant developmental work, studies that are providing information about the economic and acceptability factors so important in the innovative process.

OBJECTIVE-SETTING

Scientists and managers of scientific activities are aware that facilities are available to permit effective R & D in any area requiring it. But limitations on spending, whether public or private, are forcing these people to exercise improved judgment in the choice of the actual R & D to be done, and to identify in a much more precise way the objectives of R & D projects. This setting of objectives and priorities is now becoming common in most public and private R & D centers, in the review committees of funding organizations, and in groups at provincial and federal levels responsible for identifying the most needed R & D in particular fields. A beneficial result from such an approach is that it is becoming much more possible to predict when required information will be available in a certain problem area, because projects can be directed much more specifically to provide that new information. The scientific community is also finding benefit from knowing which areas have high priority, thus being able to submit proposals having objectives already judged to be important.

In the food field this objective-setting exercise is finding direct application in many funding organizations; the Contract Research Programs, the Research Committee of the Rapeseed Association of Canada, the activities of the Manitoba Food Product Development Centre, and the provincial counterparts of the Canadian Agricultural Services Coordinating Committee (CASCC) are examples.

INTERACTION OF PUBLIC AND PRIVATE SECTORS

An important aspect of R & D activities in food science in Canada depends on the effective transfer of research information and ideas to the private sector, which is ultimately responsible for commercial utilization of such results. To accomplish technology transfer to the private sector from the many and diverse research programs in the public sector requires continuing close interaction between those involved in the research and those in industry who must assess the results in terms of their own objectives. Transfer is facilitated if the public–private interactions are founded on the objective-setting process and are not called into play only to present results. It is clear that in the food field in Canada these interactions are becoming increasingly important in the early stages. Appropriate guidelines are being set in many provincial Agricultural Services Coordinating Committees, in the expert committees of many Canada Committees, in the recently established Canada Committee on Foods, and in scientific associations such as the Canadian Institute of Food Science and Technology. Public–private interactions are having direct effects on the setting of research priorities and hence on the funding and allocation of resources from the public organizations. This is a slow process and the benefits are often not realized immediately, but I think that where attempts are being made to make these interactions more collaborative, rather than simply "informing sessions," the industrial community is more willing to contribute and more receptive to the positions taken by public research and regulatory agencies on scientific and technical matters that directly impinge on business activities.

BROADENING BASE OF SCIENTIFIC EXPERTISE

Food science and technology have generally been considered as applied sciences and have not always been able to engender the interest and participation of many scientists in allied fields; food science was viewed as "cookery" or "plumbing." This situation is changing; many high quality research journals are now available and more and more chemists, biochemists, and molecular biophysicists are attacking problems in food science and publishing their work. The changing attitude is encouraging the development of scientific principles rather than the empirical evaluation of data. This is a world-wide development and undoubtedly reflects, in part, the response of the scientific community to the very "public" nature of food science today. The benefits are many and varied, contributing to an understanding of the materials and processes under study, and to the establishment of interrelations between the behavior of food components and plant and animal biochemistry generally.

I should like to illustrate the areas in food science and technology that are receiving special attention in this country and elsewhere, and how they relate to the concerns identified earlier. In doing this I shall have to omit or only briefly comment on much of the ongoing research that serves as a base for all the rest. A large amount of this kind of research serves plant production and protection needs. Without these continuing endeavors we should be unable to maintain the production of agricultural products of the quality and variety needed to provide the food supply.

AUTOMATION AND MECHANIZATION IN FOOD PROCESSING

Earlier I referred to food science as "cookery." This may be so, but the processing of foods is now a well-advanced engineering field. The application of highly mechanized and partially automated processing methods to the manufacture of foods places special demands on knowing and understanding the composition and properties of the foods being processed, and how variations in these characteristics affect the utility of the equipment and methods used in large scale production facilities. These remarks apply to all kinds of food products, from cheese manufacture to continuous sterilization and canning of fruits and vegetables. This understanding is critical if Canada is to be able to apply advanced processing techniques to the foods grown here. Changes in properties begin to appear immediately after collection or harvesting and, if not controlled, can negate the economic advantages of the technology available. The identification of variations in composition and properties of foods is under active study. As discussed earlier, the necessary interaction with the private sector, to determine how to use this information to assist it, is being improved continually.

CENTRALIZATION OF PROCESSING FACILITIES

Many activities in this country appear to be moving toward larger centralized facilities. The disappearance of the family farm or the small grocery are examples. Similarly, in food processing we see the growth of large production units in such diverse areas as cereal milling, vegetable and fruit canning, milk drying, and animal carcass cutting. This trend is based on economics, and all the factors affecting the economics are involved. Centralization also raises many technical questions, not unlike those related to mechanization in general. Longer times from harvest or collection to processing are usually involved, and the changes in characteristics of food that can arise during this time must be well controlled. Similarly, the transport of the product from one facility to the next, within the total system, demands increased knowledge about the storage and distribution methods that best suit the product. Much research on meat storage, packaging, and distribution from centralized cutting facilities is underway to insure that undesirable changes in quality and possibilities of contamination by microorganisms are minimized. In the milk field, the potential of partial sterilization techniques—called thermization—is being evaluated to permit longer storage of milk before processing without changes in quality.

DEVELOPMENT OF NEW FOOD INGREDIENTS

All around the world scientists and technologists are searching for sources of new food ingredients, usually protein. This is a major activity in Canada in both public and private centers. It is important to realize, however, that the search is not just for protein, because all the sources one can envisage contain large amounts of components other than protein, such as vegetable oil, starch, or fiber. From many of these components useful food ingredients can be derived, which are of considerable significance in adding value to this country's processed crops. In this kind of R & D in Canada there is a particular emphasis on setting objectives, on collaboration between the public and private sectors, and on the funding of R & D. It is important to see this R & D as a source of potential growth in industry, and we should concentrate our attention on evaluating both the technical and the economic feasibility of fractionation of crops. There is also the possibility of native crops serving as a source either of food ingredients or of industrial chemicals. It is critical that we should not be satisfied only with the laboratory findings of our research, but that we should apply them to practical industrial processes. The recent opening of the Protein, Oil and Starch (POS) pilot plant in Saskatoon, funded by IT & C and the private sector, is an example of our response to this need. The possibilities of using rapeseed and increased amounts of cereals, pulses, and other oilseeds as sources of new food ingredients are being actively studied.

SAFETY AND NUTRITION OF THE FOOD SUPPLY

Increased attention to insuring safety and nutritive value is obvious in Canadian R & D. The advances possible here stem from the continually increasing capability of scientists to isolate and identify minor components that may affect our health or well-being, and to remove or otherwise overcome their detrimental effects. Not all of the possible problems arise from the presence of materials added deliberately by man, even though we hear a lot about the danger of additives. Many naturally occurring materials that determine the composition of food are also capable of having undesirable effects on the human body and must also be a subject of our research.

Many of the processes used in food manufacture bring about alterations in the nutritive value of foods; some increase it, others decrease it. It is imperative that we assess the risks in relation to the benefits, and be able to arrive at compromises that balance quality and safety against insurance of supply. Here the collaboration of food scientists, medical researchers, and the food industry is required and is in place. This is a very difficult field of research; findings are largely derived from studies on animals rather than humans, and emotional concerns about the foods available can be as great or greater than physical concerns. Fortunately, the regulatory agencies of Canada have generally reacted to concerns of this kind firmly but not precipitately.

ENERGY CONSERVATION AND FOOD WASTE UTILIZATION

Recently the Canadian food industry has recognized the importance of R & D in decreasing the energy expenditure in food processing and distribution, and in finding means to utilize, rather than dispose of, the by-products and waste originating from food processing. The industry itself has given high priority to this research. The position of the industry, in this regard, has been fed through Ontario Agricultural Services Coordinating Committee to the Canadian Agricultural Services Coordinating Committee and should show its effect on R & D in Ontario in the near future. The Contract Research Programs are supporting research on utilization of cheese whey and of fruit and vegetable wastes. From such materials should come economically attractive alternative animal feed constituents, and here the collaboration of the food industry with the animal production sector will be required.

In looking at its energy consumption, the food industry is preparing to examine in an orderly way the various processes it uses, and to determine where it may be possible to reduce losses, alter processes to decrease energy demands, and permit effective recycling of heat to reduce total energy consumption.

I have mentioned only a few of the directions in which I see R & D in food science progressing. In the main, these are toward the high priority areas established by collaborative actions of public and private groups, and are intended to provide information that directly addresses the major concerns in the food field.

I thank the Committee for the opportunity to express these thoughts and opinions about this important field.

II Nonanimal protein

OVERVIEW

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INTRODUCTION

The oft-repeated and unquestionably true statements by FAO and WHO that millions of people in the world are suffering from protein malnutrition implies there is a world shortage of proteins.

In fact there is no current shortage of food proteins, because there is no world shortage of food. Protein malnutrition results from inequitable distribution and utilization of food proteins rather than from inadequate protein production.

According to FAO/WHO, the per capita daily requirement of reference protein (balanced protein) is 35 g. Thus the global daily balanced protein requirement, based on a population of 4500 million people, is 157 000 metric tons, or 57 million metric tons annually. Because most proteins are not balanced, a correctional factor, based on 65% of the net utilizable protein, changes the per capita daily requirement to 54 g and the annual world requirement to 88 million metric tons (Bushuk 1977).

FAO statistics show that present world consumption of protein is approximately 100 million metric tons annually, considerably above total world need. The industrialized countries, with 25% of the world's population, consume 40% of the world's protein—well above the recommended requirement. The remaining 75% of the world's population has an average daily intake of 48 g of protein, significantly below the recommended 54 g requirement.

Of the world's protein resources for human nutrition, plants contribute about 70% and animal proteins the remaining 30%.

In this paper I shall discuss a few known facts about agricultural crops as protein resources on a world basis, the Canadian component in world production, and some thoughts about the extent to which plant protein production could conceivably be increased in Canada for domestic and export uses.

WORLD CROP PROTEIN RESOURCES

The major global crop plant resources for protein are shown in Table 1.

Although a substantial fraction of the 149.7 million metric tons (see Table 1) of plant protein is used for animal feeding, especially in industrialized countries, and is therefore not available for direct human nutrition, the remainder is well above requirements—which substantiates my earlier statement that current protein malnutrition is based on inequitable distribution and utilization of total production.

TABLE 1. World crop protein resources (1974–75)

Principal crops	Grain production (million metric tons)	Protein (%)	Total protein (million metric tons)
Wheat	333	12.0	40
Rice	285	8.0	23
Maize	251	10.0	25
Barley	131	10.0	13
Sorghum/millet	85	11.0	9
Oats	54	10.5	6
Rye	33	12.5	4
Soybeans	44	32–42	16
Cottonseed	21	17–20	4
Peanut	15	25–28	4
Sunflower	10	27.0	2.7
Rapeseed	6	28.0	1.7
Flaxseed	3	26.0	0.8
Sesame	2	25.0	0.5
			Total 149.7

CANADA'S PLANT PROTEIN PRODUCTION

Perhaps the first point that should be made in this section is that Canada produces very little of the world's food crops and very little of the world's plant protein. Canada's component of the world's present 1.46×10^9 ha of crop land is approximately 5%. Because of Canada's northern latitude and predominantly dry-land agriculture, her cereal production has rarely exceeded 3% of the world's grain production.

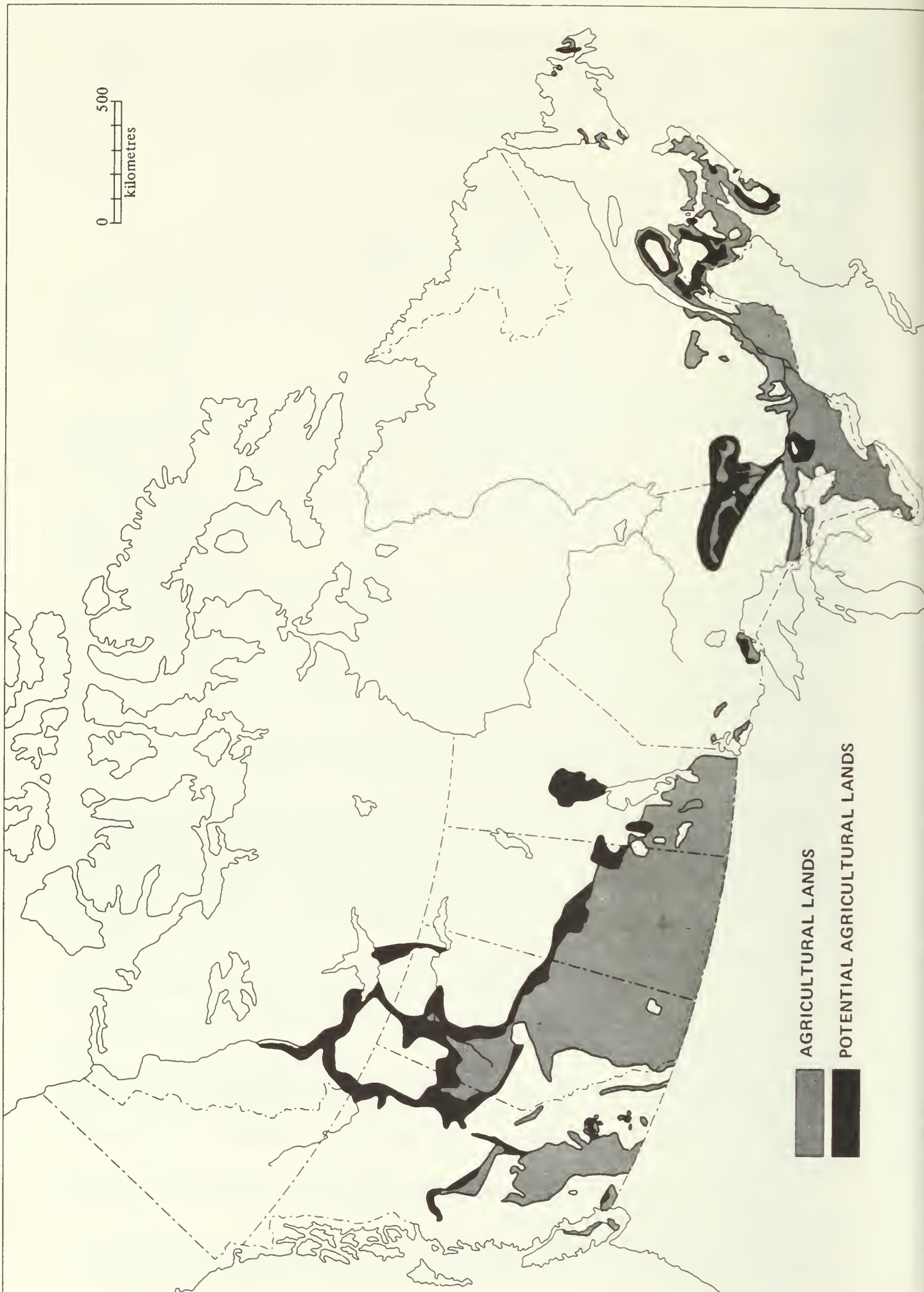
The distribution of Canada's agricultural lands and potential agricultural lands is shown in Figure 1.

Only 13% or 121×10^6 ha of Canada's 928×10^6 ha are suitable for agricultural production (Figure 2).

Not all the land considered suitable for some form of agricultural production is equally productive, and only 50×10^6 ha (Classes 1 to 3) are considered suitable for sustained production of common field crops (Figure 3).

An additional 22% or 26.2×10^6 ha of Class 4 land, although marginal for field crops, could be so utilized.

At present, only 68.8×10^6 ha of Canada's agricultural lands are now in farms, of which only 27.5×10^6 ha are annually planted to cultivated crops (Figure 4).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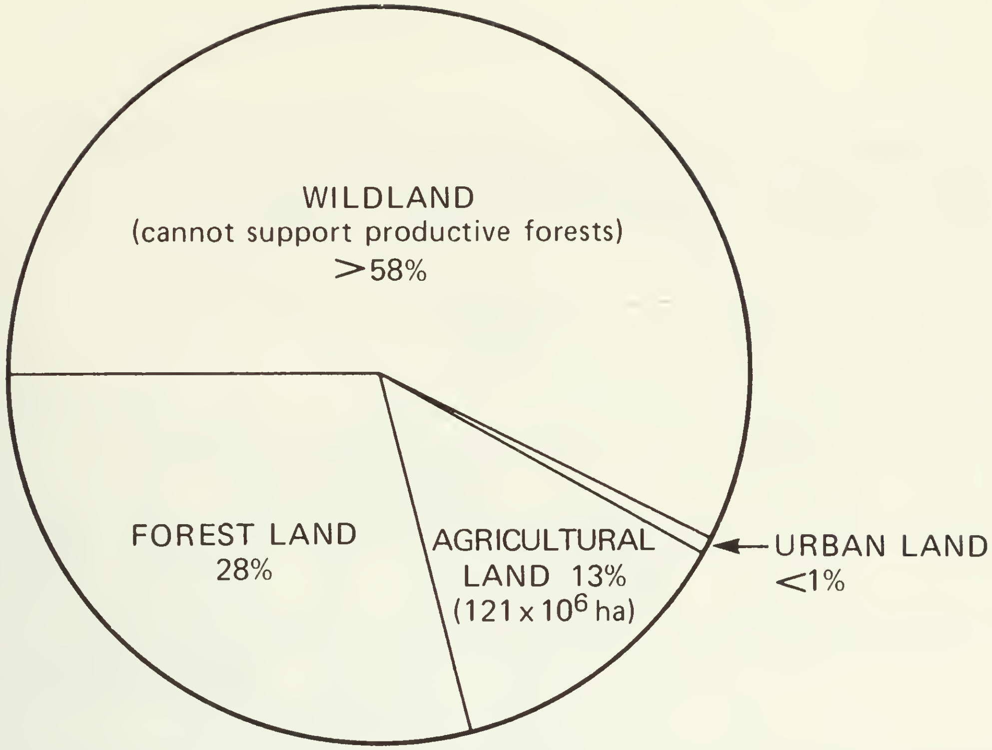

Figure 2. Land use in Canada (total 928 × 10^6 ha).

Source: Shields, J. A.; Ferguson, W. S. Land resources, production possibilities and limitations for crop production in the Prairie Provinces *in* Oilseed and pulse crops in Western Canada, Saskatoon; 1975. pp. 115-156.

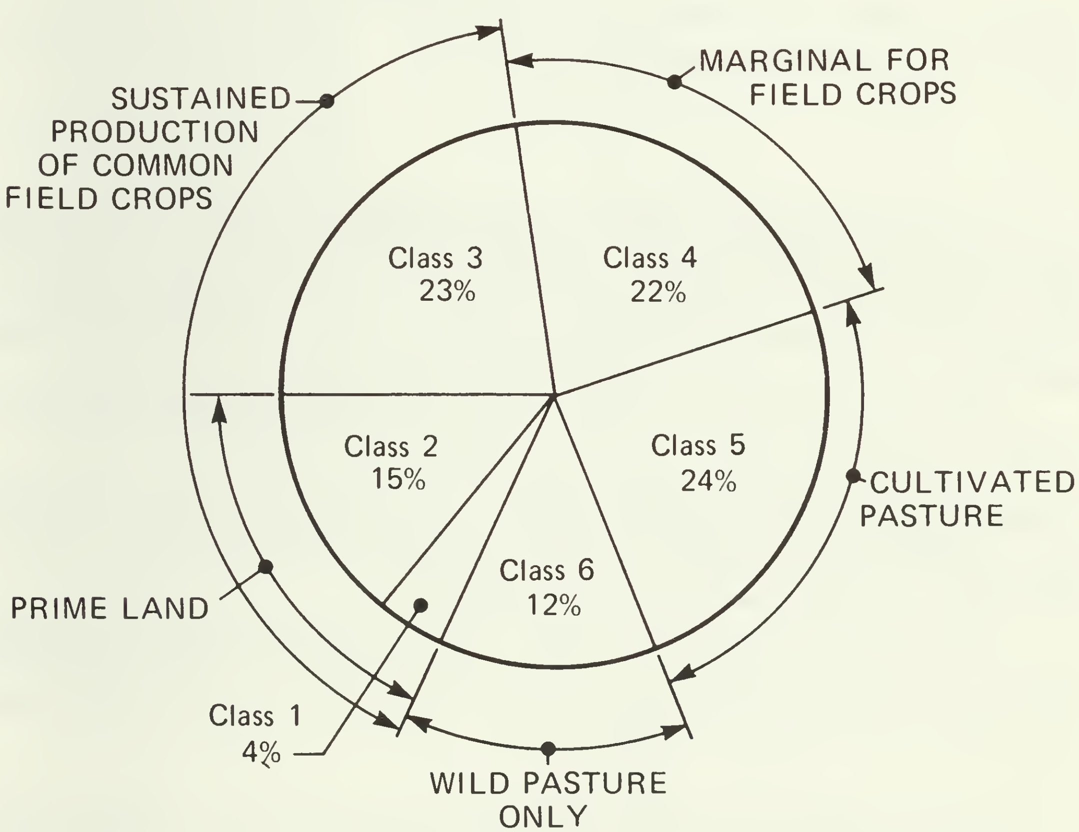

Figure 3. Land with agricultural potential in Canada (121 × 10^6 ha).

Source: McKeague, A. Canadian inventory: How much land do we have? Agrologist; Autumn 1975.

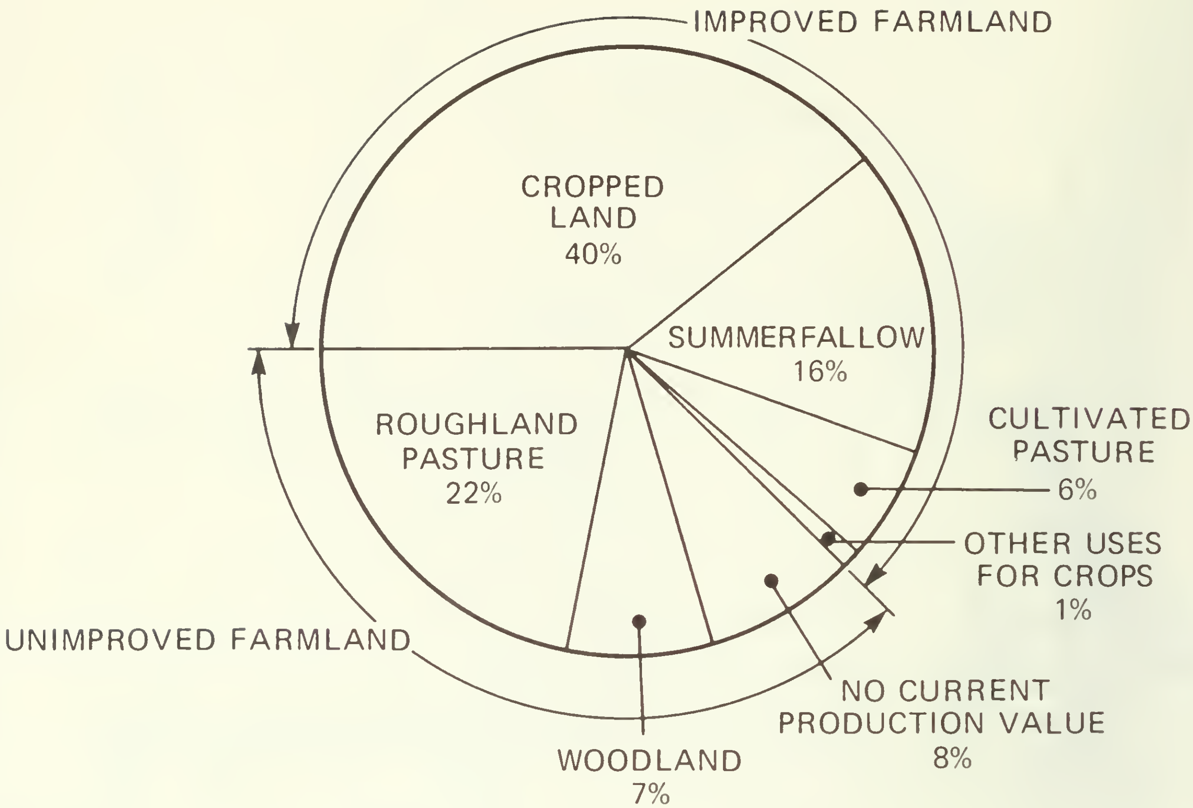

Figure 4. Land now in farms in Canada (68.8×10^6 ha).

Source: Canada Year Book 1974, Stats. Can: 1975.

For the 10-year period 1966-75, approximately 70% or 18.2×10^6 ha of the land being cropped in Canada was planted to cereals, and 7.3% or 1.9×10^6 ha was devoted to the oilseed crops. The balance of the land was planted to a wide array of fruit and vegetable crops, and to tobacco, sugar beets, potatoes, field peas, and other minor special crops (Figure 5).

During this same 10-year period, approximately 37 million metric tons of cereals and oilseed crops were produced annually (Figure 6).

To translate Canadian agricultural crop production into protein production, the data for the 1975 crop year is presented in Table 2. Data for animal proteins are included in order to present a more complete picture of Canada's protein production and utilization.

Not included in the data in Table 2 are the carry-overs and information on the plant proteins that are produced and utilized from fruits, vegetables, and other minor special crops. Irrespective of this, two conclusions are obvious from the data just presented:

1. Well over 50% of the proteins utilized by Canadians are of animal origin;
2. We export more than twice as much protein as we import and utilize from domestic production.

On the assumption that there is no protein malnutrition in Canada, our current domestic production at the present excessive average rate of utilization would easily support more than three times our present population.

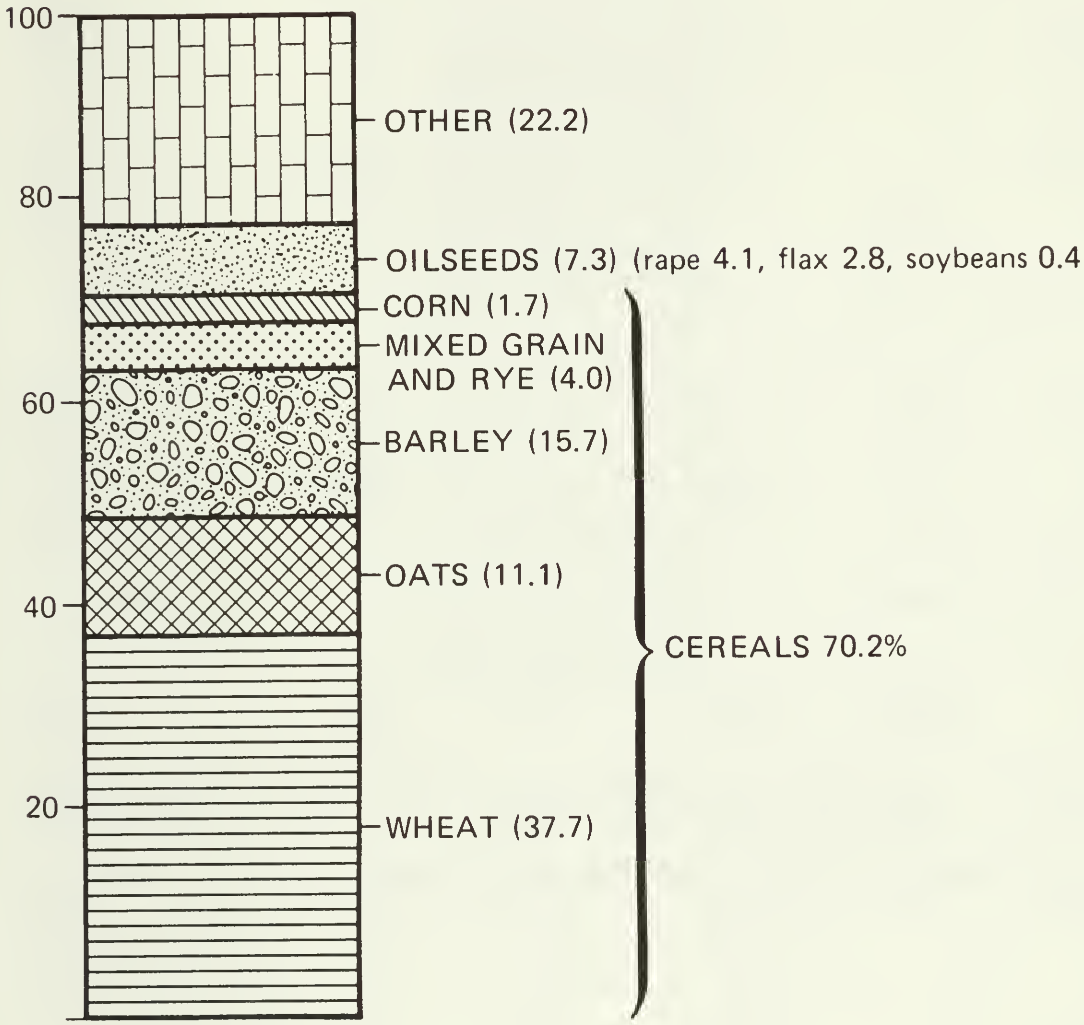

Figure 5. Areas of principal food crops in Canada, 10-year average allocation, 1966–75, (total 25.9 × 10^6 ha by percentage of total).

Source: Canada grains industry statistical handbook. Winnipeg: Canada Grains Council; 1976. p. 21.

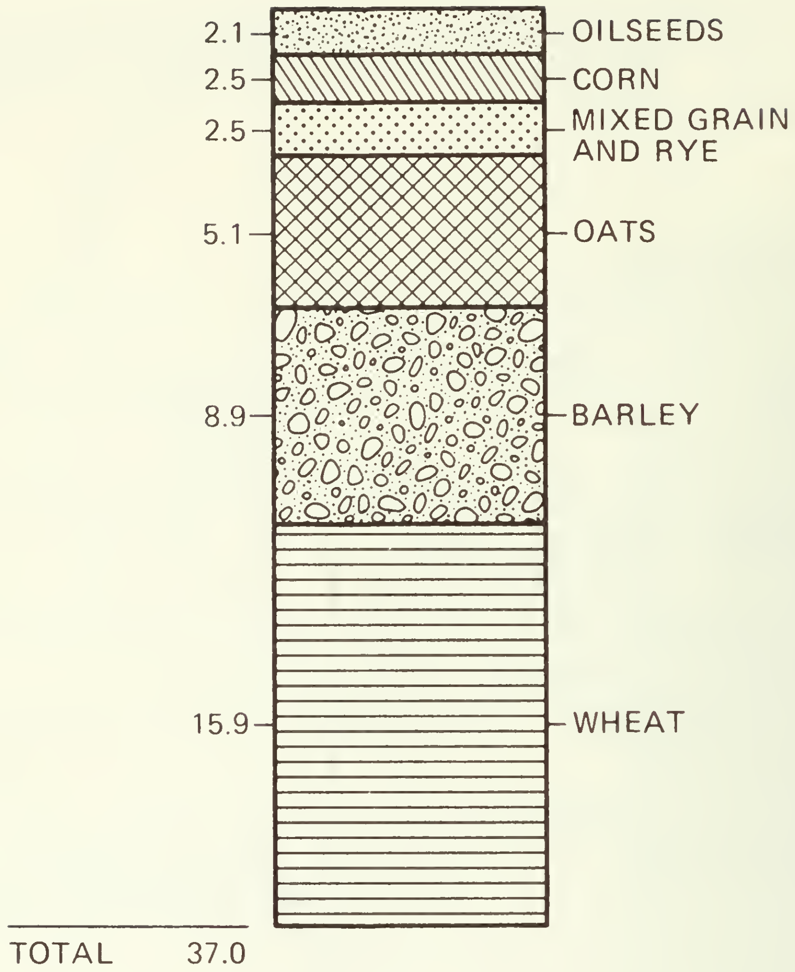

Figure 6. Production of principal food crops in Canada, 10-year average, 1966–75 (in million metric tons).

Source: Canada grains industry statistical handbook. Winnipeg: Canada Grains Council; 1976. p. 21.

TABLE 2. Production and utilization of proteins in Canada, 1975, in metric tons

Commodity	Protein (%)	Production	Domestic use*	Imports	Exports
Wheat	11.7	1 998 161	225 151	0	1 433 638
Oats	13.0	580 658	9 854	0	36 481
Barley	11.0	1 047 211	304	0	477 506
Rye	9.0	47 061	1 186	0	26 867
Flax	24.0	106 680	14	0	46 825
Rape	24.0	419 664	0	0	163 916
Corn	8.4	306 171	71 535	58 581	19 704
Soybeans	36.0	132 269	0	146 970	0
Subtotal		4 637 875	308 044	205 551	2 204 937
Pork	11.2	55 396	56 172	5 013	4 556
Beef	14.9	148 070	157 788	12 906	3 027
Veal	18.8	10 426	10 437	0	0
Sheep	12.2	1 002	3 611	2 471	10
Offal	19.0	11 278	6 727	564	5 124
Subtotal		226 172	234 735	20 954	12 717
Eggs	12.9	39 050	37 133	1 061	938
Poultry	12.0	48 784	52 215	1 544	372
Subtotal		87 834	89 348	2 605	1 310
Cheese	23.0	45 625	43 088	5 078	508
Evap. whole milk	7.0	6 357	6 381	0	2
Concent. whole milk	8.1	615	613	0	0
Powdered whole milk	26.4	335	285	0	50
Powdered skim milk	36.0	67 161	22 615	0	13 090
Fluid whole milk	3.5	92 751	92 751	0	0
Subtotal		212 844	165 733	5 078	13 650
Total		5 164 725	797 860	234 188	2 232 614

*"Domestic use" should be read as "domestic food use."

EXTENT TO WHICH PLANT PROTEIN PRODUCTION COULD BE INCREASED IN CANADA

In a paper recently presented to a symposium on Canada and World Food (Shebeski 1977), I indicated that:

> "The agricultural lands in Canada, if fully utilized, have the potential, with present technology, for more than three times the present production of field crops, and a carrying capacity considerably over ten times our present ruminant livestock numbers.
> These estimates of potential, optimistic are they may seem, could be revised upwards if adequate moisture in the more arid regions of Western Canada could be assured—and this potential does exist."

If the potential exists at least to treble the production of field crops in Canada, as I am convinced it does, it logically follows that this country has the potential for a three-fold increase in plant protein production. However, there are a number of limiting factors to achieving the production potentials, and these are outlined in the paper to which I have referred. Briefly, the capital costs of claiming 20×10^6 ha of potentially arable land of low fertility would be enormous, as would the annual management, fertilizer, and other input costs. The crops produced would be modest in quantity and the profit would be marginal to sub-marginal. The food or protein produced would be in the middle of the North American continent, thousands of kilometres from where it would be needed, and the food, like any other commodity that is costly to produce, would have to be paid for.

To respond to the growing food and protein needs of the developing nations, Canada's major contribution should be to provide the technical and scientific expertise that developing nations require if they are to make substantial improvements in their domestic food production, as they must. At the same time, Canada should continue to increase its crop production at a rate commensurate with demand and an economic return for its surplus stocks of food.

There need be no fear that by providing technical aid in agriculture to the developing nations Canada will be jeopardizing the sale of its surplus grain stocks. This point was made by Switzer (1977) last May at a SCITEC Conference in which he presented some of Lester R. Brown's data on the changing pattern of world grain trade, summarized in Figure 7.

The data indicate beyond any shadow of doubt that since the mid-thirties the demand for grain by the food deficit countries has been increasing at a very rapid rate. By 1960, the demand had almost doubled from that of the mid-thirties, trebled by 1970, and more than quadrupled by 1976. But, more importantly, whereas North America supplied only about 25% of the demand in the mid-thirties, by 1976 only North America, Australia, and New Zealand were net exporters of grain, with North America supplying 94 million metric tons (92%) of the demand. Of this, Canada's component was 17 million metric tons or approximately 17% of the world's grain exports. Thus Canada's ability to provide grain is becoming increasingly important.

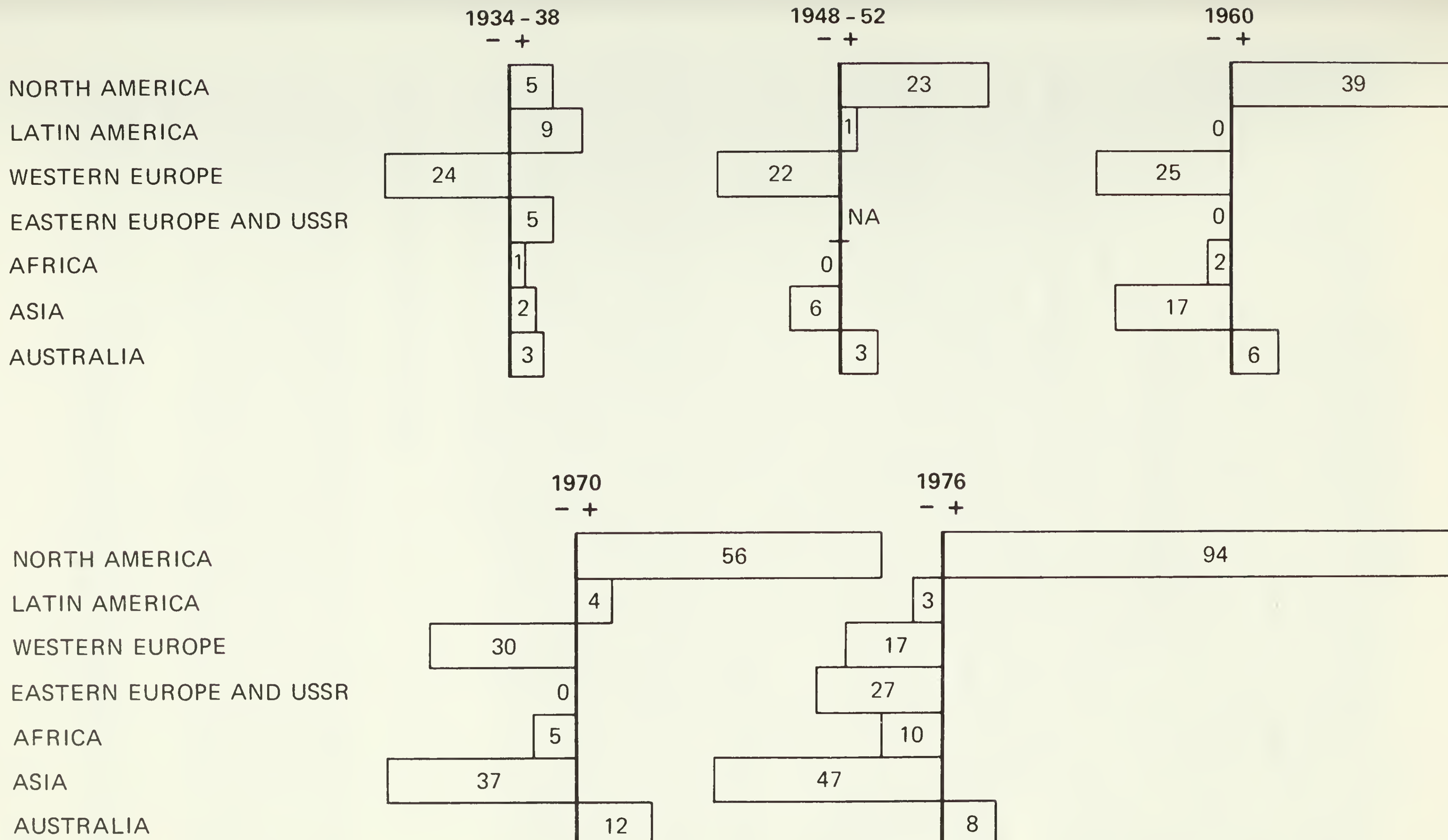

Figure 7. The changing pattern of world grain trade (in million metric tons).

Source: Brown, Lester B. Worldwatch Paper no. 2; 1975.

Before concluding this brief overview, a number of other points should at least be mentioned. It is both possible and desirable to improve the quantity and the quality of proteins in our existing crop plants through plant breeding. It is possible, by blending proteins from different crop species, to produce better-balanced protein food or feed for both domestic and export purposes. As an example, the protein of wheat flour is low in lysine and high in methionine, whereas the protein of flour from field peas or fababeans is high in lysine and low in methionine. By air classification the protein fraction of the flour from either field peas or fababeans can be increased from about 30 to 70%. A blend containing 5% of this high protein flour and 95% wheat flour would provide a vastly improved, nutritious, well-balanced protein flour. It should be possible to improve the quality of forage crops and pasture on Class 4–6 land and thus to greatly increase the production of ruminant animals.

Canada should be stepping up its research program in all areas related to crop production, storage, transportation, processing, and marketing, rather than decreasing its efforts as it is doing at present.

The extent to which Canada can help alleviate global protein malnutrition will largely depend on the priority accorded to continued agricultural development and, in particular, to the development of a strong scientific manpower base. The need is obvious and the opportunities for progress immense.

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FOOD/ENERGY (CORN VS. WHEAT VS. GRASS)

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HISTORICAL BACKGROUND

Our preoccupation in recent years with fossil fuels as an energy source has shifted attention away from a basic fact: green plants and agricultural crops are the primary harvesters of the sun's energy, as well as the means whereby all fossil fuel energy resources were accumulated in ages past. Of all Canada's current options for energy research, money directed toward bioconversion of solar energy through the photosynthetic process to produce energy other than food is least worthy of mention. Agriculture's first objective has been and will remain that of food production. Research in food production has been directed toward determining the efficiency of the photosynthetic process and in the past few decades agronomists have had remarkable success in developing superior varieties and more efficient crop-production, thereby increasing the economic yield per hectare. The use of massive amounts of fuel to mechanize agriculture has released people from the slavery of producing their own food. Fuel and mechanization have enabled 5% of our population to produce the food, freeing the other 95% to devote all their efforts to developing our present high standard of living. The agricultural use of fossil fuels has increased to the point where observers have questioned the energy efficiency of the increased productivity of North American agriculture. Indeed, a few writers have stated that primary agriculture is a net user rather than a net producer of energy (Odum 1971).

THE PRESENT SITUATION

The corn crop, an efficient sunlight converter, can utilize approximately 3% of the photosynthetically active sunlight energy during a midsummer day. The theoretical upper limit to this conversion value, depending on the wavelengths and the time period considered, is estimated as 8–12%. Present conversion rates on a national basis over the entire season seldom exceed 1%. To achieve this efficiency cultural energy is required to produce a crop. Cultural energy includes:

1. human and animal labor;
2. fossil fuels and lubricants for equipment needed in the growing, harvesting, transportation, and processing of agricultural products;

3. fossil fuels used in the production of equipment, fertilizers, other chemicals, seed, and buildings needed in agricultural production systems.

The amount of cultural energy required for crop production varies greatly with the agricultural system being considered, such as the degree of mechanization or the levels of fertility required, as well as with the crop, which may vary in efficiency as influenced by the length of the growing season, the efficiency of sunlight conversion, or the presence of disease or pests.

CORN

Consideration of an 8 m^3/ha corn crop in Ontario revealed an energy efficiency quotient of 1:4.95, that is, for each joule of energy expended in producing a corn crop to the farm gate, 4.95 J were produced (Stevenson and Stoskopf 1974). This value comprises all direct and indirect costs, including energy required to construct machines, which are estimated to have a 10-year life span with 6% repair inputs; food energy consumed by the machine operator; energy to manufacture, transport, and apply pesticide sprays and fertilizers; and artificial drying. The methods used here are modeled on Pimentel et al. 1973.

Consideration of an input–output efficiency quotient of 1:4.95 for corn must include recognition of the following facts.

1. Four areas of energy usage accounted for 84.5% of the energy inputs in corn production (Table 1) namely:

   a) nitrogen fertilizer, 45.8%;
   b) tillage and machinery operation, 17.8%;
   c) artificial crop drying, 10.6%;
   d) machinery construction and maintenance, 10.3%.

2. If the total biomass produced on 1 ha is considered, as is the case with the whole-plant silage, instead of the economic grain yield alone, the energy quotient becomes 1:9.6.
3. If nitrogen fertilizer inputs are replaced by manure or nitrogen fixing leguminous crops in the rotation, the energy efficiency quotient for grain becomes 1:10.5 and for silage corn 1:15.0.
4. The estimate for energy in – energy out for the Syncrude project is 1:8. (Tudor Williams quoting Jill Winstanley, Science Centre, Toronto, Oct. 26, 1977).

WHEAT

Less energy inputs are required for wheat production than for corn and although the output per hectare is lower than for corn, the energy efficiency quotient for wheat is 1:5.85 (Table 2). A unique enzyme system in corn, sugar

TABLE 1. Energy input - output values for corn

Input	Energy input (MJ/ha)		Percent of total	
Labor	11.4		0.01	
Machinery	1 953.6		10.3	
Gasoline for tillage and machine operations	3 364.3		17.8	
Fertilizers	10 003.2		52.9	
Nitrogen (112 kg/ha)		8 668.8		45.8
Phosphorus (56 kg/ha)		784.3		4.2
Potassium (68 kg/ha)		550.1		2.9
Seed	650.2		3.4	
Irrigation	0		0	
Insecticides	113.5		0.6	
Herbicides	113.5		0.6	
Drying	2 002.1		10.6	
Electricity	3.5		0.001	
Transportation	722.4		3.8	
Total input	18 937.7		100.0	

Output (at 8 m^3/ha assuming 16.7 MJ/kg and 700 kg/m^3) = 93 520 MJ/ha.

Therefore output/input ratio = $\frac{92\ 960}{18\ 937.7}$ = 4.95:1

TABLE 2. Energy efficiency data for winter wheat in Ontario

Input	Energy input (MJ/ha)
Labor (10 h/ha)	11.4
Machinery and fuel	4095.0
Nitrogen (33.6 kg/ha)*	2600.6
Phosphorus (29 kg/ha)*	407.6
Potassium (27.5 kg/ha)*	266.3
Seed	650.2
Herbicides	20.6
Electricity	3.1
Transportation	361.2
Total input	8416.0

Output (at 4.5 m^3/ha assuming 14.6 MJ/kg and 750 kg/m^3) = 49 275 MJ/ha

Therefore output/input ratio = $\frac{49\ 275}{8\ 416}$ = 5.85:1

*Average inputs reported in the 1969 OMAF crop survey.

cane, and sorghum (C-4 plants) gives these crops the remarkable ability to utilize the energy of the sun more efficiently than do soybeans, cotton, potatoes, and small grains, including wheat (C-3 plants).

The lesser efficiency of the C-3 plants is caused by their respiration rates, which increase markedly as daytime temperatures rise, thus reducing efficiency by respiration losses. One cannot help but speculate what the efficiency of C-3 plants might become if functional control of ribulose diphosphate carboxylase, the single enzyme difference between C-4 and C-3 plants, was achieved. There must be methods of regulating, chemically or genetically or by both means, the action of this particular key enzyme. Incorporation of the low photorespiration C-4 mechanism into C-3 plants may increase yield capacity two or three times (Zelitch 1975, Wittwer 1975).

FORAGE CROPS

Calculation of an energy efficiency quotient for forages is more difficult than for wheat or corn (energy crops) because forages are basically protein-producing crops. Like corn, however, forage grasses have a high nitrogen fertilizer requirement as compared to forage legumes. Leguminous forages, on the other hand, produce for several years without reseeding, receive manure application as a fertilizer replacement, and photosynthesize for the entire season. Thus they can be expected to have a high energy quotient. Nitrogen fixed by legumes is a source of fertility for subsequent crops. Forages and grasses can be provided on land not suitable for other crops. These roughlands can be effective areas for bioconversion of solar energy, which in turn can be converted by animals to food for human consumption.

The process of biological nitrogen fixation is almost as important as that of photosynthesis. The worldwide contribution of nitrogen fixation to agricultural productivity probably exceeds by four or five times all the nitrogen fertilizer currently fixed by chemical means utilizing high pressures and temperatures and a massive fossil fuel input (Anonymous 1975). The concept of increasing nitrogen fixation in existing legumes or of inducing species of nonleguminous grasses to fix nitrogen has enormous energy implication (Dobereiner and Day 1974, Hardy and Havelka 1975, Hardy et al. 1974).

CONCLUSIONS AND FUTURE PREDICTIONS

Canadian producers are concerned about the high and rising cost of energy and related food-producing inputs such as fertilizer and machinery. The following facts should be recognized:

- Continued mechanization of agriculture is essential if abundant and low-cost food is to be produced. A return to primitive, labor-intensive agriculture or to turn-of-the-century mechanization is not a solution to high energy inputs on the farm.

- Although agricultural production to the farm gate consumes only 2–2.5 % of Canada's total energy consumption, energy for food production is so critical and so essential that alternative forms must be sought for use on the farm to insure continued agricultural output, even when fossil fuels become yet higher priced or unavailable.
- Plant biomass, either from wastes produced on the farm or produced directly for fuel for on-the-farm use and converted by pyrolysis, hydrolysis, and microbial fermentation to solid, liquid, or gaseous fuel may supplement on-farm energy or be sufficient to make farms energy independent. The first responsibility of agriculture has been and remains that of food production, yet the essential nature of energy for food production and the relatively low level consumed on the farm may mean that a small area can be set aside for energy production. By-products such as manure, stover, and straw may be used for energy without encroaching on food output. A study on the possible use of ethanol from surplus grain, commissioned by the Hon. Otto Lang, concluded that up to half the area given to Canadian wheat would be required to provide adequate ethanol to blend at a 10% level in the national gasoline supply (Timbers 1977). To meet national needs is not the intention, however, although in Brazil ethanol produced from sugar cane and cassava (manioc) is used for gasoline blending on a national scale.
- Concern for fuel consumption on the farm and the desire for greater efficiency in agriculture is commendable. It does not mean that inefficient crops should not be grown if they meet an aesthetic need of society and society will pay a reasonable price for the product. Changes made in order to conserve fuel in agriculture or to increase the energy quotient must be based on economic factors; clearly, high energy efficiency is of no advantage if it is accompanied by malnutrition or starvation. Little information is available on the "price elasticity" of food in relation to energy; that is, it is not known what prices Canadian or world consumers will tolerate, and therefore it is not known when highly energy-dependent production schemes should be switched to ones that use less fossil fuel or when alternative forms of production should be applied.
- Greater emphasis on research into bioconversion of solar energy to improve crop efficiency is warranted.

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VEGETABLE PRODUCTION AND MARKETING IN CANADA

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INTRODUCTION

Vegetables and vegetable preparations are an important part of Canadian diet. Together, fruits and vegetables now form 35–40% of our diet in terms of kilograms per capita and, with the exception of potatoes, this proportion has been increasing. Between 1964 and 1974 the per capita consumption of fresh vegetables increased by 13.6% (to about 54 kg); consumption of potatoes decreased by 3.2% (to about 69 kg). Figure 1 illustrates the complexity of the vegetable system.

FRESH VEGETABLES

This category encompasses an extremely wide range of commodities, produced throughout the country on mineral and muck soils and in controlled environments (greenhouses). Vegetable production for the fresh market is usually located within a small radius of population centers, although some crops, such as head lettuce produced on muck soils and storable vegetables such as potatoes, cole crops, carrots, and rutabagas, are shipped to distant markets.

Table 1 shows the farm value of vegetables in 1974 and 1975. Fresh vegetables, including potatoes, were worth over 468 million dollars in 1975. Although this seems to be a substantial amount, Table 2 shows that we still import a large volume of vegetables, excluding potatoes. In fact, in 1974, the net trade in vegetables was –184.6 million dollars. Table 1 does not include sales at roadside stands and farmers' markets because data are hard to obtain. Table 2 should not be interpreted as meaning that the net can be balanced completely, because a substantial component is part of off-season imports.

Greenhouse production of tomatoes and cucumbers is an important segment and is located principally in southwestern Ontario and British Columbia. It is capital intensive and has a short production and marketing season. The cost of energy is the greatest problem currently facing greenhouse operators.

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*Deceased January 1981.

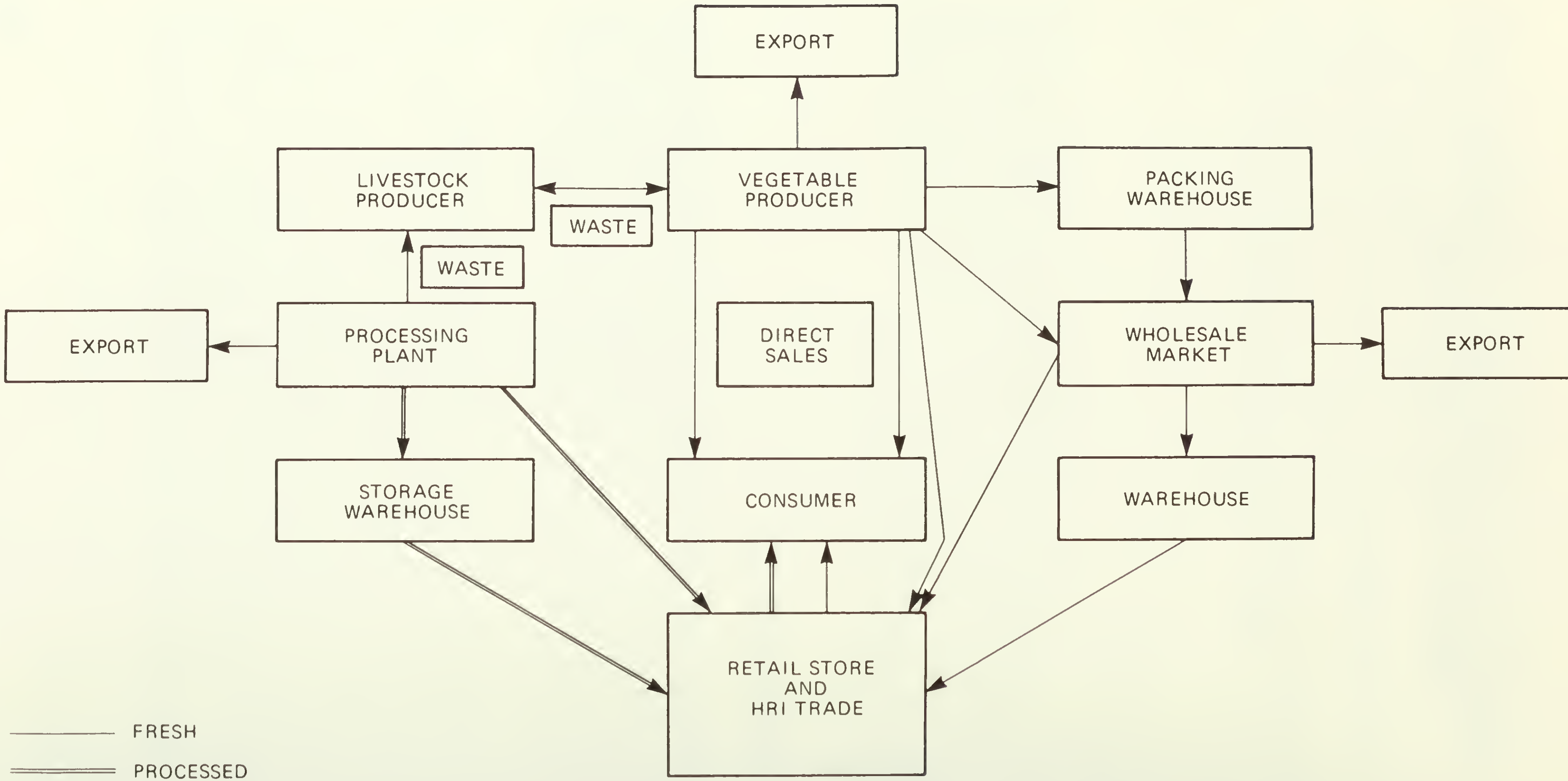

Figure 1. Vegetable system.

TABLE 1. Farms values of commercial vegetables, in thousands of dollars

	1974	1975
Asparagus	2 502	2 810
Beans	6 752	7 696
Beets	1 589	1 644
Cabbage	6 949	9 179
Broccoli	—	555
Brussels sprouts	—	789
Carrots	14 283	12 798
Cauliflower	3 876	5 245
Celery	2 488	3 823
Corn	16 084	21 276
Cucumbers	8 298	10 876
Lettuce	5 777	6 145
Onions	12 769	17 407
Parsnips	543	647
Peas	14 765	18 211
Rutabagas	8 262	8 121
Spinach	657	535
Tomatoes	32 520	42 468
Mushrooms	22 109	28 067
	160 223	198 292
Greenhouse cucumbers	4 867	5 974
Greenhouse tomatoes	10 979	14 716
Potatoes	152 147	249 242
	328 216	468 244

Source: Stats. Can.

TABLE 2. Imports and exports of Canadian vegetables from 1966 to 1974, in millions of dollars

	1966	1967	1968	1969	1970	1971	1972	1973	1974
Exports									
Vegetables and veg. preparations	39.7	48.2	44.6	50.4	51.7	42.5	54.3	73.3	76.7
Index* 1966 = 100		46.4	41.6	45.0	43.8	35.2	43.0	53.7	52.3
Imports									
Tomatoes, fresh	19.2	18.5	23.2	22.4	23.5	26.8	28.3	33.0	37.2
Other fresh veg.	56.2	56.2	63.4	68.3	72.1	74.0	86.2	117.5	126.5
Other veg. and veg. preparations	25.1	29.9	29.7	31.3	32.3	35.5	45.2	60.5	97.6
Total veg. and preparations	100.5	104.6	116.3	122.0	127.9	136.3	157.7	210.0	261.3
Index 1966 = 100		100.6	108.4	108.9	109.1	113.1	124.8	153.9	178.3
Net trade	-60.8	-56.4	-71.7	-71.6	-76.2	-93.8	-103.4	-136.7	-184.6
Index 1966 = 100		-54.2	-66.8	-63.9	-65.3	-77.9	-81.8	-100.2	-126.0

Source: Stats. Can. 62-224.
*Implicit price index Stats. Can. 11-003E.

On the production side, the major problems are labor, pest management, and high cost of inputs. Because of the diversity of vegetables and the new stringent controls on chemicals, effective pest control is difficult to maintain. To prevent production costs from increasing further, more mechanization of harvesting and more effective herbicides are required.

Because of the extremely short production and marketing season in Canada, the greatest need is to extend the season on an economic basis by the development and adoption of new technology. Emphasis should be on greater self-sufficiency. Some of the necessary technology is available but the incentive to adopt it is lacking.

Many opportunities exist to expand the market for fresh vegetables. Roadside and farm markets are important outlets and are well accepted by consumers. However, in the traditional mass-merchandising outlets, Canadian-produced vegetables are considered by consumers to be inferior to imported produce, a result of poor quality control. A greater degree of quality control and innovative and aggressive merchandising of Canadian produce are required. In addition, better coordination through market organization is needed.

There is good potential for expanding the domestic market for Canadian produce such as potatoes, carrots, cole crops, and onions. In the export market, there is potential for increased sales of rutabagas, carrots, and seed potatoes. The last already has success in international markets, but Canadian producers offer only white seed potatoes and many markets demand yellow-fleshed varieties. Our markets can be greatly expanded when good yellow-fleshed seed potatoes can be made available.

VEGETABLES FOR PROCESSING

This category includes sweet corn, peas, snap beans, carrots, onions, asparagus, broccoli, cauliflower, cabbage, cucumbers (pickling), rutabagas, tomatoes, and mushrooms. Table 3 shows the farm values in 1975.

TABLE 3. Farm values of vegetables for processing in 1975, in thousands of dollars

	1975
Beans	5 930
Corn	14 927
Peas	18 211
Tomatoes	31 361
Asparagus	1 516
Beets	804
Broccoli	555
Brussels sprouts	789
Carrots	1 286
Cauliflower	806
Cucumber	8 934
	85 119

Sweet corn, peas, and snap beans

Because of their adaptability to a wide range of growing conditions, the production of these crops for processing is spread across the country, with the greatest concentration in southwestern Ontario. Production is largely contracted. Harvesting is generally well mechanized and thus capital intensive, but processing is labor intensive. Labor quality and availability are serious problems.

Production is highly variable, largely because of vagaries of weather. Production technology and management practices are not entirely up-to-date, contributing to production variability. There is very little utilization of irrigation, for example, to reduce variability of yields. Requirements of soil and climate are not as restricted as for many other horticultural crops and therefore there are many potential production areas and potential producers.

The present trend in processing is toward a greater amount of freezing. Processing is characterized by many small plants because of the relatively easy entry and exit. At present there is excess processing capacity in some areas, with perhaps only 60% capacity being utilized. In contrast, one or two new production areas are short of processing facilities.

Processed sweet corn, peas, and snap beans are in a relatively good competitive position. There is some potential for export, especially of frozen products, but this cannot be realized until the increasing entry restrictions on export markets are eased. Domestically, Canada is largely self-sufficient in these products.

Mushrooms

Mushroom production is highly specialized. There are only about 134 producers, located principally in Ontario, Quebec, and British Columbia. Production is generally labor intensive. Because of this, intense competition in processed mushrooms has developed from off-shore producers, where labor costs are low. In Canada, producers have shifted from a reliance on processing to greater reliance on the fresh market. A number of processors, many of whom are major producers, are also importers and distributors of off-shore processed mushrooms.

Recent technological breakthroughs in management practices are making it possible for large-scale mushroom producers to mechanize and improve working conditions. This may change competitive patterns and reduce the competitiveness of off-shore producers. Three large firms in the United States are reported to be planning an expansion of their fresh market operations. Unless Canadian producers adopt the new technologies, they will be faced with increasing competition in the fresh market from imports.

At present there is very little research in Canada on mushrooms and none on mechanization or management practices.

Asparagus

Production of asparagus for processing is centered in British Columbia and Ontario. Production is highly labor intensive with little mechanization in Canada. Total production has increased slowly, largely as a result of the increase in production areas that is taking place as yields in well-established areas of production decline. The vagaries of weather cause yearly fluctuations but the steady decline in yields is largely due to disease (Fusarium wilt in Ontario and British Columbia) and to the lack of suitable varieties in Ontario. Research has not yet been able to develop a Fusarium-resistant variety suited to Canadian conditions. New varieties must be developed to replace the unsuitable California varieties now grown in Eastern Canada. One great drawback, however, is the risk producers must take in replanting because it takes 3 years growth before asparagus can be harvested.

Asparagus processing is fairly successful, but the variability of domestic supply is a limiting factor. Imports of fresh asparagus for processing are increasing. The competition from processed asparagus from Taiwan is one of the greatest problems at present, although exports of Canadian processed asparagus still exceed imports.

Cole crops

Included in this category are Brussels sprouts, broccoli, cauliflower, and cabbage. Cole crops are produced in all provinces but are particularly well adapted to the cool weather and short growing season of the Maritimes, and to parts of British Columbia. Contracting of cole crops for processing is widespread.

Cole crops, especially cabbage, can be stored for relatively long periods. Extensive research has developed the technology necessary to maintain excellent quality over long periods of time. Cabbage has exceptional potential for market expansion. The fast-food trade uses a large volume of fresh cabbage for coleslaw throughout the year. There is a good potential in the fresh market where imported cabbage is now dominant. There is also potential for processing of cabbage throughout the year; the varieties and the storage technology are available to provide the quality of "green" cabbage acceptable to the market but producers have not responded to the potential demand. The same is true of the other cole crops.

Producers need better marketing organization and more aggressiveness to take advantage of the opportunities. There is at present a government program to assist producers in the construction of storage facilities but this program has not been utilized to its fullest extent.

Mechanization is considered to be a key factor in the future of these crops and is a priority for further research. Increased mechanization, however, has two aspects; the development of machines and the breeding of varieties with the characteristics necessary for mechanization.

Onions and carrots

Onions and carrots are produced in all regions of the country but are especially important in the muck soil areas. There is good potential for increasing the production of these crops.

Onions are not significant at present as a processing crop in Canada but there is a potential for future development. The processing of onion rings in Canada is largely based on imported onions. Canadian-produced onions could replace these imports. Also, there is some potential for developing a dehydrated onion industry.

Processing of carrots is scattered throughout the country. The most important packs are canned and frozen carrots, both sliced and diced, with a trend toward more frozen products. Imports of processed carrots are increasing rapidly, even though carrot production is well suited to Canadian conditions. A new product, baby carrots, is gaining in popularity with the hotel, restaurant, and institutional (HRI) trade. Research is now under way in Canada to develop the ability to produce baby carrots and there is evidence that production is possible.

Cucumbers (pickling)

Processing of cucumbers is scattered over the entire country with the major concentration in southern Ontario. The basic problems are labor and the lack of mechanization.

Rutabagas

Although not now considered a major processing crop, frozen diced rutabagas are now in the developmental stage and may have good potential. Intensive development of the market is now required for this product to achieve its potential. Canada is an exporter of fresh rutabagas, with a steady market in the United States.

Tomatoes

Tomato processing is centered in eastern and southern Ontario. Juice and canned whole-pack tomatoes are the major products in eastern Ontario, tomato paste and ketchup in southern Ontario. At present the major competition is tomato paste from Spain and Portugal and canned tomatoes from Taiwan, although the Taiwan products are now subject to a surtax.

The major limiting factors to greater production are lack of mechanization, partly caused by the vagaries of Canadian weather, and inadequate adaptation to Canadian conditions.

FUTURE TRENDS

World demand for vegetables and vegetable preparations will continue to increase as greater understanding of nutrition develops. As economic conditions improve in developing countries, diets will become more diversified.

Processing facilities for horticultural products will continue to expand in developing countries as foreign exchange becomes more available. Multinational food corporations will continue to set up processing plants in other countries, especially in those with favorable climates and low labor costs.

Canada can be competitive with imports in vegetables requiring relatively cool temperatures. With other vegetables it will be a real challenge to compete with imports for a larger share of the Canadian market. A number of different actions are required. More effective border controls must be put into effect. Recommendations of the Tariff Board will be helpful because Canada has very little protection. Additional protection from low-price imports will be needed from time to time. Government support in the form of Agricultural Stabilization Payments is useful but does not provide a long-term solution.

A more reliable transport system is essential for the marketing of perishable crops. A viable vegetable industry in Canada will depend on lower shipping costs and adequate equipment, such as refrigerated railway cars.

Market organization can be improved by more effective coordination. Some provincial marketing agencies are doing a good job but others will have to be better organized for both domestic and export trade.

More mechanization is needed to offset the difficulty of obtaining labor at economic costs. This trend will run counter to efforts to reduce unemployment and conserve energy, but a viable vegetable system cannot survive without increased mechanization.

Increased mechanization can only be realized by greater investments and by continued research on improving machinery. For example, an effective selective harvester for asparagus would enable much larger areas to be productive than at present. Research is also required to reduce pesticide residues for both cost and environmental reasons. Better machines alone will not lead to greater use of mechanization. New varieties suitable for once-over harvesting will be needed.

To summarize, vegetable production and marketing can be more competitive if governments, industry, and research organizations work together to solve the existing problems.

PRODUCTIVITY

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INTRODUCTION

There are innumerable ways to deal with the broad topic of productivity. I shall attempt it under six headings: choice of crops; improved varieties; crop husbandry; proper use of fertilizers; judicious use of pesticides; and adequate systems for financing.

Farming, the production of food, is a risky business. Under normal dryland conditions yields vary widely, depending on the weather; there may be feast or famine. A frost, a drought, excess water, pests, and diseases, can turn productive fields into dismal failures. As conditions for growing crops become more marginal, the fluctuations in production increase and greater effort is needed to buffer the wide variations. Even where irrigation is used there are major swings in productivity from year to year or from crop to crop. What can be done to insure optimum returns? A great deal, and in fact more and more as we gain more technology. I hope to convince you that productivity of food from crops has not reached a plateau, nor do I expect it to do so within this century.

CHOICE OF CROPS

Although all crops can be divided into categories such as tropical or temperate, we find today that many countries are producing, or trying to produce, crops that are not adapted to their climate. Crops may be adaptable to foreign climates, but the new environment may also be conducive to the lush growth of weeds, or it may harbor insects or provide ideal conditions for diseases. The Brazilians are growing wheat under high rainfall, humid conditions. At or near harvest time, diseases occur in such devastating proportions that much of the yield is lost.

Sixty or 70 years ago the prairie land of the Palliser Triangle of Canada came under the plow. For many stretches of land this was a mistake, as hindsight now proves. The crop suitable for most of that short-grass prairie is grass, not wheat. We paid the toll for this mistake in the thirties. It must be remembered that the Canadian west exists under minimal conditions for growth because of the short season.

Forage crops are the best suited to most Canadian soils because of periodic droughts and the risk of frosts. But forage crops mean a livestock operation, which is not always economically feasible.

What about mixed cropping? The subsistence farmer is an anachronism in Canada. His choice of crops has been replaced with types of crop that can be exported to gain hard dollars for Canada. The railway started that trend about 90 years ago, but we find that transportation from the center of the country is much less than ideal. And what about drought-resistant crops that provide some flexibility? Under dry conditions sorghum does better than corn; fall rye is better than spring barley, and so on. Not all areas of the world can make the changes.

The point to be remembered here is that under our democratic process, each farmer is considered master of his own food-production factory. He makes the choice of crop. It is not always the best. Many nations that struggle unsuccessfully to be self-sufficient in wheat would not contemplate producing radios or cars, even though such nations might have greater success with these items.

By choosing the crop best suited to the region, advances in productivity can be made. Adjustments on the returns from the crop may be necessary on a national basis. Nevertheless, if we are serious about increasing productivity these choices must be made.

IMPROVED VARIETIES

How much do the new, improved varieties mean to agricultural production and productivity? The green revolution has been described many times and you are well aware of its impact. New varieties are higher-yielding because of their combinations of genes specifically for yield, for increased disease resistance, and for greater straw strength, allowing more fertilizers to be used. The Rockefeller team in Mexico deserves the honor for the breakthrough of the sixties—Pitic is the most widely adapted high-yielding wheat. There are many more varieties in the class of short-strawed wheats. Norman Borlaug rightly deserved the Peace Prize for his untiring efforts. Many others were also developing new varieties.

It is fairly safe to say that the most productive teams of Canadian crop scientists have been our breeder-pathology teams who, over the years, have developed varieties resistant to leaf and stem rust as rapidly as the organism mutated. Rust is not a limiting factor every year, but in very bad epidemics it could cut our productivity in half.

A Canadian, Sir Charles Saunders, produced a wheat variety that had a most important impact on productivity. Marquis wheat, produced in 1904 by Sir Charles, is the wheat that "opened up the West." Without its earliness and high quality, Canada would never have become a world exporter of spring wheat. The old variety of Red Fife was a week later in maturing and the risks were great.

As Canadians we should be proud of Conquest barley. Its widespread adaptation, good straw strength, high yield, and excellent malting quality have meant millions of dollars to western farmers. The Harosoy soybean, Tower rapeseed, Selkirk wheat, Garry oats, and the MacIntosh apple should be added to the list.

Unique high-yielding varieties of some crops have survived even though they were developed about 100 years ago. They include potato varieties such as Irish Cobbler, Green Mountain, and Burbank's Netted Gem. Corn hybrids, on the other hand, may only last 3 years before they become obsolete and are replaced by new single or three-way crosses.

A great potential in plant breeding remains to be exploited, both for self-pollinated crops and for cross-pollinated crops, where hybrid vigor gives an additional boost. I note that genetic engineering is discussed in another paper, so will not expand on the topic here.

CROP HUSBANDRY

Crop husbandry, a term disliked by some agronomists, encompasses all practices from land preparation, seeding, and harvesting to preparing the land for the next crop. It includes rotations, cultural practices, and management, although for convenience I exclude protection from pests in order to give that section special attention.

Apart from situations where pests devastate crops, good husbandry practices have meant more to productivity than any other procedures. This holds true under primitive conditions and in the developed world. Conditions on our Prairies exemplify this point. In the thirties, a farmer spent a month putting in his crop with gangs of horses. Today the operation can be completed in one week! By taking advantage of timely rains better crops are produced.

If asked whether we would ever return to the dust bowl of the thirties, I readily answer no, because we now have equipment to put seed deep enough in the ground to reach the moisture layer, till the land, reduce weeds, and yet keep the soil relatively safe from drifting. In developing countries there will still be mining of the land, but once farming becomes a national concern priorities in land use will have to be reassessed.

The practice of double cropping or intercropping is popular in several areas of the world where food is scarce. In China soybeans are planted in wheat or corn, producing higher total yields than with single cropping. By contrast, in Western Canada we use a system of grain–fallow–grain in order to save moisture and help insure a crop.

Although there are farm equipment companies with world-wide sales, there are also many small companies of farmers who develop machines to suit local needs. It is fascinating to see in the journals the many innovations that arise in this manner. In Canada we can be proud of our Noble blade, which has found use on a wide range of soil types.

Harvesting methods, although more efficient than the flail, still leave a lot to be desired. Losses of up to 5% are still occurring because of speed of working, or loss of grain or forage. I must make a point about straw. People talk freely about the use of biomass for energy production. The good farmer returns as much straw as he can to his land in order to keep the level of organic matter as high as possible to guarantee future production.

Books have been written on water use in agriculture. I cannot say enough about the use of water. With it, the deserts turn green. With it, production becomes 100 times greater. Where it is available it *must* be used to increase our capacity to produce. You may have seen irrigation districts in California, Spain, India, or Alberta. I can take you to a spot in Alberta where on one side of the road "under the ditch" a 2.5 m^3 crop of wheat is possible. On the other side it takes 12 ha to sustain one cow.

And yet there are many areas of the world where improper use of water has soured the land and turned it into saline wastes. Proper management can save or reclaim the land. In Obregon in Mexico the land must be flooded every 7 years in order to remove salts. Some of the water for this comes from the Colorado River, which supplies about seven irrigation and other projects in the course of its tortuous descent through the USA and into Mexico. Its salt content gets progressively higher as it goes south. And yet it irrigates most of the Imperial Valley, a name synonymous with high productivity.

Crop husbandry can increase crop yields. But technology must be well advanced and the information must be available to producers, who must be in a position to make use of it. The Canadian–Indian dryland project demonstrates that proper cropping practices can aid Indian production. But the technique must be suited to small holdings and not to large tracts of land such as are farmed in Saskatchewan or Montana.

FERTILIZER USE

It has been estimated that 40–70 kg/ha of fertilizer (N–P–K balanced) is sufficient to increase crop production by 50%. This is a blanket statement covering all soil types and climates. Obviously, the more moisture there is the more fertilizer can be used. In a dry year on our Prairie brown soils, applications are made cautiously, or the fertilizer may still be lying undissolved in August. By contrast, a corn grower in Ontario automatically includes a high rate of fertilizer as one of the many treatments for his crop.

Fertilizer, like water, is essential for crop production. Unless compounds are put back to compensate for crops removed there will be a reduction in the capacity to produce a crop. The three main elements required universally are nitrogen, phosphorus, and potassium. Most western soils in Canada do not have any deficiency of potassium.

Minor elements such as copper, zinc, and boron are frequently lacking in some soils. Their addition is needed for certain crops. As a rule their absence limits quality more than quantity.

Another important factor that frequently limits production is the state of acidity or alkalinity of the soil. In low pH (and thus acid) soils, there is usually a problem of aluminum toxicity. Soils in Eastern Canada, and indeed most soils under high rainfall conditions, are acidic. The treatment is lime. Without lime, crop production is miserably low. It is interesting to note that most countries have policies for lime distribution to farmers.

I must mention legume crops, which have the capacity to find fix-nitrogen from the air and make it available to plants. Much research is concentrated on this phenomenon. To date, although much is known, there is still the limiting factor that energy is used for the action of the bacteria that fix nitrogen. Furthermore, the nitrogen produced by legumes is frequently not used efficiently. The complete chain from use to reuse needs more attention. A few isolated cases have shown that bacteria may also associate with nonlegume crops and produce nitrogen. The rate is low and depends on many factors.

Fertilizer use will increase productivity and must be recognized as a key requirement for future production. It should be considered as a national resource and ways and means must be found to insure an adequate supply.

PESTICIDE USE

In describing crop husbandry practices I noted that protection from pests, although part of good husbandry, was worthy of special attention. I read the other day that over 30×10^6 ha of land in the USA are being used to grow weeds, feed insects, and produce diseases. Some Canadian estimates show our annual losses from wild oats alone can be in the order of 300 million dollars. A sound Delicious apple is worth 30 cents. The addition of one small larva reduces its value to 3 cents.

Weeds take their tithe by competing for moisture, nutrients, and in some cases, light and energy. To remove them manually is possible for some high-priced crops. Herbicides and hormones are used universally to reduce competition. For some crops and some weed species, the research has been successful and rewarding; for other crops and for some particularly difficult weeds, the struggle is still being waged. Corn is an example where good weed control is possible, both by culture and by chemicals.

It is safe to conclude that our need for chemicals will continue to be of prime importance for crop protection. Insects both above and below ground reduce plant growth and quality. Although normally controlled within certain population cycles, they frequently increase rapidly and cause natural disasters. There are many crops in the world that would not be productive at all without 2 or 3, or sometimes 10–15 sprays for insects. Problems in tropical areas are more severe than in northern climates, where some natural control occurs.

The problem with insecticides is that they are animal poisons and are therefore dangerous to humans if not used properly. The chemical means of control are also self-defeating because they reduce the natural enemies and parasites that keep insect populations down. The ultimate aim in insect control is to breed crop varieties with resistance. For many crops this is not too practical, although success has been achieved for some, such as the control of sawfly in wheat, and earworm in corn.

We must not forget that insects also reduce production by destroying crops in storage. Estimates of losses in storage range from 10–100%, depending on the type of crop and the locality in which it is stored.

Losses from disease can be 1 or 100% depending on the crop and the year. Canada, as has been noted, is often quoted as a country where enormous losses from leaf and stem rust are prevented by plant breeding. However, we might also record that we are losing millions of dollars every year to other fungi over which we have no control, such as *Helminthosporium*. We must still resort to spraying for blight in potatoes and scab in apples. In Europe, much has been made of systemic fungicides that are applied to grain crops. Although possible in Canada, the increased yield would rarely compensate for the costs incurred.

Weed control by selective herbicides is one of the world's most advanced technologies. The herbicide 2,4-D has been sprayed on millions of hectares. Both broadleafed weeds and grasses can be controlled, although there are many resistant weeds and some that resemble grain crops so closely that they cannot be eradicated. Nevertheless, we still sustain losses because applications cannot always be made when they should be, or do not completely work because of temperature or moisture.

Crop protection practices are essential for maintaining or increasing productivity. Despite the danger to the environment and to humans who apply chemicals, their use is essential if we are to keep down losses from pests.

ECONOMICS

This section is relatively brief because it will be covered by other papers. One major point needs to be made—farming is a business. Inputs for capital and labor must be added in every analysis. It is not enough to say that crops and food are of national concern and therefore controls must be exercised. The farmer who is the producer must be compensated for his work as much as the white or blue collar worker. Without an adequate capital base the farmer has little chance of increasing productivity.

American and Canadian farmers have been remarkably successful in terms of numbers of people that each one provides food for. The numbers go up in almost direct proportion to the size of the tractor the farmer uses and the size of the farms. But costs increase while prices for goods received for each cubic metre fluctuate as markets vary. The price of gasoline will never be 15¢ a litre again but prices of wheat or corn could plummet any time the market is flooded. In our society we cannot talk about increased productivity without discussing economic returns.

THE INTERNATIONAL AGRICULTURAL RESEARCH SYSTEM

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INTRODUCTION

Until comparatively recently most of the crops research carried out in developing countries was devoted to cash crops for export to and reprocessing in developed countries. Subsistence food crops for domestic consumption were comparatively neglected by colonial governments. Notable among the exceptions to this general neglect were the wheat, maize, and bean research programs conducted by the Rockefeller Foundation in cooperation with the Mexican Government that started in 1943 and laid the foundation for the eventual creation of the International Maize and Wheat Improvement Center (CIMMYT), and the Ford Foundation's rice research program in Asia from which arose the International Rice Research Institute (IRRI).

THE ESTABLISHMENT OF THE FIRST INTERNATIONAL AGRICULTURAL RESEARCH CENTERS (IARCs)[1]

Two significant events took place during the early 1960s with the establishment of two international agricultural research centers: IRRI in the Philippines and CIMMYT in Mexico.

The main purpose of IRRI, which was jointly sponsored by the Ford and Rockefeller foundations, is to strengthen the capabilities for undertaking research on rice in all the producing countries of Asia and, in consequence, to increase Asian rice production through improved agricultural technologies.

CIMMYT was created in 1966 by the Ford and Rockefeller foundations in collaboration with the Mexican Government. Its purpose is to expand and intensify applied research on wheat and maize in order to encourage increased production of these crops among those developing nations that depend on them for subsistence.

By the late 1960s the Rockefeller and Ford foundations had established two more international agricultural research centers, the International

[1]For a complete and comprehensive description of each center see "Consultative Group on International Agricultural Research (CGIAR) New York, 1976." Obtainable through United Nations Development Programme, New York.

Institute of Tropical Agriculture (IITA) in Nigeria and the International Center for Tropical Agriculture (CIAT) in Columbia.

The purpose of IITA is to develop improved farming systems in the lowland humid tropics, especially in Africa. IITA's headquarters is at Ibadan in Nigeria and its main emphasis is on initiating intensive cropping systems to replace shifting cultivation. IITA is also responsible for improving cowpeas (*Vigna unguiculata*), an important legume of the semiarid tropics. CIAT's mandate also covers cropping systems in the humid tropics but its main area of interest is Latin America; CIAT's headquarters is at Cali in Columbia. It is also the world center for cassava improvement.

RATIONALE OF THE CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH (CGIAR) AND THE NEW IARCs

Recognition of the successes of CIMMYT and IRRI during the late 1960s in the production of new high-yielding varieties (HYVs) of wheat and rice led to the formation of a unique international organization. Various donor agencies, including governments, development banks, and several foundations from around the world, decided that the base of financial support for the four IARCs should be broadened. These donor agencies decided to form a permanent body of international financial support, which came to be known as the Consultative Group on International Agricultural Research (CGIAR). In 1971, when the CGIAR had its first meeting, the total budget for the four existing IARCs was about 11.5 million dollars. In 1972, the first year of collective funding, the CGIAR supported a total budget for the IARCs of 15 million dollars. In 1977 it had a proposed budget in excess of 80 million dollars and was supporting 11 international centers and related organizations.

The rapid expansion from 4 international centers in 1967 to 11 in 1977 was stimulated by a number of considerations including:

1. the manifest advantages of a concentrated international research effort dedicated to the improvement of the productivity and quality of subsistence crops;
2. the encouraging degree of adoption (in spite of what the detractors may say) of the HYVs of wheat and rice by farmers in Asia and Latin America.

The IARCs, supported by the international consortium of donors, are able to sustain a level of research that has a scope and depth quite beyond the financial and human resources of any one developing country. This is especially true of the poorer least-developed nations. Each IARC can recruit its staff internationally; it can assemble and sustain a critical mass of scientific effort essential in order to tackle crops research in a truly comprehensive manner. Each IARC provides a focal point and center for the collection, ordering, evaluation, and dissemination of both germ plasm and relevant information. Because most of the centers have a worldwide responsibility for certain specific crops (such as wheat and maize at CIMMYT, rice at IRRI, cassava at CIAT) they also become centers of world germ plasm collections and repositories of information. Several IARCs have already established worldwide information services on the crops and cropping systems of their responsibility. The environment within which agriculture operates is constantly changing. Changes in agricultural methods, land use, and possibly even the weather, require that a diverse collection of genetic material be maintained to suit the various forms the agricultural environment may take. All IARCs participate in the collection, preservation, and exchange of this important material.

Another major advantage of the IARCs is their ability to stimulate and support national agricultural research programs in developing countries. It was never the CGIAR's intention that the IARCs should replace national programs of developing countries, but rather that the CGIAR family should provide national programs with a wider range of relevant technological choices in the form of improved germ plasm and agronomic practices that the less developed countries (LDCs) can adapt to their own agroclimatic and economic conditions.

It is probably true to say that the HYVs of wheat developed at CIMMYT and rice developed at IRRI have provided the main stimulus for the growth of the CGIAR family of IARCs. For example, the increase in total production of rice and wheat in the years 1970–73, compared to 1960–63, for various countries were:

> India, 115% for wheat and 19% for rice; Pakistan, 78% for wheat and 113% for rice; Philippines, 34% increase for rice; Malaysia, 67% increase for rice; and Indonesia, 53% increase for rice.

Within this 10-year period 35×10^6 ha were put under the HYVs of wheat and rice, planted by approximately 30 million farmers.

These remarkably increased yields encouraged a widespread belief in the possibility of a major breakthrough in agricultural production in the LDCs, thus justifying expanded support for existing IARCs and the creation of new research centers within the CGIAR family.

INDIVIDUAL IARCs

There are now 11 IARCs sponsored by the CGIAR. The first four, formed before the CGIAR, have already been mentioned. The subsequent seven are:

The International Potato Center (CIP), Lima, Peru

This center, established in 1971, concentrates solely on the potato, trying to improve varieties and expand production in the developing countries. It puts much effort into the development of production specialists, who can quickly extend and apply the research results of the center to the farmers' fields. It has already reported success in identifying genotypes adapted to the humid tropics and others high in protein content of superior nutritional quality.

The International Crops Research Institute for the Semiarid Tropics (ICRISAT), Hyderabad, India

ICRISAT was established in 1972 for the major purpose of improving crops of greatest concern to farmers in the semiarid tropics. ICRISAT has worldwide responsibility for two cereals (sorghum and pearl millet), two pulses (pigeon peas and chickpeas), and one legume oilseed crop (groundnuts). ICRISAT's program is aimed at economies that are short of capital. Such economies are typical of the developing countries of the semiarid tropics; they have an excess of rural labor and limited access to mechanical power and other forms of capital. The semiarid tropics, which embrace much of Africa surrounding the Sahara and large areas of India, are the home of many of the poorest people of the world. The area under sorghum and millet exceeds the area under maize in the LDCs, although the average yields of sorghum and millet are barely 0.5 t/ha. Among the large collection of cereal and legume germ plasm at ICRISAT there are many varieties that offer significant potential improvement in both yield and nutritional quality.

The International Laboratory for Research on Animal Diseases (ILRAD), Nairobi, Kenya

ILRAD was established in 1973. Its function is to conduct research to develop immunological methods for controlling two major diseases of cattle: theileriosis, also known as East Coast Fever, which is carried by ticks; and trypanosomiasis, the sleeping sickness characterized by severe anemia and transferred by the tsetse fly. Both diseases give rise to high morbidity and mortality among domestic cattle, and hence cause severe economic loss to African farmers. Research at ILRAD is underway to define and isolate the antigens involved in protection, and to determine methods for inducing long-term resistance. ILRAD has begun cooperative research efforts in both the developed and developing world in such areas as immunology, parasitology, and biochemistry, complementary to ILRAD's in-house work.

The International Livestock Center for Africa (ILCA), Addis Ababa, Ethiopia

ILCA's purpose is to enable countries in Africa to improve their systems of production and marketing of livestock and livestock products. It is now realized that the sectoral approach to livestock research is inadequate because livestock production and management is a complex system of physical, biological, economic, and social factors. Therefore ILCA's program uses interdisciplinary research including teams of animal scientists, agronomists, economists, and social scientists.

ILCA performs another important function related to the livestock industry in Africa, namely collection and documentation of information. To this end it has established a cooperative network of the principal world documentation centers concerned with raising tropical livestock. ILCA has formed its own team to collect conventional and nonconventional literature, which is then made available to its own research scientists and to others interested in the various countries of Africa. ILCA cooperates with ILRAD in both research and exchange of information.

The West Africa Rice Development Association (WARDA), Monrovia, Liberia

This association was formed in 1971 by 13 English and French speaking West African countries for the purpose of making West Africa self-sufficient in rice. These countries finance a major portion of WARDA's program with the CGIAR supporting several related research activities.

WARDA's research activities include coordinated trials in cooperation with IRRI and IITA and the testing of improved rice types and agronomic practices throughout West Africa.

As its name implies, WARDA is also a "development" association. To fulfill this role it has gathered a multidisciplinary team of agriculturalists to identify, prepare, and evaluate projects for the various member countries. It also helps these countries obtain financial assistance for their projects and, in cooperation with IRRI and IITA, provides for rice research and extension workers from all of its member countries.

International Board for Plant Genetic Resources (IBPGR), FAO, Rome, Italy

This is not a research center in the same sense as the others described. Its purpose is to encourage and facilitate the collection, preservation, and exchange of plant genetic materials of importance to the LDCs.

The IBPGR pursues its objectives in several ways. It identifies priority regions, those where there is significant genetic diversity but where agricultural practice is changing most rapidly. It identifies priority crops, based on criteria such as economic and social importance, danger of loss, or replacement by modern cultivars, and determines whether an extensive collection has already been made.

Recognizing that an adequate data classification and system is essential, one of IBPGR's major programs is establishing the Genetic Resources Communication, Information, and Documentation System. It is also helping both international and national research centers to install a computerized classification of crop genetic resources. Eventually, it is hoped, the inventories of all major collections will be filed on this or some other related system.

International Centre for Agricultural Research in the Dry Areas (ICARDA), Cairo, Egypt

This is the newest of the IARCs, established in 1976. Its purpose is to help increase and stabilize food production in the developing countries of subtropical and temperate zones having an arid or semiarid climate. Its main area of interest is the Mediterranean basin and North Africa.

There are two major aspects of ICARDA's research and training program. One is to improve the productivity of farming systems, which are based on both crops and animals, including sheep and goats. The other is to improve the yield and quality of the principal crops of the dry areas. ICARDA is to serve as a world center for research on barley, durum wheat, broad beans, and lentils. Some of its research will be performed in conjunction with CIMMYT and ICRISAT, because it is also trying to encourage the introduction of durum wheat, maize, and sorghum into other semiarid regions of the world.

Eventually it is intended that ICARDA will have working facilities in three primary locations. Plant breeding will be undertaken in the Bekaa Valley in Lebanon, farm systems research in Syria, and research on the problems of high plateau agriculture in Iran, in the region of Tabriz. This last research activity is unique and important, because it is the first research within the CGIAR system to be concerned with high, dry areas that are cold in winter and hot and dry in summer.

COMMON TRENDS WITHIN THE IARC

Although each of the IARCs has a unique orientation in its research program, there are common elements running through all IARCs' structure and methods of operation.

First, each of the IARCs is an autonomous, international research and training institution with an international staff of scientists supported by locally recruited technicians. Each is governed by its own international board of trustees; and each board contains members from both developed and developing countries.

Second, research in the IARCs is primarily applied, practical, and problem-oriented, with little emphasis on pure science. Whenever desirable, efforts are made to coordinate or share trial results with other centers. With the help of the IBPGR, several of the centers are building up collections of the world's germ plasm for the crops for which they are responsible. Genetic materials from these collections are to be freely available to all centers and those who cooperate with them. Also available is the vast repository of information that results from each center's research on its own specialty. Each center sponsors training programs, seminars, and workshops for scientists from the LDCs.

Third, a characteristic of the centers is that their research is carried out by multidisciplinary teams of scientists, including plant breeders, geneticists, soil scientists, plant physiologists, animal scientists, and economists. The nature of the problem is the deciding factor in choosing the skills required to solve it.

Fourth, in attempting to apply the fruits of their research directly for the benefit of farmers in the developing countries, each center undertakes special projects or programs specifically designed for and carried out within individual countries. These and similar outreach activities complement various national programs, especially in the use or training of local scientists and technicians. These special research programs are designed to address local agronomic problems. Some individual research programs are not yet equipped to solve such problems, or lack the necessary financial and physical resources for the purpose. These outreach activities are recognized as among the most important functions a center can perform. In terms of the total 1975 budget they accounted for one dollar out of every four spent.

Fifth, in addition to the training that is provided in the outreach programs, each center trains scientists and production specialists as part of its regular on-site research activities. The trainees acquire skills and knowledge they can use in their own country's national agricultural research programs. Up to the present, over 3000 people from LDCs have been trained in the existing IARCs.

PERFORMANCE OF THE IARCs

An important and justifiable question is how well this general IARC method of operation performs in terms of increasing agricultural production. A major problem in answering this is that only two of the IARCs have been in full-scale operation for more than 8 years; seven of the 11 have been established within the last 5 years. Knowing that the time lag between research expenditure and practical results is usually expected to be at least 6 years, we can look at only three, possibly four, IARCs to answer our question. To date, the early HYVs of CIMMYT and IRRI are our best examples for evaluating research impact on actual world production of the developing countries.

The original research approach of CIMMYT and IRRI was that the best way to achieve improved output from traditional agriculture was to introduce a "package" of new technology. This package consisted of new seed varieties, fertilizer, some mechanization, and improved water management.

The early results of newly introduced wheat varieties in Mexico and rice varieties in the Philippines, based on this package approach, were dubbed (by the media, not by scientists) the "Green Revolution." This is a misnomer. It was never thought by knowledgable scientists that this single breakthrough was to be the sole means of alleviating the fear of famine among the developing nations. The early improved yields did nothing more than provide a breathing space in the constant struggle for sustenance. Successful agricultural research is continuous; the benefits of one success will, in time, run out and new breakthroughs will continue to be required no matter how small they may be.

This in no way discredits the exceptional work of CIMMYT and IRRI. The increases in total production for certain countries are impressive. The successes achieved in so short a time were unprecedented and have yet to be equalled elsewhere. It is also important to note that they occurred in those areas of the world considered to be the most famine-prone, namely, the Indian sub-continent, South Asia, and Mexico.

What we now realize is that the HYVs had limitations and, more importantly, we are beginning to understand what these limitations are. The package approach, as outlined earlier, placed constraints on some small farmers that they could not fully bear. Some of the new technologies required a production system that was more expensive or complex than the traditional rural farmer could fully accept. Consequently, it was mostly the large, more commercial farmers who first adopted and used the new seed varieties, fertilizers, and water management techniques. In his study of farmers in the Punjab and Sind provinces of Pakistan, M. H. Khan (personal communication) showed that for the improved rice and wheat varieties it was the owners of large farms who first planted them and adopted the use of fertilizer and water management as recommended by the extension service. It was further noted that when looking at farms of equal size, it was the farmers who lived in areas of already commercialized agriculture who adopted the new varieties and management practices first. This is attributed to their greater capacity to accept investment risk and uncertainty, and their access to established lines of credit.

Another constraint was that the new varieties developed were suited to specific geographical areas of the world, in terms of climate or topography. The earlier improved wheat and rice varieties did not encourage production on new land, but instead displaced traditional crops and, in some cases, other nonsimilar crops. This is not a valid criticism in the case of Southeast Asia because, regardless of the crop introduced, there is virtually no new land that can be brought into production. Increases in yield rather than environmental adaptability will be the main criterion for the development of new varieties for this part of the world.

CIMMYT and IRRI, along with the other IARCs, have continued to develop and adjust their programs in order to overcome as much as possible those factors that will limit production. This is done in a number of ways.

First, when designing a new technology to increase production it is important that the social, economic, physical, and biological environments be understood. This knowledge will aid the IARCs in developing technologies that minimize the financial risk to the farmer.

Second, realizing that the greatest potential for increased food production lies within the tropical and semiarid tropical zones of the world, new plant varieties and production systems need to be developed that are adapted to the various local topographical and climatic conditions within these zones.

Third, experimental trials conducted at the research centers now take more account of the various conditions existing in typical on-farm situations.

Most important, the established centers devote a larger proportion of their effort to on-farm research—research carried out in farmers' fields under farmer management. A particularly good example of this trend is to be found in IRRI's Multiple Cropping Systems research, carried out with farmers in the Philippines, Indonesia, Bangladesh, Sri Lanka, and Thailand.

In response to the lessons learned, the centers have recently begun to turn their efforts to developing plant types and practices that benefit the small farmer, who must operate without the benefit of controlled irrigation, fertilizers, or pesticides. Centers are also deepening their studies of the constraints to production that lie outside the realm of biology, such as social customs, consumer habits, costs of inputs, and availability of input supplies. Economists and other social scientists are now playing an expanding role as members of the multidisciplinary research teams.

DESCRIPTION OF THE CGIAR

Having described at some length the research centers themselves, it may be helpful to describe the CGIAR.

The CGIAR is sponsored by the World Bank (IBRD), the Food and Agriculture Organization of the UN (FAO), and the United Nations Development Program (UNDP) and comprises 39 members (listed at the end of this paper), including donor agencies and organizations, the Regional Development Banks, and representatives from the five major developing regions of the world (Africa, Asia, Latin America, Middle East, Near East and Eastern Europe). Each of these five provides a nondonor representative. The CGIAR meets Directors of the IARCs at least once each year to review the programs of work and the budgets requested by each center. Each donor then decides what contribution it will pledge to which center(s). In the event of an excess of contributions to one and a deficiency to others, the CGIAR Secretariat tries to persuade CGIAR members to readjust their contributions in order to provide a balance of financial support.

To assist the CGIAR members in deciding what should be financed, a group of 13 scientists, called the Technical Advisory Committee (TAC), was created when the CGIAR came into being. Apart from its Chairman, TAC positions are equally held by scientists from developed and developing nations, although each member is present in his own right and not as a representative of his nation. The purpose of the TAC is to advise the CGIAR members on priorities for research in agriculture in the developing world and to recommend a balanced program of research effort among the IARCs. TAC members make frequent visits to the IARCs to discuss and evaluate programs.

The CGIAR has grown quickly since it started in 1971-72. Originally it consisted of 15 donor members, sponsoring five research centers, with a total budget of 15 million dollars. In 1977 there are 29 donor members supporting 11 research centers with a total budget in excess of 80 million dollars. Although this may seem like a relatively large annual expenditure, it represents only 5% of all resources spent on agricultural research in the developing countries. The operating cost of the research in the IARCs has grown from 15.4 million dollars in 1972 to 51.2 million dollars in 1976, an average annual rate of increase of 30% in current prices, or 25% in constant dollars.

Canada's contribution (through International Development Research Center (IDRC) and Canadian International Development Agency (CIDA)) has grown from 1.3 million dollars in 1972 to 7.5 million dollars in 1976. This by itself equals 11% of the total contributions made to the CGIAR over the same 5-year period. Canada, after the United States, is the second largest donor member of the CGIAR.

PERFORMANCE OF THE CGIAR

Having dealt briefly with the cost of the CGIAR family of IARCs, the next obvious questions are: what benefits have been derived? Has the outcome been worth the expenditure?

No unequivocal or indisputable answer is possible, but if we did not consider it worthwhile, Canada would not continue its support for this remarkable organization. During its relatively short life of 5 years the CGIAR has already achieved several important objectives.

First, it has helped agricultural research to gain the prestige and respect it has long been denied, in both developed and developing countries. It has also stimulated and complemented national agricultural research in developing countries. Although firm data are hard to come by, there is good reason to believe that agricultural research is now assigned a higher priority by LDC governments than it was 10 years ago.

Second, the CGIAR has brought together and is developing a large body of expertise and knowledge related to the basic food commodities of the developing world.

Third, the system established by CGIAR has helped to increase total food grain production and give hope of even larger increases in developing countries in the future.

Fourth, it has provided the IARCs with a guaranteed source of continuing support and thus enabled them to plan imaginative long-term programs. Agricultural research, if it is to have any lasting benefit, must be regarded as a long-term endeavor. New and more productive technologies are not developed by short-term and *ad hoc* projects.

Fifth, the CGIAR system has developed an intense, effective, and nonpolitical international network of communication in which both information and genetic material is widely exchanged. Avoidance of the shifting, uncertain political and bureaucratic obstacles created by numerous government bodies permits the resources available for international agricultural research to be used much more effectively. This happens because, first, beneficial results from research, regardless of their source, can be made available to all those interested, irrespective of their political attitude; and second, the manpower required to administer the total resources is minimized, thereby shortening the lead time between the commitment of resources and the realization of results.

PROPOSED CHANGES TO THE CGIAR

Given the dramatic growth in terms of its membership, the size and number of activities it supports, and the resources provided by its members to fund them, the CGIAR in 1975 decided to do an in-house review. This review of its scope of activities and programs was to aid in planning its future role in promoting research for the development of agriculture, particularly food production, in developing countries. By October of 1976 the Report of the Review Committee was made available.

The review reinforced what was almost a general consensus, namely the need for the CGIAR to develop new approaches for international agricultural research. The review contained many recommendations, but in reference to the centers themselves and their activities the following are among the more important.

First, increasing cooperation among the IARCs and the various national agricultural research programs will be encouraged.

Second, the IARCs will seek to establish closer working relations with established institutions, particularly those in developed countries. Ideally, problems encountered in the IARCs' applied research programs can often be successfully tackled by a more fundamental study at a university in a developed country. IDRC has sought to create partnerships in which a Canadian university studies, under contract, a project defined by the IARC staff in consultation with the university.

The third relates to the management of the IARCs and urges that the director of each center give attention to long-term planning and budgeting to enable the CGIAR to predict and seek assured support for the future.

Fourth, in developing their plans for the future, the IARCs will need to give greater attention to technological forecasting in its broadest sense and, in particular, to the manner in which the products of their research can best be delivered to those they are intended to benefit.

CGIAR has initiated a remarkably effective system of integrated international agricultural research that has shown previously unimagined increases in productivity to be possible. The most important problem and opportunity for the future is to develop a system by which the new and improved technologies can be adapted and adopted by the farmers of the developing world for the benefit of the least privileged of the world's people.

The views expressed are those of the author and do not necessarily represent the views of the International Development Research Centre.

CONSULTATIVE GROUP ON INTERNATIONAL AGRICULTURAL RESEARCH

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ECOLOGY

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GOAL

To interest the reader in ecology and provide sufficient information to:

1. compare alternative strategies for feeding people by means of ecological criteria;
2. suggest ecologically sound strategies for providing Canadians, and those served by our aid programs, with access to the necessary foods (or resources to obtain them) to achieve optimal physical and mental health.

BEHAVIORAL OBJECTIVES

After reading this paper you will be able to define ecology in words or diagrammatically and list:

1. two of the four laws of ecology discussed below;
2. two implications of these laws for our food system;
3. two of the seven goals of a normative food policy;
4. five ecological strategies for food production in Canada that should be implemented, expanded, or supported by additional research funding;
5. three benefits of the ecological approach.

INTRODUCTION

In his fascinating book "Life on a little known planet" Professor Howard Evans (1970) states that "ecology . . . is truly the science of tomorrow" and "productivity is basically a problem in ecology and . . . must be considered on a global scale." In this paper I will examine the meaning of these statements.

Ecology is classically defined as the study of the home of organisms, and ecologists have focused on the interrelationships between organisms and their living and nonliving environment. Reference to current literature, however, shows that ecology could now be defined as the relationship between everything and everything; it tends to emphasize a holistic, long-term view, and is often concerned with complex relationships among influencing variables and with the prediction of future events by means of on-line computer models.

INDUSTRIAL AGRICULTURE: PROBLEMS AND ALTERNATIVES

Although it is true that food production per area and per farmer effort has dramatically increased over the past 50 years, so have the levels of inputs and associated environmental impact, while energy efficiency and the capital within the system have declined. Other features of modern agriculture that have negative implications are shown in Figure 1.

These developments within agriculture are not unique, but are part of our changing relationship with our support environment; from being, to some extent, at its mercy, to exercising considerable control over it, for instance through the use of fertilizers, pesticides, and powerful machinery. If we continue to increase our dependence on these inputs, crises will undoubtedly result as finite resources become scarce and environmental damage thresholds are reached.

It is the view of many ecologists that we must develop a new postindustrial relationship with our support environment, including a renewable resource base, the use of ecological strategies, and an emphasis on individual real needs as opposed to mass-manipulated wants.

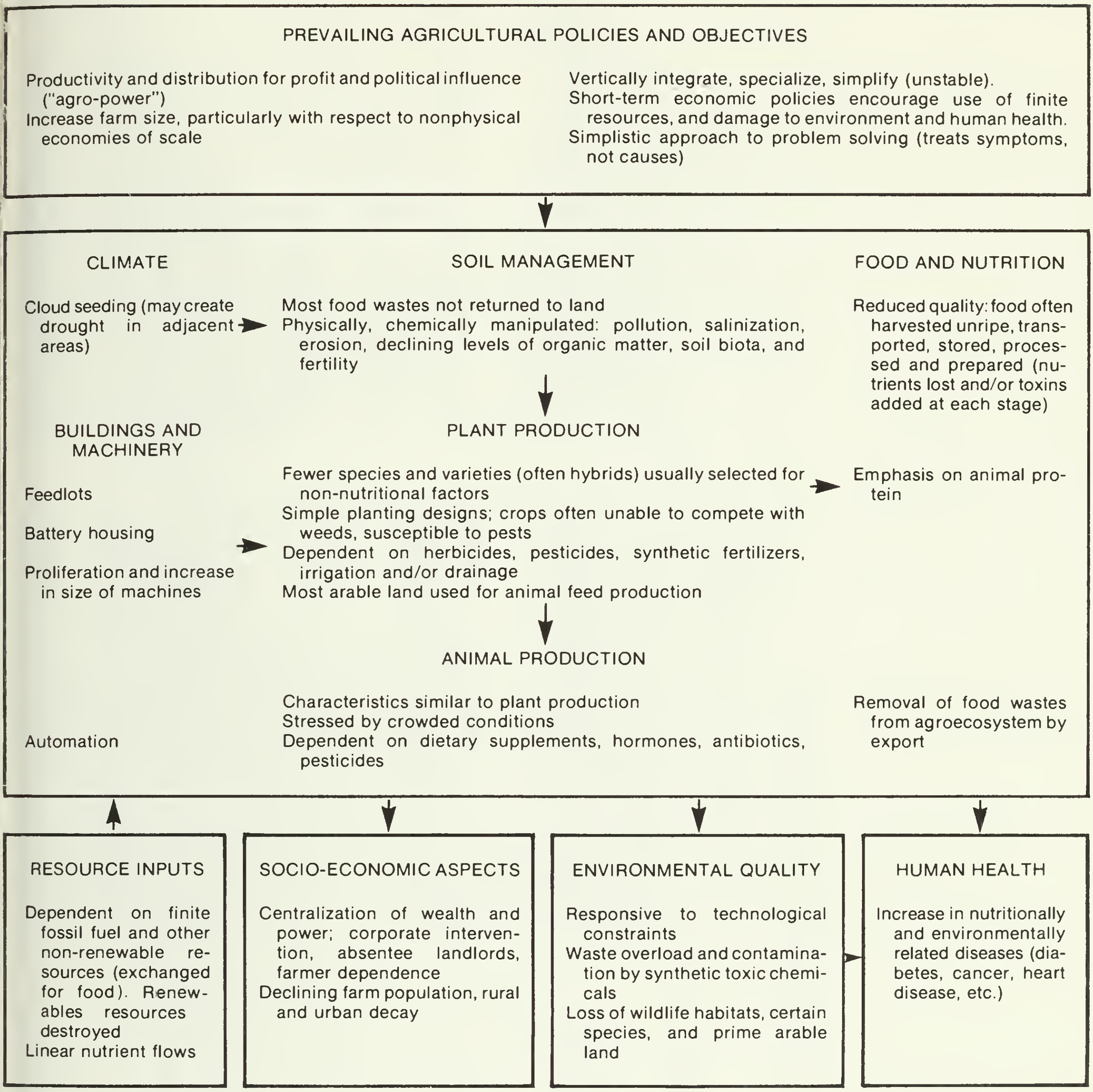
LAWS OF ECOLOGY, ECOLOGICAL AGRICULTURE AND A NORMATIVE FOOD POLICY

One approach to establishing an alternative ecological agriculture is to examine natural ecosystems for clues to the laws governing their operation. Four such laws relevant to food production are listed, with their implications, in Table 1. Such laws constitute the criteria against which alternative food production strategies must be tested.

An example of an alternative ecological agriculture, based on these laws, is given in Figure 2.

Clearly such an alternative could not be reached by extrapolation but requires normative planning, that is, defining our long-term goals and working backwards from them to the present (*cf.* Lovins 1976). An example of a normative food policy is given in Table 2. The goals of such normative, ecological approaches focus on health, permanence, efficiency, environmental quality, and fair rewards for those employed within the food system. These goals are long-term and comprehensive, emphasizing real needs and respecting biochemical constraints and the complex, cyclical character of the natural environment. Such approaches are likely to reveal influencing variables and alternative strategies that would not be apparent under present approaches; they are also able to predict future events more accurately.

FIGURE 1. Some possible negative aspects of modern agriculture



Although our theoretical basis for ecological agriculture is well advanced, there is an urgent need to expand the support for appropriate basic biological and ecological research and for the development of associated technology, such as equipment for waste handling and mixed cropping systems.

Three examples will now be presented to illustrate the ecological approach: developing and maintaining fertile soils, preventing outbreaks of pests and diseases, and insuring the production of high quality food. These three issues strongly influence our ability to meet the protein requirement of a population.

TABLE 1. Laws of nature in relation to food production

Law of nature	Some ways in which our current food system contravenes this law	Policy implications
1. Survival is based on:	Much of our system is geared to supplying not real but manipulated needs.	Identify real needs (as distinct from manipulated wants) and control all other activities that are likely to interfere with their satisfaction over the long-term, e.g. reduce wastage in the food system, of both inputs and outputs.
Needs (food, space, shelter, clothing, education and other quality of life factors).	Every stage of production and subsequent handling has become addicted to non-renewable resource inputs (particularly fossil fuels).	
Availability of the resources on which they depend.	Additional health hazards have been created with the industrialization of agriculture, e.g. machines and chemicals.	Support the development of lifestyles that depend only on renewable resources and are environmentally supportive or minimally disruptive, e.g. nonpolluting.
The incidence of mortality factors.		Establish strict priorities for the use of non-renewable resources.
		Support the development of lifestyles that prevent premature human mortality.
2. Relationships in the environment are cyclical.	The system is characterized by linear nutrient flows with their associated dependence on nonrenewable resources and resultant pollution.	Support the development of cyclical systems that depend only on renewable resources and are nonpolluting, e.g. those that utilize organic wastes, along with other biological strategies to maintain soil fertility (facilitated by regional self-sufficiency).

3. Natural systems tend to become more complex and diverse with time through an increase in the number of species and in the interactions between them.	An increasingly complex technology is being used to manage more and more simplified agroecosystems, e.g. —reduced gene pool —monocultures —removal of competitors by cultivators, herbicides, pesticides, traps, etc. —creation of uniform soil conditions through tillage, irrigation, drainage, and fertilizer application —uniform farm environment by specialization and removal of non-productive areas: e.g. hedges, field borders, woodlots, ponds. Solutions to problems tend to ignore this complexity and deal with symptoms (pesticides, fertilizers, antibiotics, food enrichment).	Support the development of "complex" food production systems, e.g. mixed farms, crop rotations, mixed cultures. Support the development of a decentralized food system with minimal handling between producer and consumer. Treat causes of problem rather than symptoms; largely by using preventive approach based on management strategies. These, in turn, are based on an understanding of the complex interrelationships within the farm environment.
4. All organisms are subject to certain common biochemical constraints.	Production and processing are dependent on synthetic organic compounds that have no counterpart in nature (pesticides, food additives).	Utilize only organic compounds that have a counterpart in nature, i.e. that will decompose.

FIGURE 2. An alternative ecological agriculture

ECO-AGRICULTURAL POLICIES AND OBJECTIVES

"Permanent" production strategies for individual nutritional needs (environmentally supportive, respecting "laws of nature," part of a survival ethic)
Holistic approach to problem solving (multidisciplinary, preventive methods)

Regional self-sufficiency; decentralized food systems, supportive of: (1) urban food production: (2) self-sufficient homesteads, with small surplus: (3) large farms, redesigned along ecological lines

↓

CLIMATE AND COSMIC INFLUENCES

Cognizant of planetary influences
Long-range weather forecasting

→

SOIL MANAGEMENT

Conservation or improvement of soil fertility
Biological and chemical indicators for balancing nutrients
Microbial inoculants, compost, sewage, green manure, other natural organic materials; minimal use of inorganic materials and tillage; mulching, drip irrigation

↓

PLANT PRODUCTION

Breeding, selection, management, minimal environmental impact, dependence on synthetic chemicals and energy, and optimal nutritional quality; new uses for crop outputs
Preventive disease and pest control; expanded gene pool
Complex planting designs; naturally occurring plant nutrients, hormones, microorganisms; "herbal" and indigenous pasture mixtures

↓

ANIMAL PRODUCTION

Characteristics similar to plant production; improved and alternative sources of feed and animal protein
Disease prevention and treatment: early indicators, gut microflora, herbs, nonspecific antigens, trace minerals, vitamins; mixed pasture management; humane handling

BUILDINGS AND MACHINERY

Energy efficient, low environmental impact technology
Fuel and animal powered (including small scale) machinery for mixed crop operations →

Compostors; seed energizers, solar driers, barns, and greenhouses

FOOD AND NUTRITION

Improvement of food quality to meet individual nutritional needs

Minimal processing to permit storage and distribution

Promotion of alternatives to animal protein where appropriate

Return of food wastes to agroecosystem

RESOURCE INPUTS

Dependent on solar and renewable energy, managed on a regional basis for permanence without pollution; conserving nonrenewable resources
Supportive of cyclical nutrient flows through optimal management of waste

SOCIO-ECONOMIC ASPECTS

Meta-economic approach
Redistributed wealth and power
Deurbanization, direct and cooperative marketing
Use of cybernetics in long-term planning
Human-capital intensive; ecologically appropriate technologies; sensitive to work quality; supportive of rural people

ENVIRONMENTAL QUALITY

No synthetic organic chemicals or waste overload: controlled production, recycling, environmental quality; manipulation of diversity and succession for stability
Conservation of rural landscape and wildlife habitats and nonproductive land rejuvenated

→

HUMAN HEALTH

Environmantal-nutritional models of health and disease
Cognizance of soil-food-health relationships and importance of identifying optimal diet for each individual

TABLE 2. Primary goals of a normative Canadian food policy

Goals	Comments
National	
1. All Canadians to have access to the necessary foods (or resources to obtain those foods) to achieve optimal physical and mental health	Consumer education Incentives and controls within the food system Research into food-health relationships and preventive medicine Recognition of individual needs and tolerances
2. Only utilize strategies that could, if necessary, be permanent	Self-sustaining, based on the use and conservation of renewable resources
3. Utilize the most efficient and appropriate strategies for each situation	Emphasizing optimal use of resources Recycling of wastes Net energy efficiency National and regional self-sufficiency Sociological compatibility
4. Utilize strategies that will establish and maintain an optimal spatial environment for Canadians	Sensitive to relationships between quality of environment and quality of life
5. Provide those employed in the food system with a fair wage, safe working environment, and acceptable range of social services	Consideration of more factors in setting food prices
International	
6. Interact with other nations in such a way that their ability to achieve the above goals, particularly the establishment of self-sufficiency in food, is not impaired	
7. Support food aid programs that emphasize transfer of appropriate strategies compatible with local customs and resources (ecodevelopment)	Avoid intervention of foreign systems and technologies that increase dependence or that could result in eventual instabilities within their food systems through resource depletion or environmental damage

Developing and maintaining fertile soils

It is relevant first to review how soil is formed. The process requires two material inputs: rock (the earth's crust), and dead organic matter, these being converted to soil largely through the process of decomposition.

There is certainly no shortage of rock and, in temperate countries there should be no shortage of dead organic matter, as the optimum temperature for its production is nearer the annual mean temperature than is the optimum temperature for its decomposition. This, in fact, is the main reason why we find a deep litter layer in most of our forests, whereas there is usually no litter layer in lowland tropical forests. The biological decomposition process is carried out largely by bacteria and fungi. However, at least six factors limit their activity (food, space, dispersal, competition, cropping, and senescence). The soil fauna play an important role because, through their feeding and movement, they are continually removing these limiting factors, particularly through their ability to disperse the microflora. Thus, if certain members of the fauna are killed or reduced by agricultural practices, the activity of the bacteria and fungi that rely on those particular species will decline.

Our detailed knowledge of these processes is poor, but it is sufficient to know that by taking into account the organisms in the soil, and catering to their needs, soil fertility can be built up and maintained. The primary requirement is that organic materials taken from the land be returned. This follows from the law of ecology concerning cycles given in Table 1.

Rather than forcing the resident "decomposer industry" out of business by applying synthetic chemical fertilizers, or killing some of them by applying biocides, we should be investigating their productive potential within each soil type and developing management strategies whereby any potential can be realized. Such strategies are likely to save money and energy, and avoid damage to the support environment and to human and livestock health. This contrasts with our current approach, which involves the removal of several dozen minerals at harvest time followed by the replacement of only a few of them as chemical fertilizers.

Preventing outbreaks of pests and diseases

Pests and diseases are symptoms of poor management (Figure 3). Pesticides, like antibiotics and drugs, have generally been regarded as "magical bullets" that can eliminate problems. But the real situation is that we do not suffer from pests because of a deficiency of pesticide in the environment, just as we do not get a headache because of a deficiency of aspirin in the blood.

The use of pesticides and antibiotics to control pests and pathogens leads to the development of a long list of serious secondary problems (resistance, damage to beneficial organisms, secondary pest outbreaks, persistence and dispersal, concentration up the food-chain, and sublethal effects).

FIGURE 3. Relationships between plant production and pest damage

Plant production practices (a similar model could be established for animal production)	Modes of action	Pest damage
Selection of plant (species, variety) introduction breeding and selection vegetative propagation **Selection of site** natural factors: soil elevation, slope, aspect, climate, location, adjacent bodies of water and woodlots historical factors farm and non-farm pollutants **Planting design** plot size, shape, and layout hedgerows, field borders monoculture, rotation, mixed planting **Maintenance of site** tillage and cultivation irrigation drainage use of inorganic and organic fertilizers and mulches use of pesticides and growth regulators timing of operations **Harvesting and distribution** harvesting distribution storage	→ PROPERTIES OF PEST preferences tolerance ranges metabolic rate and size assimilation efficiency reproductive potential rate of development and longevity susceptibility to natural and artificial controls DISPERSAL OF PEST initiation of dispersal ease of dispersal to suitable habitats by active and passive means AVAILABILITY OF SUITABLE HABITAT FOR PEST **Food and space** quantity quality distribution in time and space competition **Natural controls** (incidence and effectiveness) predators parasites pathogens	→ AMOUNT OF DAMAGE DONE BY PESTS AND DISEASES

Moore (1967) has pointed out that we really only have three alternatives with respect to controlling pests: continual development of new pesticides as pests become resistant; exclusion of pests in enclosed, artificial environments (the science fiction solution); and prevention by modifying our agroecosystems. The pesticide approach predominates largely because most of the costs (such as environmental and human health) are not taken into account in our cost–benefit analysis. As a member of the British Labour party once explained, this encourages "private, short-term gain at public long-term expense."

In order to treat pest problems at the causal level, it is necessary to examine more closely the relationships between agricultural practices and pest damage (Figure 3). This approach has been used to generate the strategies outlined in Table 3. These must be designed for each situation; consequently the particular strategies employed should ideally be selected by the farmer himself, or someone else who is familiar with the area and the operation of the particular farm. Although these approaches could be considerably refined if the money and effort currently directed toward pesticides were used to develop such ecological strategies, I believe that most pests could be brought below the economic threshold with the knowledge that we possess right now; we just need to use it! The history of pest control shows that this ecological approach comprises the only means of achieving long-term control of pests and diseases (Moore 1967). It is significant that the use of pesticides has *not* decreased the percentage loss of crops to pests; it remains at about 33% (May 1977).

Insuring the production of high quality food

One approach to understanding what is happening to food quality is to propose a deductive model (Figure 4) and check whether the evidence supports or contradicts it. The model is based on the concepts of Roger Williams (1971), who argues that cells, and therefore organisms, can only suffer from two nutritional problems: malnutrition and poisoning. Malnutrition occurs when certain nutrients are missing or are not in balance, poisoning when toxins are present. Thus, in order to understand the influence of our food system on food quality we must examine how food production and handling practices might lead to loss of certain essential factors and the addition of various toxins.

Plant production is comprised of the following stages: plant and site selection, planting, maintenance, and harvesting. At every stage of production there is a high chance that nutrients will be lost or toxins added. Plants are selected primarily on the basis of productivity, size, shape, cosmetic appearance, and machine pickability, factors that have nothing to do with food quality. Selection for these characteristics is likely to lead to a reduction in food value.

TABLE 3. Ecological strategies for pest control

1. *Selection of plant*
   Stricter limits on plant introduction.
   More thorough quarantine procedures for introduced plant materials.
   Increase genetic diversity.
   Develop and use resistant varieties.
   Only use healthy seeds and plants, e.g. certified disease-free and from reliable dealers.
   Use varieties suited to your soil and climate.
   Use seeds inoculated with beneficial microorganisms.
   Develop and use varieties able to compete with weeds.
   Develop and use varieties able to grow in mixed culture.

2. *Selection of site*
   Select site, particularly the soil, for its ability to satisfy all the needs of the plant and to avoid pest damage. This requires detailed knowledge of plants, soil, and pests.

   Consider:
   soil type, fertility, structure, and drainage;
   elevation, slope, aspect;
   location in relation to other features of the landscape;
   climate;
   previous history of site, i.e. crop, tillage chemicals, pests.

   Modify site, if necessary, to meet needs of crop.

3. *Planting*
   Include in planting design:
   crop rotation;
   mixed or companion planting;
   management of field borders and other adjacent environments to favor natural controls, e.g. by provision of nursery or trap crops, nesting, and overwintering sites.
   Plant at the best time and in the best way for the plant and the worst time and way for the pest.
   Introduce preventive pest control devices, e.g. tree bands, barriers, pheromone, or other traps.
   Design size and shape of plots to discourage pests.

4. *Maintenance of site*
   General:

   Create and maintain optimum soil conditions for the plant and for beneficial soil and above-ground organisms, and unfavorable conditions for pests, e.g. through appropriate tillage, irrigation, drainage, and application of organic and inorganic amendments and mulches; inoculation of plant and/or soil with beneficial organisms.
   Avoid damaging the plant or stressing it with growth stimulants or toxins, e.g. unbalanced fertilizers, hormones, herbicides, and pesticides.
   Practice good sanitation.
   Prune and thin where and when necessary.
   Monitor pest populations.

TABLE 3. Cont'd.

If pest outbreak occurs:

Remove and destroy pest and/or plant, e.g. picking, jarring.
Cultivate to destroy pests or expose them to predators and sunlight.
Introduce traps and attractants or repellents.
Encourage and/or introduce predators, parasites, pathogens, sterile or genetically incompatible pests (biological controls).
Spray or dust with naturally occurring materials that are: effective; specific and safe; degradable; economic; easy to apply.

5. *Harvesting, distribution, storage, and end-of-season chores*
Time harvesting to avoid late pest attack.
Store only healthy, pest-free produce in optimal conditions for crop and unfavorable conditions for pests.
Destroy crop residues and potential over-wintering sites of pests.
Manage soil during winter to reduce pests and encourage natural controls.

FIGURE 4. Factors that might negatively affect food quality

AGRICULTURAL PRACTICES INVOLVED IN PLANT PRODUCTION

(equivalent practices associated with animal production could be examined in a similar way)

Selection of plant

for nonnutritional factors
e.g. productivity and profit (by hybridization)
cosmetic appearance
shape and size
shelf life
pest and disease resistance
ability to be machine picked

Selection of site

criteria may conflict with nutritional objectives
e.g. economic factors
ease of mechanization

Planting design

may reduce food quality
e.g. monoculture depletes soil of certain plant nutrients

Maintenance of site

cultivation: damage to plant roots may lead to mineral imbalance
irrigation: in drylands may lead to salting up of soil; in other areas to leaching out of nutrients

fertilizer use: use of limited nutrients may cause imbalance in others; N use often increases sugar, water, and NO_3 content of plants
pesticide use: may leave residues of herbicides, insecticides, etc. in crops

Harvesting

may compromise food quality
e.g. picked when unripe
damaged during harvesting

FOOD HANDLING

Transportation

harvesting before ripe to prevent transport damage and contamination

Storage

physical or chemical treatment to:
prevent ripening or to ripen
control pests

Processing

physical and chemical treatment to:
prevent deterioration
make "more attractive"
change the form and flavor

Packaging

contamination with:
PCB's and other chemicals in packaging materials

Preparation

cooking may involve loss of nutrients by:
heat
salting out in oil or water

Consumption

under stress; with other foods that interfere with their assimilation

→

POTENTIALLY NEGATIVE NUTRITIONAL CHANGES

Reductions in certain

amino acids
vitamins
trace minerals
enzymes
flavor factors
and in fiber

Additions

synthetic organic chemicals:
herbicides
insecticides, etc.
growth regulators

natural organic chemicals:
sugars
fats
toxins
antibiotics
hormones
botanical pesticides

inorganic chemicals:
water
nitrates
heavy metals

food additives:
preservatives
colors
flavors
antioxidants, deodorizers
emulsifiers, stabilizers
extenders
modifiers, texturizers
bleaches
acidifiers
clarifiers, etc.

More subtle changes

in the balance between nutrients;
from levo- to dextro-rotary amino acids and certain vitamins;
from *cis* to *trans* fatty acids

A preferable strategy would be to select plants to meet the needs of local populations. More emphasis should be placed on nutritional quality and palatability, as well as resistance to pests and disease, ability to compete with weeds, suitability to local conditions, ability to improve soils, and a low dependence on energy inputs (such as fertilizers, pesticides, and machinery).

Site selection is currently based on climatic and economic factors. Soils are manipulated by tillage and the application of fertilizers and pesticides in order to grow the most economically rewarding crop, regardless of the long-term effects on the soil or the long- or short-term effects on nutritional quality.

The practice of continuous cropping removes many nutrients. Usually one, two, or three of them (N, P, or K) are replaced on the misunderstanding that this will replenish the soil. The use of unbalanced fertilizers may also result in plants being deficient in certain essential amino acids. Crops also remove other essential and trace minerals, which are not returned to the soil in most fertilizer programs. The soils become more deficient in these minerals with time, resulting in plants that are not only lacking the minerals but also those vitamins that depend on the minerals for synthesis.

Most pesticides are synthetic organic poisons that have no counterpart in nature and consequently pose a considerable problem for our bodies, which must detoxify or eliminate them.

The crop is often harvested before ripening so that it may be conveniently picked by machine; hence it is likely to be of inferior nutritional quality.

Food handling involves the addition of numerous chemicals and loss of certain nutrients. Cooking usually results in a further loss of nutrients.

IMPLEMENTING THE PROPOSED CHANGES

Changing from conventional strategies will not be easy. Modern agriculture has become dependent on simplistic chemical solutions to problems, just as heroin addicts have become dependent on their drug. Neither pesticides nor stimulatory drugs treat problems at the causal level.

Because of the addictive nature of the problem, the implementation of alternative strategies will require an enormous cooperative effort involving the general public (consumers), industry and commerce (including producers), researchers (in federal and provincial governments, universities, and industry), communicators (media people, educators, and extension agents), and governments (federal, provincial, and local). The alternative to cooperation is to respond to the crises that will undoubtedly occur with increasing frequency if we continue with the kinds of solutions to problems that are exemplified by the use of agricultural chemicals (Whiteside 1977). Some of the strategies available to governments are laws, regulations, standards, codes, taxation, incentives, education, models, research and development, public participation, policy and planning.

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CONVERSION FACTORS

Metric units	Approximate conversion factors	Results in:
LINEAR		
millimetre (mm)	x 0.04	inch
centimetre (cm)	x 0.39	inch
metre (m)	x 3.28	feet
kilometre (km)	x 0.62	mile
AREA		
square centimetre (cm^2)	x 0.15	square inch
square metre (m^2)	x 1.2	square yard
square kilometre (km^2)	x 0.39	square mile
hectare (ha)	x 2.5	acres
VOLUME		
cubic centimetre (cm^3)	x 0.06	cubic inch
cubic metre (m^3)	x 35.31	cubic feet
	x 1.31	cubic yard
CAPACITY		
litre (L)	x 0.035	cubic feet
hectolitre (hL)	x 22	gallons
	x 2,5	bushels
WEIGHT		
gram (g)	x 0.04	oz avdp
kilogram (kg)	x 2.2	lb avdp
tonne (t)	x 1.1	short ton
AGRICULTURAL		
litres per hectare (L/ha)	x 0.089	gallons per acre
	x 0.357	quarts per acre
	x 0.71	pints per acre
millilitres per hectare (mL/ha)	x 0.014	fl. oz per acre
tonnes per hectare (t/ha)	x 0.45	tons per acre
kilograms per hectare (kg/ha)	x 0.89	lb per acre
grams per hectare (g/ha)	x 0.014	oz avdp per acre
plants per hectare (plants/ha)	x 0.405	plants per acre