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AN ECOLOGICAL APPRAISAL OF AGRICULTURE WITH PARTICULAR REFERENCE TO SOUTHERN ALBERTA

by

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ABSTRACT

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Prepared in partial fulfillment of the requirements for the degree Master of Environmental Design (Environmental Science) in the Faculty of Environmental Design, University of Calgary.

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The developing field of agricultural ecology is reviewed and the features of agricultural ecosystems are discussed. An examination of energy flows, nutrient cycles, and ecosystem development revealed that agricultural ecosystems are characterized by auxiliary energy flows which minimize energy allocated for internal maintenance and maximize energy allocated for production; open cycles of nutrient transfer which result in nutrient loss; and an early stage of ecosystem development which increases susceptibility to pest and disease outbreaks. An analysis of agricultural data for southern Alberta indicated that trends affecting the long-term production of agricultural goods and services in the region are declining soil fertility, expanding dryland salinity, increasing acidity of cultivated soils, and intensified soil erosion. Monoculture and summerfallow are evaluated in detail. A relationship between monoculture and declining soil fertility and increased incidence of pest and disease outbreaks is shown. Summerfallow is associated with a low moisture storage efficiency, reduced soil nitrogen and organic matter content, increased dryland salinity, and an enlarged area exposed to erosion. Suggested areas for further study are designing alternative energy technologies to facilitate the transition to a diversified energy base; investigating energy conservation and efficiency of use to increase the time-span available to develop and implement alternative energy technologies; determining how to balance nutrient transfers to diminish the rate of nutrient loss; determining short and long-term management practices on a site-specific basis to prevent erosion, maintain soil fertility, and reduce pest and disease incidence; and designing mechanisms to implement research findings at the farm unit level.

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My supervisor, Dr. R. Revel, provided much advice, direction and encouragement. Without his support, rudimentary ideas would not have evolved into an "intuitively recognizable and scientifically acceptable" concept. Dr. J. Dormaar and Dr. L. Hills provided valuable suggestions from the inception of this project through to its final draft. The collective support of the entire committee is sincerely appreciated.

To my wife and parents I am most grateful. My parents instilled in me the convictions of creational stewardship. My wife devoted her love and dedication as I strived to give expression to these convictions. It is to her that this project is dedicated.

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CHAPTER 1

INTRODUCTION

1.1 Background

Agriculture can be simply defined as the production and processing of plants and animals for man's use and enjoyment (Winburne, 1962). More specifically, it is the activity of capturing, transforming, and utilizing resources for the production of agricultural goods and services. In this project, agriculture refers to the "on-farm" activities of utilizing and managing resources employed in the production and harvesting of food and fiber, and it does not include aspects relating to processing, distribution, or consumption.

This definition can be expanded by summarizing the aims of agriculture. Duckham and Masefield (1969) state that these are to:

1. optimize inputs (e.g., management, abiotic materials, suitable genotypes)
2. maximize crop plant growth
3. minimize plant and animal wastage
4. obtain an adequate economic return
5. ensure that economic return or food output is reliable from year-to-year and persistent over decades or even longer.

Similar aims are stated by Watt (1973). These are to:

1. maximize production per unit of land in a way con-

sistent with the next three aims

2. operate at a maximum profit
3. minimize year-to-year uncertainty in production
4. function so as to prevent long-term degradation of the productive capacity of the agricultural system.

If production of agricultural goods and services is to be maintained, all the aims of agriculture need to be considered in the decision-making process. Historically, however, this has not always occurred. An aim which has received relatively little research attention is the prevention of long-term degradation of the productive capacity of the agricultural system, so that production of goods and services is reliable and persistent over time. This aim has been inadequately considered mainly because resource allocation in modern agriculture has developed according to the direction of conventional economic analysis aimed primarily at short-term profit maximization (MacKinnon, 1976; Loucks, 1977). Traditionally, this has been achieved by maximizing production per unit land, labour, and capital on a year-to-year basis with little regard to long-term effects such as declining soil fertility.

Thus, profit maximization alone is an inadequate basis for long-term management. Of equal importance is an aim which recognizes that if production is to be reliable and persistent over time, long-term degradation of the productive capacity of the agricultural system must be prevented. This aim requires further assessment.

Two ecological concepts useful to this assessment are stability and the ecosystem. Although stability is a controversial concept in the field of ecology, the problem is one of definition not application. E.P. Odum (1971) has eased much of the controversy by defining stability as the ability to resist perturbations (i.e., disturbances resulting in degradation). It is possible to apply this concept to agriculture by integrating it with the aim of agriculture noted previously. Applied in this sense, stability means resistance to perturbations which induce long-term degradation of the productive capacity of the agricultural system, so that continuous production of agricultural goods and services is maintained.

Tansley (1935) introduced the term "ecosystem" to convey the idea that nature is comprised of systems. A system implies that a structure is maintained by a set of elements interacting together. E.P. Odum (1971: 8) defines the ecosystem within the context of a system as follows: "Any unit that includes all of the organisms (i.e., the community) in a given area interacting with the physical environment so that a flow of energy leads to a clearly defined trophic structure, biotic diversity, and material cycles (i.e., exchange of materials between living and nonliving parts) within the system is an ecological system or ecosystem."

The ecosystem concept provides a systematic approach to agriculture. Greater reliance is placed on a knowledge of the elements and interactions within an agricultural system, so that the consequences of any action can be predicted. More specifiically, the ecosystem concept provides a mechanism to:

1. identify and delineate various types of agricultural systems
2. define various components of the system and analyse interactions between these components
3. evaluate change, fluctuation, or intervention within the system
4. assess long-term stability by forecasting long-term degradation of the productive capacity of the system.

Therefore, the ecosystem concept provides an improved information base upon which to make long-term decisions, as compared to resource allocation based on conventional economic analysis aimed primarily at short-term profit maximization.

1.2 Project Description

An assessment of the long-term stability of agricultural systems, based on the ecosystem as the underlying concept, provides the focus of study in this project. As part of the total information which is integrated into the decision-making process, it can help one determine the optimal strategy for achieving all of the aims of agriculture, as opposed to achieving any one of them in isolation.

Information necessary for this assessment is available but widely dispersed. Minimal effort has been directed toward its assimilation and synthesis. Much information is inaccessible or in a form incomprehensible to the layman. Therefore, the overall objectives of this project are as follows:

1. to undertake a broad integrative survey of the literature pertaining to long-term stability of agricultural systems
2. to assimilate and synthesize this information in a form comprehensible to the layman
3. to identify issues and areas of concern requiring further study.

Two fundamental assumptions are recognized. First, agricultural systems are, in essence, ecological systems (ecosystems) implying that they can be described and understood in terms of their ecological function and structure. (The term "agricultural ecosystems" is used to express this relationship.) Second, based on the first premise, it follows that agricultural ecosytems are subject to the principles of ecology and, therefore, are amenable to ecosystem management techniques. Based on these assumptions, the specific objectives of this project are as follows:

1. to discuss the concept of the agricultural ecosystem
2. to review the basic ecological function and structure of the agricultural ecosystem
3. to conduct an ecological appraisal of selected agricultural practices in southern Alberta in order to

assess their effect on the long-term production of agricultural goods and services in that region.

An approach based on a review, assimilation, and synthesis of the literature is employed. Information sources include scientific publications, census statistics, unpublished data, and personal communications. An important constraint is that the task of assimilation and synthesis is hindered by a lack of quantitative data specifically derived from site-specific studies. A similar constraint was identified by Eckholm (1976: 22): "Precise figures on ecological trends and their impact on agricultural systems are scarce. This does not make the trends any less real or menacing, it does suggest the exceptional difficulty of isolating and measuring these factors." In this project, areas where quantitative information are lacking are identified and direction to future research given.

For the purpose of organization, this document can be divided into two parts. The first four chapters broadly examine the application of ecological concepts to agriculture. The latter three chapters focus on southern Alberta as a study area and identify specific constraints to the long-term production of agricultural goods and services. Two prevalent cropping practices, monoculture and summerfallow, are reviewed in detail. Each chapter is briefly outlined below.

Chapter two briefly describes the developing field of agricultural ecology. Since the agricultural ecosystem forms the basic unit of study in agricultural ecology, its features are outlined. The analysis of agricultural ecosystems is briefly discussed.

Chapter three reviews the ecological function and structure of agricultural ecosystems. A survey of energy flows in primitive and modern agriculture demonstrates man's increasing control of these flows. Attention is focused on the modern energy-subsidized agricultural ecosystem with particular reference to the food production systems of Canada, Great Britian, and the United States. Only a cursory review of nutrient cycles in agricultural ecosystems is presented because of information constraints and the discussion is centered on Frissel's model of nutrient cycling. The attributes of the strategy of ecosystem development, as outlined by E.P. Odum (1971), serve as a useful model to describe the ecological structure of agricultural ecosystems.

Several ecological concerns which may affect the long-term stability of agricultural ecosystems are highlighted in chapter four. These concerns include the problem of diminishing returns of energy subsidies, disruption of nutrient cycles resulting from constant removal of nutrients, and a trend toward ecological simplicity (low crop diversity, and low pattern or spatial diversity).

Chapter five describes southern Alberta as the study area. Data presented demonstrate that a finite quantity of good arable land has resulted in an intensification of inputs which, in turn, has increased production significantly. Several constraints are reviewed which suggest that the long-term production of agricultural goods and services may be adversely affected.

Chapter six focuses on monoculture as a cropping practice in southern Alberta. The concept of monoculture is briefly outlined and its extent is exemplified in the proportion of the total crop area in wheat. The effects of monoculture on soil fertility, incidence of insect pests, and disease incidence are discussed.

The practice of summerfallow is investigated in chapter seven. Its extent in southern Alberta is exemplified in a manner similar to that employed for monoculture. The effects of summerfallow on soil nitrogen and organic matter, soil moisture, dryland salinity, and soil erosion are reviewed. Alternatives to summerfallow are briefly discussed.

Chapter eight provides a summary and suggests further areas of study.

CHAPTER 2

AGRICULTURAL ECOSYSTEMS

Agricultural ecology is a developing field emerging out of agricultural science and ecology. The agricultural ecosystem is its major unit of study and ecosystem analysis its major tool of study.

2.1 Agricultural Ecology

Agricultural ecology suggests a relationship between the fields of agricultural science and ecology. The practice of agriculture has existed since the domestication of plants and animals - a period of about 6,000 years - but it was not until the mid - 1800's that the study of agriculture was accepted as a scientific discipline (Mayer and Mayer, 1974). Ecology developed as a scientific discipline during the same period. It is derived from the Greek word "oikos" or "home of man" and by extension has come to mean the study of interrelationships between organisms and their environment (Major, 1969).

The relationship between agriculture and ecology has been described by several authors. Moore (1920) contended that essentially all agricultural research is ecological in character because it is concerned with plants and animals (i.e., organisms) within the context of their environment. Azzi (1956) suggested that the developing field of agricultural ecology could provide a unifying link between meteorology and soil science which form the basis of agricultural science. He defined agricultural ecology as "... the study of the physical characteristics of environment, climate and soil, in relation to the development of agricultural plants, and to the yield of such plants from the quantitative (amount of the product), qualitative (quality of the product) and generative (characters of the seed) points of view" (Azzi, 1956: xiii). Winburne (1962) proposed the term agroecology to denote the relationship between agricultural crops and their environment. Cox and Atkins (1975) broadened the definition of agricultural ecology to the examination of food production activities in the context of the world ecosystem. The objective is to examine agriculture in as broad a temporal and spatial context as possible. Two general assumptions are proposed. First, the systems from which man obtains food are ecosystems. Second, different human food production systems are interrelated by common energy and nutrient pathways.

In this document, agricultural ecology refers to the study of the application of ecological concepts and principles to the production of agricultural goods and services. The basic unit of study is the agricultural ecosystem. The objective is to prevent, mitigate, or rehabilitate long-term degradation of the productive capacity of the agricultural ecosystem, so that continuous production of agricultural goods and services is maintained.

2.2 Agricultural Ecosystems

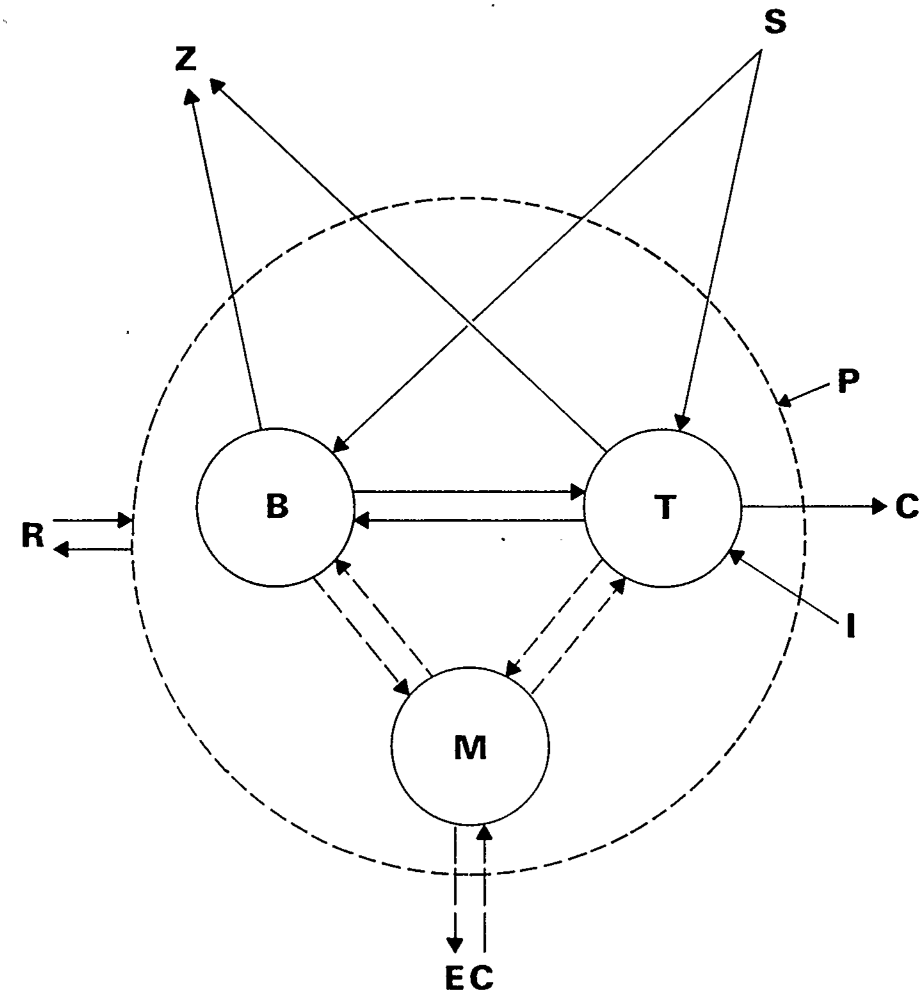
Since the agricultural ecosystem is the basic unit of study in agricultural ecology, it requires elaboration.

An agricultural ecosystem is frequently defined in simple and broad terms as a geographic unit in which agriculture is a predominant activity. A more comprehensive definition sometimes sacrifices usefulness for precision but it does provide a less ambiguous connotation. Such a definition should include within it the notions of management of resources to a greater or lesser extent by man, organization or structure of component parts, and production of agricultural goods and services.

Of the literature surveyed, only two reports present comprehensive definitions of agricultural ecosystems. Smith and van den Bosch (1967: 300) define an agricultural ecosystem as "... a unit composed of the total complex of organisms in the crop area together with the overall conditioning environment as modified by the various agricultural, industrial, social, and recreational activities of man." This definition emphasizes the reciprocal relationship between organisms and the environment, particularly as affected by man, but does not explicitly include the notions of organization or production. Frissel (1978: 17) defines an agricultural ecosystem as "... a recognizable part of the biosphere, affected or determined to a certain degree by agricultural practices, and deriving its properties and features from those of its structural components and, most typically, from interactions between those components." In this definition, the notions of management and organization are apparent but the notion of production is indistinct.

Both of the above definitions are characterized by shortcomings. Thus, for the purpose of this project, an agricultural ecosystem is a geographical unit in which abiotic (e.g., energy, nutrients, moisture) and biotic (e.g., producers, consumers, decomposers) resources are channeled, directed, and/or arranged by various forms and degrees of agricultural activities into an ecological structure or system for the production of agricultural goods and services.

For clarification, it is useful to briefly consider the agricultural ecosystem as discussed theoretically by MacKinnon (1976). Figure 2-1 depicts an agricultural ecosystem consisting of interacting biological, technical, and management systems. The biological system (B) consists of plant, animal, and abiotic components. The technical system (T) consists of building and machinery components. The management system (M) provides overall control of all components and their interactions. Energy and information flows represent major interactions in the production system (P). Solar energy (S) is captured by both B (e.g., photosynthesis) and T (e.g., passive heating of buildings) systems which, in turn, release thermal energy (Z). Energy is exchanged between systems B and T during tillage operations and regulation of plant/animal environments. Energy from the agricultural industry (I) enters system T and is exchanged with system B as required. Both systems B and T interact with the local ecosystems



LEGEND

P - PRODUCTION SYSTEM
M - MANAGEMENT SYSTEM
I - INDUSTRY
S - SOLAR ENERGY
EC - SOCIO-ECONOMIC INFORMATION
B - BIOLOGICAL SYSTEM
T - TECHNICAL SYSTEM
C - CONSUMPTION
Z - HEAT SINK
R - LOCAL ECOSYSTEM

—— ENERGY FLOW
--- INFORMATION FLOW

FIG. 2-1. COMPONENTS OF AN AGRICULTURAL ECOSYSTEM (MACKINNON, 1976)

(R) (e.g., climate). The entire food production system produces agricultural goods and services for consumption (C). Interactions between the management system (M) and systems B and T are represented by information flows. These flows are evident in the transfer of socio-economic (EC) information (e.g., market supply and demand) and continuous interaction between system M and systems B and T.

The above model is a simple but useful representation of agricultural ecosystems because it is based on the ecosystem as the underlying concept. It delineates and defines a specific arrangement of components and identifies major interactions between them. These components and interactions can be quantified to determine overall system performance (e.g., energy efficiency, nutrient budgets). This analysis permits change, fluctuation, or intervention into the system to be evaluated in terms of the long-term stability of the agricultural ecosystem.

2.2.1 Features of Agricultural Ecosystems

Agricultural ecosystems are natural resource ecosystems, as distinct from natural ecosystems. This distinction is not always clear implying that a continuum exists between them. Spurr (1969) states that natural ecosystems and natural resource ecosystems function under the same ecological principles but they differ in that the goal of a natural resource ecosystem is the production of goods and services for direct or indirect use by man. Management is an implicit component of this goal and, therefore, is a feature common to all agricultural ecosystems. Southwood and Way (1970) and Apple (1977) summarize additional features that generally distinguish agricultural ecosystems from natural ecosystems. These features are outlined below:

1. continuity - agricultural ecosystems are not self-perpetuating and their production cycles are of limited but variable duration ranging from several months for cereal crops to decades for orchards. Natural ecosystems are self-perpetuating; some are virtually permanent (e.g., climax forest) and others (e.g., seral stage) are more temporary but generally continuous in space.
2. selection of vegetation - natural ecosystems evolve vegetation through natural selection in response to local climatic and edaphic conditions and the biotic potential of an area. Man selects for cultivated species in agricultural ecosystems, promoting their propagation and protecting them from inter and intra-specific competition, predation, and parasitism. Cultivated species may be more susceptible to extreme variations in climate than the vegetation of natural ecosystems.
3. species diversity (vascular plants) - agricultural ecosystems usually contain lower species diversity per unit area than natural ecosystems in comparable environments and are commonly characterized by a

trend toward monoculture (see chapter 6). Some natural ecosystems also consist of relatively pure stands of one or two species, particularly in extreme climates (e.g., high arctic polar desert ecosystems)

4. intra-specific diversity - planting practices ensure that vegetation in agricultural ecosystems is of a uniform age; likewise, varieties planted are generally genotypically and phenotypically similar resulting in synchronized germination, leaf development, flowering, and maturation.
5. nutrient and water supply - through fertilizers and irrigation, nutrient and moisture levels can be increased to the point where neither may act as a limiting factor in agricultural ecosystems.
6. pest and disease outbreaks - ecological theory and limited evidence support the proposition that lower species diversity in agricultural ecosystems encourage outbreaks. (See chapter 6.)

The above features distinguish most but not all agricultural ecosystems. Exceptions occur because of variations in the degree of management intensity between and within agricultural ecosystems. For example, a native range ecosystem, characterized by a low degree of management intensity, is normally self-perpetuating and exhibits a high floral diversity relative to an intensely managed cereal ecosystem composed of a monoculture crop.

2.3 Analysis of Agricultural Ecosystems

An agricultural ecosystem requires delineation of its boundaries for analytical purposes. Boundaries of natural ecosystems are usually delineated on the basis of climate, vegetation, soil, topography, or a combination thereof, but a similar basis for delineating the boundaries of agricultural ecosystems is inadequate. This is because the agricultural ecosystem is a management unit. The boundaries of a management unit rarely coincide with the perimeter of natural features but rather parallel political or socio-economic boundaries. Thus, an agricultural ecosystem is commonly represented by a single farm unit. This is significant because the farm unit serves as a base for generating information and making decisions.

An analysis of agricultural ecosystems requires that the variables (components) of the system, the processes operating on them, the parameters regulating the processes, the inputs and outputs, and the external environmental influences operating on the system all have to be identified, quantified, and evaluated (Loucks, 1977). Modelling is commonly employed as a technique to analyse natural resource ecosystems. However, despite more than a decade of ecosystem analysis (Van Dyne, 1969), virtually no effort has been made to develop a comprehensive model of the ecological properties of agricultural ecosystems (Loucks, 1977).

The absence of such a model can be attributed to an imbalanced approach to the analysis of agricultural ecosystems. For example, Van Dyne and Abramsky (1975) extensively reviewed more than 75 models of agricultural systems. Most models focused on management aspects (e.g., decision-making, economic returns), some focused on production aspects (e.g., crop growth, animal weight gain), and very few models focused on ecological aspects (e.g., pest control, energy flows, nutrient cycles). Spedding's (1975) model of agricultural systems is indicative of this imbalanced approach. The model is descriptive and based on concentric circles of which the center indicates the desired input/output ratio. All other factors (e.g., growth rates, market conditions, labour) are arranged in concentric circles such that importance and distance from the center are positively related. The main objective of the model is to improve the input/output ratio, usually with emphasis on reducing costs, improving marketability, and broadening income opportunities.

A more comprehensive analysis at the ecosystem level is required. Harper (1974) describes this analysis as the science of agro-ecosystems to emphasize an approach which recognizes that each component of an agricultural ecosystem is part of a whole and that the whole itself must be a subject of study. Harper (1974: 2) states that "A strong science is a predictive science and the strength of a science of agro-ecosystems must be proved by its development to a stage at which it becomes possible to predict interactions between and within ecosystems." Loucks

(1977) concludes that the time is ripe for such a science and that future research will be directed toward the long-term stability of agricultural ecosystems.

CHAPTER 3

FUNCTION AND STRUCTURE OF AGRICULTURAL ECOSYSTEMS

Agricultural ecosystems can be described in terms of their function and structure, both of which are greatly affected by human decisions. E.P. Odum (1968) refers to function as the:

1. range of energy flow through the system
2. rate of material cycling
3. regulation by physical environment and by organisms;

and to structure as the:

1. composition of the biological community (i.e., species number, biomass)
2. quantity and distribution of abiotic materials
3. range or gradient of conditions (e.g., light, water).

The function of agricultural ecosystems is discussed below in terms of energy flows and nutrient cycles; structure is discussed in terms of the attributes of ecosystem development.

3.1 Energy Flows in Agricultural Ecosystems

Agricultural ecosystems are commonly characterized by auxiliary energy flows or energy subsidies. E.P. Odum (1971: 45) defines an energy subsidy as "Any energy source that reduces the cost of internal self-maintenance of the ecosystem, and thereby increases the amount of other energy that can be converted to production..." This definition can be made more specific by referring to the cost of internal self-maintenance of the primary producers rather than the ecosystem because plants are the main agents of energy utilization and production. More specifically, an energy subsidy reduces the cost of internal self-maintenance of the primary producers and converts a greater amount of available energy into net primary production. Examples of energy subsidies include fertilizers, mechanization, irrigation, and pest and disease control.

Agricultural ecosystems characterized by energy subsidies can be described as energy-subsidized agricultural ecosystems. Their energy flows are distinct from that of primitive agricultural ecosystems.

3.1.1 Energy Flows in Primitive and Modern Agriculture

Man's control of energy flows in agricultural ecosystems has increased, as evidenced in the evolution of primitive agriculture into modern agriculture. This evolutionary process reflects man's effort to minimize energy allocated for internal maintenance and maximize energy allocated for production.

H.T. Odum (1971) has compared energy flows in primitive and modern agriculture. Figure 3-1 is an energy network diagram with average energy flow rates for a primitive agricultural ecosystem common to the Dodo tribe in Uganda. This tribe subsists on both animal products (milk, blood, meat) and grain crops. The only energy source is the sun which supplies about 1,460,000 kcal/m^2/yr. Much more energy enters the animal production process (1,299,000 kcal/m^2/yr) than the grain production process (161,000 kcal/m^2/yr) but the former contributes significantly less net energy (0.2 kcal/m^2/yr) than the latter (19.5 kcal/m^2/yr). This is because the animal production process has an additional order of consumers which require large quantities of energy for metabolism, grazing, protein production, and reproduction. The net energy output available to man is 19.7 kcal/m^2/yr. Human energy (6.9 kcal/m^2/yr) is returned in the form of shepherding and tilling.

Primitive agriculture rapidly evolved into modern energy-subsidized agriculture with the advent of fossil fuel. A simplified energy circuit of an energy-subsidized agricultural ecosystem is shown in Figure 3-2. Although the major energy source is

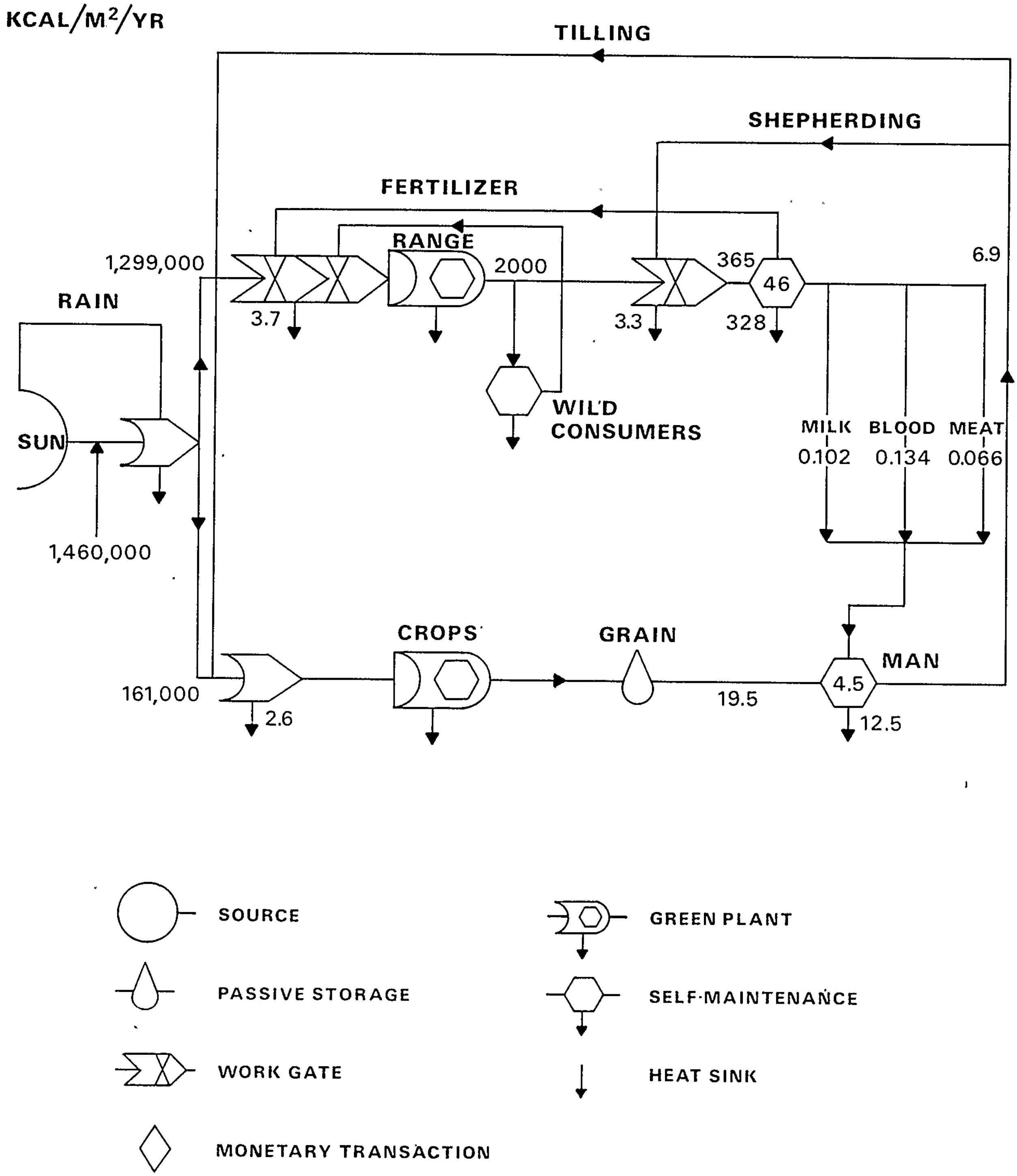


FIG. 3-1. ENERGY FLOWS IN A PRIMITIVE AGRICULTURAL ECOSYSTEM (H.T. ODUM, 1971)

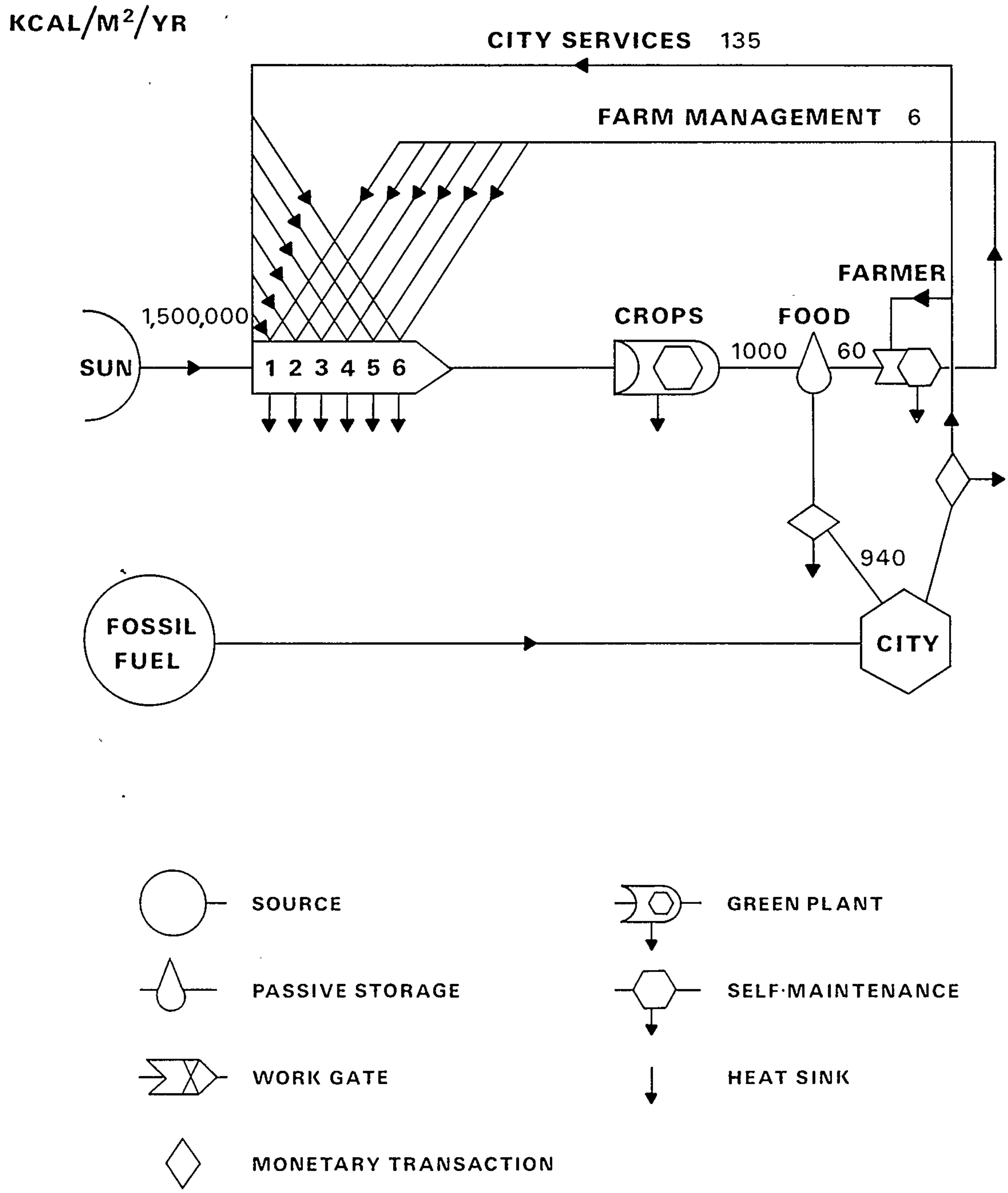


FIG. 3-2. ENERGY FLOWS IN AN ENERGY-SUBSIDIZED AGRICULTURAL ECOSYSTEM (H.T. ODUM, 1971)

the sun (1,500,000 kcal/m^2/yr), an auxiliary energy source is provided by fossil fuel. This is distributed by centralized industrial-marketing systems (cities) and supplies about 135 kcal/m^2/yr. Work done by fossil fuel is evident in such agricultural activities as 1) tillage for seedbed preparation, 2) mechanized planting, 3) addition of nutrient supplements, 4) chemical and mechanical control of weeds, 5) chemical control of insect pests and disease organisms, and 6) mechanized harvest. These activities enable crops to convert more available energy into net energy output. Figure 3-2 shows that crops produce a net energy output of 1000 kcal/m^2/yr of which 940 kcal/m^2/yr is available to the city and 60 kcal/m^2/yr is available to the farmer. This output is 50 times that produced by crops (19.5 kcal/m^2/yr) in the primitive agricultural ecosystem of the Dodo tribe. However, it should be noted that a significant portion of the crops produced in energy-subsidized agricultural ecosystems is usually consumed by livestock resulting in a much lower total net energy output. It is generally recognized that the flow of energy through an ecosystem is reduced in magnitude by ten from one trophic level to another (E.P. Odum, 1971; Smith, 1974).

Energy flows in primitive and modern agriculture can also be distinguished by energetic efficiency. The energy ratio (Er) is frequently used to express energetic efficiency and is a measure of the ratio of energy flows calculated by dividing the total energy output by the total energy input.

Energy accounting in agriculture has recently emerged as an intense area of research (Leach, 1976; Lockeretz, 1977; Timbers, 1977). Energy ratios have been calculated for many types of agriculture. Some of these are summarized in Table 3-1. Five broad categories of different types of agriculture ranging from primitive hand cultivation to modern energy-subsidized agriculture are shown for various locations. The energy input and output and energy ratio (Er) are presented for each type. The data reveal that modern agriculture has a lower energetic efficiency than that of more primitive forms of agriculture. For example, the energy ratios of corn (2.8), wheat (2.5), and barley (2.4) produced under modern agriculture are significantly lower than that of rice (34) and sorghum (20) produced under hand cultivation. Similarly, rice produced under modern agriculture in Hong Kong has an energy ratio of 0.8 compared to a ratio of 15 for rice produced under a draught animal system in India. Energy inputs and outputs have generally increased many times since primitive agriculture but energy ratios have declined to the point where the ratio of some intensively-grown crops is approaching one and the ratio of some intensively-grown crops (rice, sugar-beet) is already less than one indicating that energy input is greater than energy output. For example, energy input into sugar-beet production in Great Britian is 33 per cent greater than energy output.

Table 3-1. Energy Ratios for Various Types of Agriculture

TYPE OF AGRICULTURE	LOCATION	CROP	INPUT (kcal x 103/ha)	OUTPUT	Er	REFERENCE
Hand Cultivation	Sarawak	dryland rice	76	2584	34	Black (1971)
	Gambia	sorghum	24	483	20	Black (1971)
Swiddening	New Guinea	taro-yams	124	2102	17	Rappaport (1971)
	New Guinea	sweet potato	116	1825	16	Rappaport (1971)
Draught Animals	India	rice	167	2472	15	Black (1971)
	North Vietnam	rice	329	4612	14	Leach (1976)
Early Mechanized	U.S.A.(1)	corn	926	3427	3.7	Pimental (1973)
	U.S.A.(2)	corn	1206	3830	3.2	Pimental (1973)
Modern	U.S.A.(3)	corn	2895	8165	2.8	Pimental (1973)
	Canada(4)	wheat	698	1733	2.5	Thompson& Gimby (1979)
	Britain	barley	3740	8885	2.4	Leach (1976)
	Britain	potato	8640	13590	1.6	Leach (1976)
	Hong Kong	rice	16470	13575	0.8	Leach (1976)
	Britain(5)	sugar-beet	29711	19799	0.7	Leach (1976)

(1) for the year 1945
(2) for the year 1950
(3) for the year 1970
(4) data given is for one Saskatchewan farm only
(5) includes energy for refining sugar

3.1.2 Energy in Modern Food Production Systems

Several studies have analysed energy use in modern food production systems. Pimental _et al_. (1973) assumed an input-output model based on corn production to be representative of energy intensive agriculture in the United States. They found that, with the exception of on-farm labour, energy inputs increased significantly between 1945 and 1970. Nitrogen fertilizer input increased 16 times during this period. Despite these increases, the energy ratio for corn production declined from 3.7 in 1945 to 2.8 in 1970.

In a subsequent study, Steinhart and Steinhart (1974) extended the findings of Pimental _et al_. (1973) to the entire food production system of the United States. Their analysis showed that modern food production systems require five to ten calories of energy subsidy to obtain one food calorie. Similarly, Hirst (1974) calculated that 6.4 calories of energy subsidy are required to produce one calorie of food energy.

A comparison of energy flows in the modern food production systems of Canada, Great Britian , and the United States is shown in Table 3-2. Total energy input into British agriculture (90.4 kcal x 10^{15}) is slightly higher than that of Canadian agriculture (85.6 kcal x 10^{15}). However, agriculture in the United States consumes (526.1 kcal x 10^{15}) about six times as much as Canadian agriculture, reflecting a much larger agricultural land base. In terms of energy intensity, measured as energy input per hectare, British agriculture is most intensive, followed by Canada and the

Table 3-2. Energy Use in Three Selected Food Production Systems

ENERGY INPUT	CANADA (1)	GREAT (2) BRITIAN (kcal x 1015)	UNITED (3) STATES
Direct			
fuel	26.1	16.7	231.9
electricity	0.2	7.1	63.8
other		2.1	
Indirect			
fertilizer	41.9	19.6	93.9
machinery	1.3	7.6	79.9
buildings & steel	2.0	5.4	2.0
other	14.1	31.9	54.3
Total Energy Input	85.6	90.4	526.1
Total Energy Output	274.8	31.1	89.4
Energy Ratio(4)	3.2	0.34	0.17
Energy Input/ hectare (kcal/ha)(5)	5.2	19.4	4.9

(1) Data is for the year 1971. Adapted from Downing and Feldman (1974). See also Timbers (1977).

(2) Data is for the year 1968. Adapted from Leach (1976). See also Blaxter (1974).

(3) Data is for the year 1970. Adapted from Steinhart and Steinhart (1974) and Hirst (1974). See also Heichel (1976).

(4) Energy Ratios are not directly comparable. See text for explanation.

(5) Total farmland for Canada, Great Britian, and the United States during each year in which data is given is 68.7, 19.5, and 446.2 million hectares, respectively (Statistics Canada, 1975; Central Office of Information, 1979; U.S. Department of Commerce, 1978).

United States.

The energy ratios shown in Table 3-2 are not directly comparable. The Canadian energy ratio (3.2) is derived mainly from primary production of field crops, particularly prairie cereals. In contrast, Leach (1976) and Steinhart and Steinhart (1974), in calculating the energy ratios of British (0.34) and American (0.17) agriculture, respectively, also included energy inputs consumed in secondary production (e.g., meat, poultry, and dairy products). Thus, their calculations are based on an additional level in the food chain which consumes about 90 per cent of the energy fixed as primary production (E.P. Odum, 1971; Smith, 1974). This is the main factor affecting the low energy ratios of the American and British food production systems.

A more complete analysis of all energy flows in the Canadian food production system would likely yield similar ratios. Preliminary estimates by the Science Council of Canada (1976) indicate that Canadian field grains and hay crops return 11 calories of food for one calorie of input (11:1); secondary foods such as meat, milk, and eggs are about one-tenth as efficient (1:1), and processed foods reduce energy efficiency another 10-fold (1:10).

3.2 Nutrient Cycles in Agricultural Ecosystems

Nutrient cycles follow the same pathways as energy, passing from one trophic level to another, however, nutrients are recycled to varying degrees, whereas energy is ultimately dissipated. Nutrient cycles are traditionally explained as consisting of a series of compartments and transfers between those compartments. The sequence: soil to plants to animals to soil constitutes a simple representation of a nutrient cycle. Practically, however, there are many more compartments and transfers.

Despite numerous agricultural studies on the relationship between nutrients and yields, patterns of nutrient cycling within agricultural ecosystems are still insufficiently understood (Loucks, 1977). Generally, nutrients are channeled and directed away from the relatively closed cycles that characterize natural ecosystems. Open cycles of nutrient transfer are prevalent and these are prone to losses. One source of loss is the export of harvestable products across the boundaries of the agricultural ecosystem; where they are subsequently consumed and rarely returned to the point of origin. Harper (1974) states that, if productivity is to be maintained, it is necessary to replenish nutrients removed in cropping, or lost through other processes (e.g., leaching). However these nutrients are replenished, whether at levels to balance losses, or at rates designed to increase crop production, the intervention does not correspond to the closed character of nutrient cycles in natural ecosystems. The addition of nutrients can result in changes in the agricultural ecosystem itself, such as alterations in soil acidity or modified population structures of soil organisms, and it can also affect neighbouring ecosystems into which excess nutrients enter by leaching or runoff.

Agricultural ecosystems have relatively rapid nutrient exchange rates which increase the concentration of available nutrients. This concentration is amplified by cultural practices. For example, continuous stirring and breaking up of the soil intensifies soil nitrification to the degree that nitrate may accumulate in cultivated soils at a rate three times that of undisturbed grassland soils (Smith, 1974). Legumes and fertilizers are additional sources which increase the supply of available nutrients.

3.2.1 Frissel's Model of Nutrient Cycling

Models of nutrient cycling are readily available for each nutrient. However, nutrient flow models on an ecosystem basis are commonly lacking. Such an approach requires a definition of the boundaries of the ecosystem, a quantification of nutrients crossing those boundaries, a knowledge of the elements and their chemistry, and an understanding of the cycle's compartments and transfers between those compartments.

Frissel (1978) has outlined a model of nutrient cycling in agricultural ecosystems (Figure 3-3). This flow-diagram reveals the transfer of nutrients between three major compartments: plants, livestock and soil; the latter is subdivided into avail-

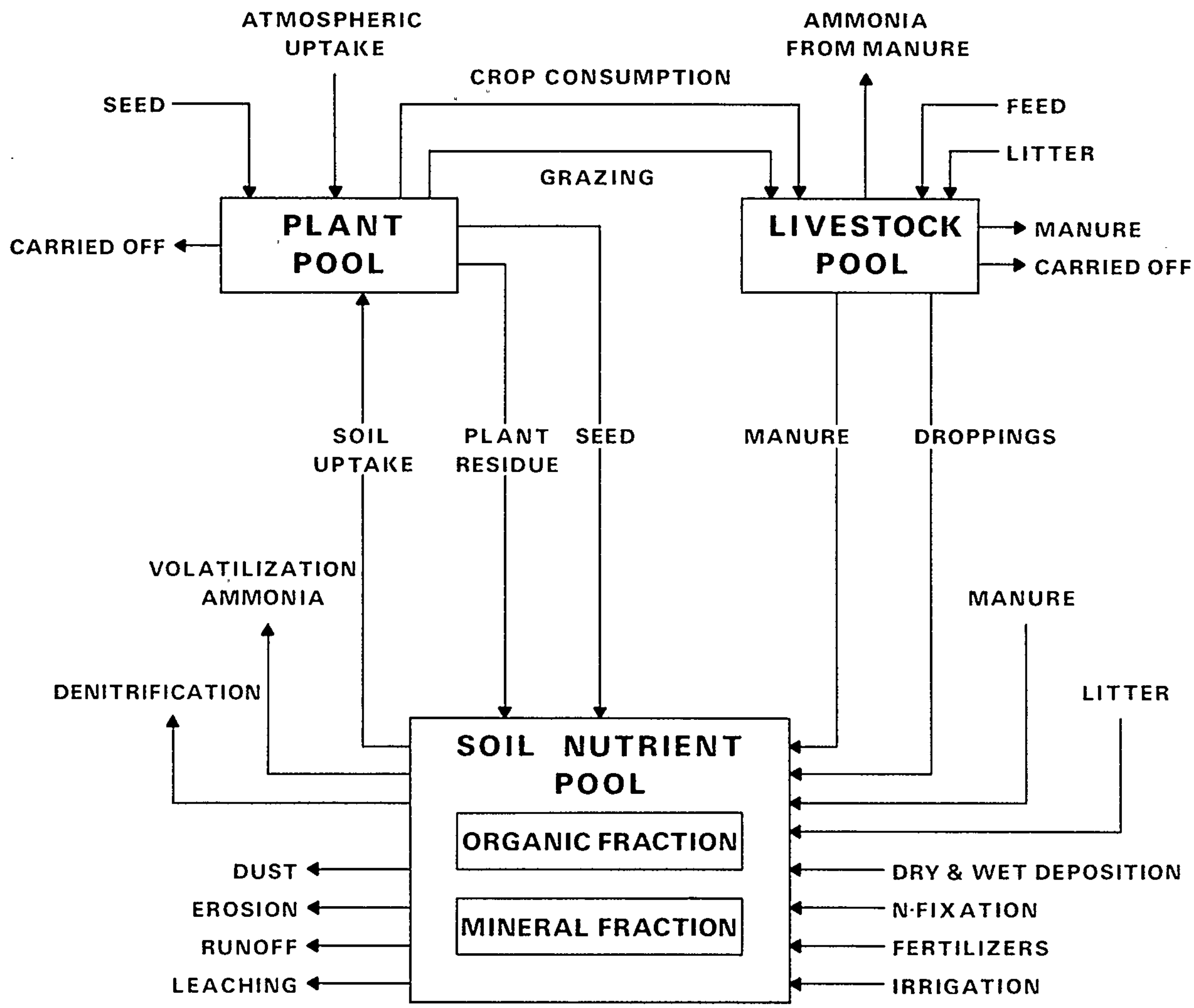


FIG. 3-3. NUTRIENT CYCLING IN AGRICULTURAL ECOSYSTEMS (FRISSEL, 1978)

able organic and mineral pools. In most agricultural ecosystems nutrients spend only a small portion of the overall cycle time in the plant compartment because of regular cropping or grazing. Nutrients remain in the vegetation of natural ecosystems for considerably longer periods of time. The livestock compartment retains a very small part of the total amount of nutrients consumed because most are passed on to the soil compartment as excreta. Plants obtain their nutrients from the available soil pool completing the cycle.

The three major nutrients, nitrogen (N), phosphorus (P), and potassium (K) are transferred between the compartments by various pathways (Figure 3-3). These transfers differ in rates by several orders of magnitude. The rate of transfer may vary from minutes in exchanges involving micro-organisms, to months for uptake and growth by annual crops, to years for intake and growth of livestock, and to thousands of years for transfers involving the physical environment (e.g., weathering of rock).

Three types of nutrient transfer are apparent in Figure 3-3. These are 1) inputs into the agricultural ecosystem (e.g., feed, seed, fertilizer), 2) outputs from the agricultural ecosystem (e.g., plant and animal products carried off for consumption, leaching), and 3) transfers between compartments within the agricultural ecosystem (e.g., grazing, plant residue, manure). The amount and rate of nutrient transfer is strongly affected by external and internal conditions and processes. Externally, control is exerted primarily by the physical environment. For example, solar energy regulates photosynthesis, microbial processes are temperature dependent, and water acts as a transport medium. Internally, control is exerted primarily by the ability of the compartments to respond to forces and fluctuations in the physical environment. For example, transfers are affected by the rates of volatilization, leaching, fixation and crop uptake, and on the conditions of aeration, acidity and temperature.

Frissel's (1978) study of nutrient cycles in agricultural ecosystems is the most comprehensive to date. Extensive quantitative data are given, analysed, and classified for 65 agricultural ecosystems, usually the size of single farm units. The model outlined above is the basis of analysis. A quantitative summary of nutrient flows in an agricultural ecosystem characterized by intensive wheat production and located in central Kansas is shown in Table 3-3. Transfers of NPK, measured in kg/ha/yr, are indicated for the plant and total soil components. Since there are no livestock, the livestock component of the nutrient cycle is by-passed.

Table 3-3 shows that the supply and removal of nutrients in the plant component is in a state of balance. For example, the uptake of nitrogen from the soil (56 kg/ha/yr) equals that removed by primary products (36 kg/ha/yr) and plant residue (20 kg/ha/yr). The supply and removal of nutrients in the total soil component is not in a state of balance. The nitrogen and potassium transfers are characterized by net losses (10 kg/ha/yr and 14 kg/ha/yr, respectively) whereas the phosphorus transfer is

Table 3-3. Nutrient Flows in an Agricultural Ecosystem, Central Kansas (Frissel, 1978)

Component	N	P	K
	Nutrient (kg/ha/yr)		
Plant Component			
Supplies: input by seed	-	-	-
: transfer by net uptake from soil	56	10	50
: input from atmospheric uptake	-	-	-
Subtotal	56	10	50
Removals: transfer by crop consumption	-	-	-
: transfer by grazing	-	-	-
: output of primary products	36	7	6
: transfer by plant residue	20	3	44
: transfer by seed	-	-	-
Subtotal	56	10	50
Supplies-Removals	0	0	0
Total Soil Component			
Supplies: transfer by manure application	-	-	-
: transfer by droppings	-	-	-
: input by manure application	-	-	-
: input by fertilizers	34	13	0
: input by N-fixation	-	-	-

(continued)

Table 3-3. (continued)

Component	N	Nutrient P (kg/ha/yr)	K
: input by litter (sludge)	-	-	-
: input by dry and wet deposition	6	0.1	2
: transfer by plant residue	20	3	44
: transfer by seed	-	-	-
: input by irrigation	-	-	-
Subtotal	60	16.1	46
Removals: output by denitrification	5	-	-
: output by volatilization	-	-	-
: output by leaching	4	-	5
: output by nutrient runoff	1	3	5
: output by dust	-	-	-
: output by organic matter runoff	4	-	-
: transfer by plant uptake	56	10	50
Subtotal	70	13	60
Supplies-Removals	-10	+3.1	-14

characterized by a net gain (3.1 kg/ha/yr). Nutrients are supplied mainly by fertilizer and plant residue and removed primarily by plant uptake.

Application of Frissel's model to the 65 agricultural ecosystems studied by Frissel (1978) reveals that intensive agriculture is characterized by a high turnover rate of nitrogen (i.e., a high exchange rate) which depends on the addition of external nutrients for its supply. Nitrogen fixation is frequently completely suppressed as a result of high nitrogen fertilizer applications. Thus, biologically fixed nitrogen is less pronounced in intensive agriculture than in any other type.

Conversely, extensive forms of agriculture, characterized by no or minimal additions of external nutrients, depend on the decomposition of the organic soil fraction which was formed prior to the conversion of agriculture. Here nitrogen is often limited by the amount of available nitrogen in reserve in the soil organic pool. Once reserves are depleted the alternative is abandonment or intensification of fertilizer inputs.

3.3 Structure of Agricultural Ecosystems

The design of an agricultural ecosystem that is adapted to its environment is a fundamental and foremost objective of any farming system (MacKinnon, 1976). This design is directed toward an optimal fit between genotype and environment such that the environment is modified to fit the genotype or the genotype is modified to fit the environment (Snaydon and Elston, 1976).

Except for the source of innovation (man), this process of adaptation is similar to that for natural ecosystems. In ecology, this adaptation process is commonly known as ecological succession or ecosystem development.

3.3.1 Ecosystem Development in Agricultural Ecosystems

E.P. Odum (1969, 1971) has outlined in detail the strategy of ecosystem development in natural ecosystems. He defines ecosystem development in terms of three parameters:

1. it is an orderly process of community development that is reasonably directional and, therefore, generally predictable
2. it results from modification of the physical environment by the community; that is, succession is community-controlled even though the physical environment determines the pattern, the rate of change, and often sets limits as to how far development can go
3. it culminates in a steady state in which maximum biomass (or high information content) and symbiotic function between organisms are maintained per unit of available energy flow.

The word "strategy" refers to an increased control of, or homeostasis with, the physical environment in the sense of achieving maximum protection from its perturbations (E.P. Odum, 1971). Table 3-4 outlines 24 attributes which measure the degree of this control. Depending on the value or the state of the attribute, an ecosystem can be said to be in a developmental or mature stage.

The above concept serves as a useful model to describe the structure of agricultural ecosystems. Features common to agricultural ecosystems are analogous to the attributes of the developmental or immature stage of ecosystem development. Put simply, agricultural ecosystems are immature ecological systems (De Soet,1974; Harris, 1969; and Snaydon and Elston, 1976). This concept is discussed below on the basis of Table 3-4.

The energetics of an immature ecosystem are such that the rate of total gross photosynthesis (P) exceeds the rate of community respiration (R), so that the P/R ratio is greater than one. This means that biomass (B) accumulates as long as P exceeds R, implying that the ratio P/B is high during the the developmental stage. As (B) continues to accumulate, the amount of biomass supported per unit of available energy (E) increases to a maximum in mature ecosystems, that is, a high B/E ratio. Conversely, immature ecosystems are characterized by a low B/E ratio.

These values indicate that a large quantity of energy is directed into rapid growth and relatively little into maintenance during early successional stages. A high net community production is associated with these early stages. Thus, production can only be harvested on a sustained basis from ecosystems of a successional type. Obviously, this condition must hold for agricul-

Table 3-4. Attributes of Ecosystem Development (E.P. Odum, 1969, 1971)

Attribute	Developmental Stage	Mature Stage
1. gross prod./community resp. (P/R ratio)	> 1	approaches 1
2. gross prod./standing crop biomass (P/B)	high	low
3. biomass supported/ unit energy (B/E)	low	high
4. net community prod. (yield)	high	low
5. food chains	linear, grazing	weblike, detritus
6. total organic matter	small	large
7. inorganic nutrients	extrabiotic	intrabiotic
8. species div.(variety)	low	high
9. species div.(equit.)	low	high
10. biochemical div.	low	high
11. pattern div.	unorganized	organized
12. niche specialization	broad	narrow
13. size	small	large
14. life cycles	short	long
15. mineral cycles	open	closed
16. nutrient exchange rate	rapid	slow
17. role of detritus	unimportant	important
18. growth form	'r'-selection	'K'-selection
19. production	quantity	quality
20. internal symbiosis	undeveloped	developed
21. nutrient conservation	poor	good
22. stability	poor	good
23. entropy	high	low
24. information	low	high

tural ecosystems if they are to produce food and fiber.

An ecosystem's energy flows and nutrient cycles link organisms together to form food chains. Initially, these are relatively simple and linear but increase in complexity as an ecosystem matures. Food chains are of two basic types (E.P. Odum, 1971): the grazing food chain represented by the plant-herbivore-carnivore sequence and the detritus food chain represented by the organic matter-microorganism-detritivore-predator sequence. The former is predominant in immature ecosystems whereas the latter is predominant in mature ecosystems. In agricultural ecosystems, the grazing food chain is apparent in the sequence: grassland and tillage crops to livestock to man (Duckham and Jones, 1969). The detritus food chain is not as apparent because of the export of large amounts of organic matter.

Diversity is usually higher in the mature stage of ecosystem development. When expressed as a species-number ratio or a species-area ratio, species variety tends to increase with succession. Generally, a low species diversity occurs in the developmental stage. Using Simpson's index of dominance, Auclair (1976) measured changes in species diversity during the transition of a natural ecosystem to pre-intensive agriculture to intensive agriculture. He found an increasing tendancy toward extremely low species diversity as the conversion to an agricultural ecosystem took place (see chapter 4.3). This dominance of a population of uniform individuals also reduces stratification and spatial heterogeneity (pattern diversity) (Watt, 1973).

In immature ecosystems, life cycles are short and simple as evidenced in annual cereal crops. This is analogous to the pioneer stage in secondary succession; in fact, many cereal species held that position prior to their domestication (Snaydon & Elston, 1976).

Nutrient cycles are open with rapid exchange rates. Their application to agricultural ecosystems was discussed previously.

Selection pressure favours species with high growth potential ('r'-selection) during developmental stages. In contrast, selection pressure favours species with lower growth potential ('K'-selection) but better capabilities for survival under the more competitive conditions of mature stages. In agricultural ecosystems man intentionally selects high growth species which have a high proportion of useable biomass and an extended environmental tolerance range. Agricultural research (e.g., plant-breeding) and management (e.g., selection of cultivar) strive continuously to select these species.

Finally, immature ecosystems are characterized by poor nutrient conservation and low stability. In agricultural ecosystems, nutrient conservation is poor because nutrients are removed by cropping and leaching. A low degree of stability (i.e., resistance to perturbations) is apparent in the constant need to apply pest control measures in order to maintain pest populations at desired levels.

Agricultural management practices amplify man's control of energy flows and nutrient cycles in agricultural ecosystems. These practices strive constantly to minimize resources allocated for internal maintenance and maximize resources allocated for production. This maintains the agricultural ecosystem in a relatively young or immature successional stage comparable to the attributes which characterize the developmental stage of ecosystem development in natural ecosystems.

CHAPTER 4

SOME ECOLOGICAL CONCERNS

Ecological concerns discussed in this chapter include those related to energy subsidies, disruptions in nutrient cycles, and ecological simplicity. Concerns related to environmental quality are not reviewed because these have been documented extensively elsewhere (Brady, 1967; Groth, 1975; Loehr, 1977; National Academy of Sciences, 1974; and Ryszkowski, 1974).

4.1 Energy Subsidies

E.P. Odum (1971) estimates that energy-subsidized agricultural ecosystems yield four times the output of non-energy-subsidized agricultural ecosystems but at a cost of 100 times the energy. He also predicts that, based on past trends, doubling the yield of energy-subsidized agricultural ecosystems will require a further ten-fold increase in energy input. These projections say nothing about the potential adverse effects associated with such levels of energy use (e.g., increased leaching of nitrogen fertilizer). This requires still further energy inputs in order to offset lost productivity and, as a consequence, a spiralling increase in energy subsidies may occur.

A major concern of energy-subsidized agricultural ecosystems is diminishing returns. The Science Council of Canada (1976: 28) states that "... the greater the intensity of energy subsidy, the less is the increase in yield per unit increase of that subsidy."

In other words, an increasingly larger energy subsidy is required to obtain an additional unit of output. This is shown theoretically in Figure 4-1. Initially, an increasing rate of yield per unit area occurs as energy inputs are increased. However, this rate begins to decrease as energy inputs continue to intensify resulting in a typical S-shaped growth curve. Ultimately, an upper yield plateau is reached and the problem becomes one of attempting to achieve new plateaus (Smith, 1974).

The problem of diminishing returns is shown for the U.S. food system in Figure 4-2. This graph corresponds strikingly to the theoretical S-shaped curve in Figure 4-1. An initial phase of exponential increases in farm output occurred from 1920 to about 1955. After this phase, increments in production declined despite continued growth in energy use. Steinhart and Steinhart (1974) maintain that with regard to the extent that increased energy inputs will increase production significantly, the end of an era is near.

A most important observation related to energy subsidies is that dependance on a rapidly dwindling resource is increasing. In the U.S., direct fuel use increased more than 300 per cent between 1940 and 1971 (Steinhart and Steinhart, 1974). Direct fuel use by Canadian agriculture increased 25 per cent between 1961 and 1971 (Science Council of Canada, 1976). Reliance on non-renewable energy resources cannot be maintained indefinitely, let alone increased, because of finite energy supplies and diminishing returns. To reduce this reliance, Pimental _et al_. (1973)

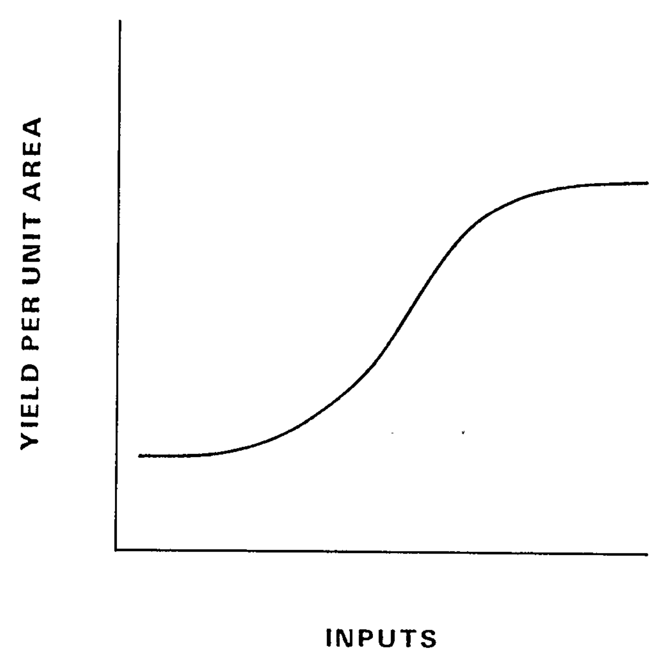


FIG. 4-1. RESPONSE OF YIELD TO ENERGY INPUT
(SMITH, 1974)

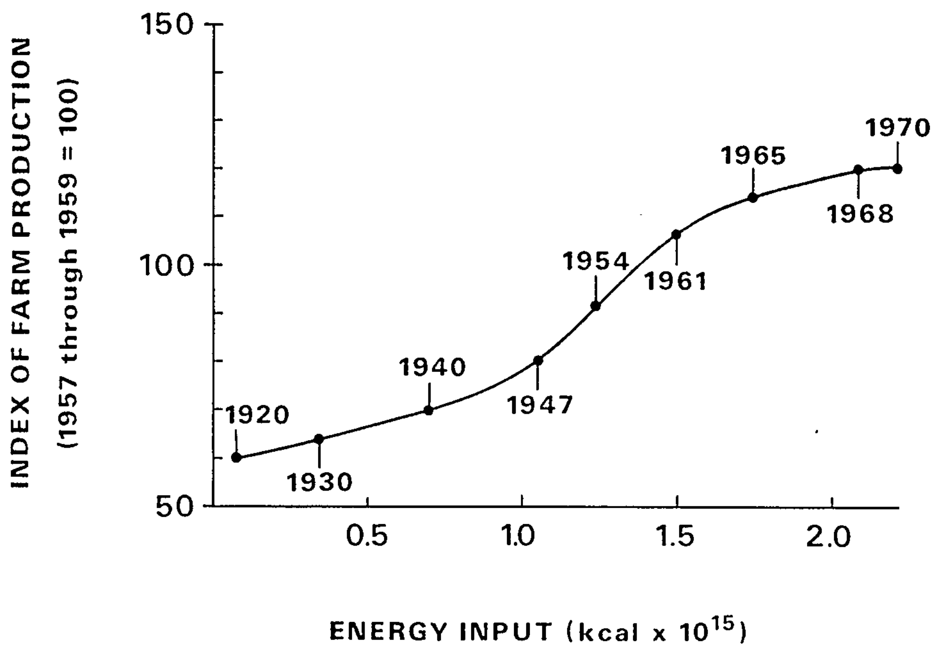


FIG. 4-2. ENERGY USE IN THE U.S. FOOD SYSTEM (STEINHART AND STEINHART, 1974)

suggest scaling of machinery, operating at efficient speeds, increasing the amount of area per machine, reduced tillage, mechanical control of weeds, breeding for hybrids which increase photosynthetic efficiency and reduce vulnerability to limiting factors, and more intensive use of manure, legumes, crop rotations, integrated pest control, multiple and inter-crop planting, and soil and water conservation measures. The authors estimate that use of the above, or any combination thereof, could reduce energy inputs by one-half and still maintain present yields. Until recently, economic cost has inhibited the implementation of many of these energy conservation measures but current economic trends may reverse this trend. For example, increases in the price of agricultural fuel have improved the feasibility of minimum tillage because of reduced fuel costs.

Despite the realistic nature of these suggestions, caution is required in their implementation for two main reasons. First, implementing one suggestion may reduce one form of energy input but simultaneously increase another. Second, suggestions to conserve energy need to be evaluated in terms of their effect on other parameters such as environmental quality. The importance of these reasons has been demonstrated by Dvoskin and Heady (1976) who, using a linear programing model, studied the effect of five energy reduction strategies on agricultural production and environmental quality. The five strategies are: (A) a base run, (B) energy minimization, (C) a 10 per cent energy reduction, (D) high energy prices, and (E) high exports.

Results indicate that use of energy conserving practices vary according to different strategies. The use of inorganic nitrogen fertilizer declines under strategies B, C and D but total nitrogen use remains unchanged due to greater use of manure and legumes. Reduced tillage practices increase only slightly under high energy prices (D), moderately under energy minimization (B), and quite substantially under a 10 per cent reduction (C). However, pesticide use also increases under the 10 per cent energy reduction (C) and energy minimization (B) strategies. Increased use of pesticides reflects a substitution for pest control normally achieved by conventional tillage. Thus, energy savings realized by reduced tillage are offset, at least partly, by increased pesticide use.

With regard to reduced energy use and environmental quality, the model predicts a paradox. On the one hand, use of inorganic nitrogen fertilizer declines in response to a reduction in energy use. This may improve environmental quality by reducing the potential for leaching and contamination of groundwater (Singh and Sikhon, 1978). On the other hand, the frequency of tillage operations also declines in response to a reduction in energy use. However, as shown above, reduced tillage operations generally necessitate intensified use of pesticides which are potential sources of environmental degradation (Groth, 1975).

4.2 Disruptions in Nutrient Cycles

Few studies have compared nutrient budgets before and after a serious perturbation. One such study by Bormann and Likens (1970) examined nutrient inputs and outputs in an forest ecosystem under pre-disturbance conditions and after extensive clear-cutting. Their analysis showed that undisturbed forest ecosystems accumulated nitrogen (2 kg/ha/yr) whereas disturbed forest ecosystems lose nitrogen (120 kg/ha/yr). The major sources of nutrient loss were removal of biomass, leaching, and erosion.

Disturbances also explain the loss of nutrients in agricultural ecosystems. Their nutrient cycles are disrupted by the removal of harvested crops and crop residue (Burwell et al. 1977; Neal, 1944); the addition of biocides which destroy beneficial organisms necessary for nutrient cycling (Groth, 1975); and an acceleration of such processes as erosion, leaching, volatilization, nitrification, and denitrification (Frissel, 1978).

Neal (1944) examined the removal of nitrogen, phosphorus, and potassium by cropping and erosion on a sandy loam soil in New Jersey. The crops used were tomatoes and sweet corn. Results indicate that most of the nitrogen was removed through crops and most of the phosphorus and potassium was removed by erosion. It is noted that nutrients removed by cropping represent a loss of available nutrients, whereas erosion removes nutrients without regard to availability. Conservation practices, such as manuring and mulching, decreased losses of all elements through erosion but increased losses through crops due to greater yields. However, the total amount of nutrients removed was less than if no conservation measures were applied.

A parallel study by Burwell, et al. (1977) supports the observation that cropping contributes to the depletion of nutrients. This study compared the removal of nitrogen and phosphorus by crop uptake (corn) and stream discharge (surface runoff and subsurface flow) for four agricultural watersheds in Iowa over a five-year period. The mean annual removal of both nitrogen and phosphorus by corn was consistently higher than that removed by stream discharge.

Nutrient loss varies according to the intensity of management. Generally, the greater the intensity of management, the greater the amount of nutrients lost from the agricultural ecosystem. Frink (1969) showed that management intensity is a strong determinant affecting the loss of nutrients from dairy farms in Connecticut (Figure 4-3). Management intensity is measured as the amount of available land per cow (ha/cow) and nutrient loss is measured in kg/ha. When the intensity of management is high, or the number of hectares per cow is low, losses of nitrogen, phosphorus, and potassium are high. As management intensity decreases, nutrient losses also decrease. Frink (1969) attributes nitrogen losses to leaching whereas phosphorus and potassium losses accumulate in the soil in unavailable forms.

Frissel's (1978) comprehensive study of nutrient cycles in 65 agricultural ecosystems supports the observation that nutrient losses tend to increase as the intensity of management increases.

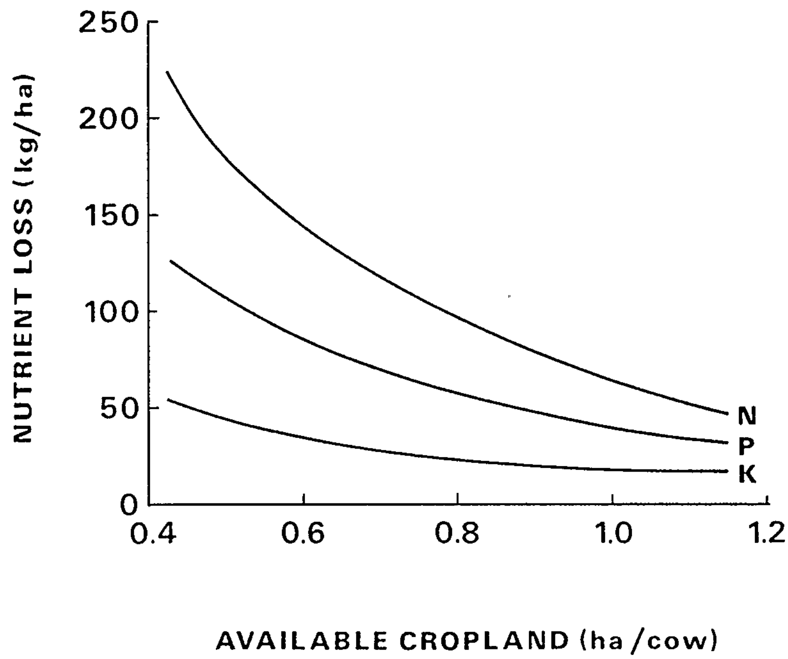


FIG. 4-3. EFFECT OF MANAGEMENT INTENSITY ON NUTRIENT LOSS (SMITH, 1974)

This study measured management intensity in terms of nitrogen input (kgN/ha/yr) into the agricultural ecosystem. Results show that nitrogen losses increase as nitrogen inputs intensify. For example, nitrogen losses by leaching from agricultural ecosystems with inputs below 150 kgN/ha/yr are about 10 per cent. Losses from agricultural ecosystems with inputs exceeding 150 kgN/ha/yr are about 20 per cent, indicating a greater nitrogen loss for systems with higher management intensity.

The effect of management intensity on nutrient loss is complicated by the type of farming system. It affects the amount of nutrient loss and also the source by which this amount is removed. Frissel (1978) found that nitrogen output efficiency of arable farming systems is between 30 and 100 per cent of the nitrogen input. Arable farming systems with a nutrient input below 150 kgN/ha/yr have an output efficiency averaging 66 per cent; systems with inputs above 150 kgN/ha/yr have an output efficiency averaging 50 per cent, indicating a greater nitrogen loss for arable systems with higher management intensity. In arable systems the process of denitrification tended to dominate. Nitrogen output efficiences are generally lower in livestock systems than arable systems ranging primarily between three and 30 per cent. Of the 24 livestock systems studied by Frissel (1978), nine have a nitrogen output efficiency of less than 10 per cent, 12 have an efficiency between 10 and 30 per cent, and three have an efficiency higher than 30 per cent. Absolute nitrogen losses of livestock systems are much higher than those of arable systems (three cases exceeded losses of 500 kgN/ha/yr). In livestock systems the process of volatilization of ammonia tended to dominate.

Nitrogen output efficiencies for mixed farming systems are intermediate between those of arable and livestock systems. Efficiences usually range from 30 to 50 per cent (Frissel, 1978).

Soils in agricultural ecosystems are being subjected to nutrient depletion because of disrupted nutrient cycles. With regard to the total soil nutrient pool for each of the 65 agricultural ecosystems studied by Frissel (1978), 45 showed a loss of one or more major nutrients. Of these, 17 reveal a net nutrient loss despite the application of fertilizers (of which 13 are arable systems, 3 mixed, 1 livestock). These losses cannot be sustained indefinitely in any stable system and it is difficult to state how much longer they can be sustained. It is essential for the long-term stability of all agricultural ecosystems that nutrient loss not exceed nutrient gain.

4.3 Ecological Simplicity

The net effect of agricultural management techniques is to amplify man's control of energy flows and nutrient cycles. The large energy subsidies required by these techniques simplify interrelationships and linkages between the components of production, consumption and decomposition. This process of simplification is evident in low crop diversity and spatial homogeneity or low pattern diversity.

Low crop diversity is apparent primarily in the form of monoculture (see chapter 6.0). Diversity of flora is very low and there is little possibility of a natural predator or control agent being present to stabilize perturbations (van Emden and Williams, 1974; Pimental, 1961). Natural checks and balances are frequently suppressed and, as a consequence, huge inputs of energy subsidies, mainly in the form of cultivation practices, soil amendments and pest control, are required to maintain resistance to perturbations.

On a large scale, low crop diversity may generate spatial homogeneity or low pattern diversity between two communities. Trophic relationships are simplified as emphasis is placed on either the producer component (e.g., grains) or the consumer component (e.g., livestock). The advantage of spatial homogeneity is obvious for production purposes but it may also increase the potential for pest outbreaks since there are few spatial or biological barriers (Watt,1973). Vast homogeneous areas simplify the landscape promoting a greater potential for pest and disease outbreaks than a higher number of small diverse fields encompassing the same area (van Emden, 1964). The importance of hedgerows, shelterbelts, crop rotations, and strip cropping in reducing this potential has been documented by Caborn (1971), van Emden (1964), and Laster (1974).

The process of simplification begins during the conversion of natural ecosystems to agricultural ecosystems and increases during intensification. The only known study which has examined this process from the pespective of ecosystem conversion and intensification is that of Auclair (1976). It is useful to review this study in detail because it supports the proposition that shifts in ecological parameters coincide with changes in management intensity. The study area is located in south-central Wisconsin. Changes in the importance of ecological parameters (e.g., vegetation, land use, soil characteristics, and crop yields) were measured for three stages of development: (1) conversion of natural vegetation to pre-intensive agriculture (1833-1934), (2) agricultural intensification associated with chemical subsidies and mechanization (1934-1948), and (3) recent shifts in crop diversity and production (1934-1972).

Results indicate that virtually none of the pre-settlement vegetational cover-type (savanna and prairie) remains today. About 92 per cent of the original prairie area was converted to a cropland-pasture rotation system during the first stage of development. These sites correlated strongly with high moisture capacity and soil fertility typical of original prairie.

The distribution of cover types in 1961 was similar to that in 1934 with the exception of forest cover which increased from 24.3 per cent of the total area in 1934 to 34 per cent in 1961. The increase was mainly at the expense of cropland which decreased from 72.8 to 64 per cent in this period. Reduced cropland occurred because of abandonment of marginally productive sites. Crop production, however, did not decrease because of intensification of higher quality sites.

Crop diversity was measured using Simpson's index of dominance which is a measure of each species' importance in relation to the community as a whole and is calculated by summing the squares of the relative area of the major crop species in a given time period. Crop productivity and diversity changes since 1931 indicate that yield increases were accompanied by a marked tendancy toward monoculture (Figure 4-4). This was especially apparent between 1951 and 1965. Auclair (1976) suggests that a slight increase in the dominance index since 1965 is indicative of a peak in monocultural trends under prevailing conditions of management.

Throughout the 1934-1972 period, species composition also changed, primarily to high-yield crops. Grain corn increased at the expense of oats and alfalfa-bromegrass almost completely replaced clover-timothy hay. Finally, changes in soil characteristics were associated with increased management intensity. Most notably, moisture-related variables (e.g., evapotranspiration) replaced nutrients as limiting factors due to inorganic fertilizer use.

Auclair's (1976) study indicates that the conversion of natural ecosystems to agricultural ecosystems is characterized by a relatively simple ecological structure. This is most evident in the trend toward lower species diversity which simplifies interrelationships between the producer, consumer, and decomposer components. These interrelationships are simplified primarily by eliminating or regulating the population levels of species com-

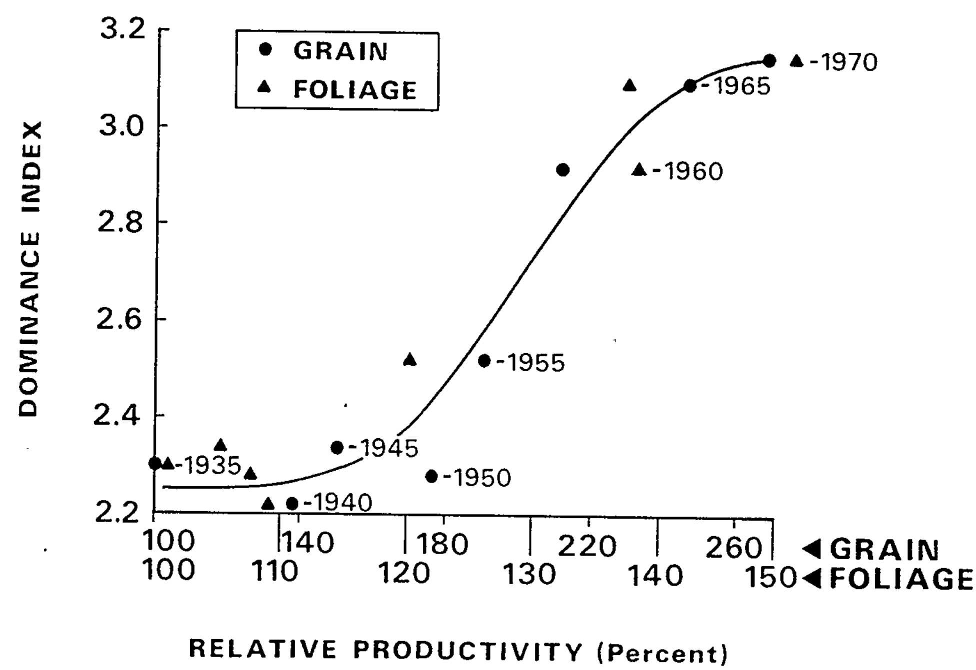


FIG. 4-4. CROP DIVERSITY IN AGRICULTURAL ECOSYSTEMS (AUCLAIR, 1976)

peting with the desired crop species. Energy subsidies are required on a continuing basis to maintain a relatively simple structure and to retard the progression back into a natural ecosystem.

CHAPTER 5

AN OVERVIEW OF AGRICULTURE IN SOUTHERN ALBERTA

The preceding chapters have reviewed, evaluated and recommended a systems approach to agricultural management. This approach implies that all the components of a system, and the linkages between those components, need to be understood to make appropriate management decisions. The systems approach provides the basis for employing the analytical tools of systems analysis and the predictive powers of systems modelling.

A systems approach to agriculture reveals that agricultural systems are comprised of a complex of interacting biophysical, technological, and socio-economic management components that vary significantly in their regulatory function and serve to distinguish various types of agricultural systems. The main variables affecting the agricultural system, assuming stable controlling factors, are man-directed activities which alter the structure and dynamics of the system by regulating the rate and quantity of energy flows and nutrient cycles.

One of the difficulties in studying an entire agricultural system is the large variation in size, number and spatial arrangement of the components and their variables. For study purposes, parts of the agricultural system may be examined in isolation provided that their relationship within the total system is understood. A unique characteristic of the systems approach is that the components, and the variables regulating these components, can be identified and studied separately from the whole system. This is possible because the relative independence of every component is a basis for identifying subsystems. Separate subsystem studies can then be integrated to obtain an overall understanding of the agricultural system.

It is beyond the scope of this project to comprehensively analyse all the components of an agricultural system. Scale and time constriants, as well as the difficulty in collecting, analysing and interpreting large amounts of quantitative data, pose significant limitations to conducting a thorough study of a whole system. The remainder of this document focuses on parts of the agricultural system. Two agricultural practices, monoculture and summerfallow, were selected for further detailed study. These practices are examined in terms of their effect on the long-term production of agricultural goods and services.

Monoculture was selected because relatively little ecological research has been directed toward the long-term implications of growing a single crop species on a given area. Previous studies have hypothesized that these implications may include a deterioration of soil quality (Siemens, 1963), an increase in insect pest outbreaks (van Emden and Williams, 1974), and a greater disease incidence (Adams, Ellingboe, and Rossman, 1971; Wade, 1972). For example, ecological theory supports the presupposition that lower crop species diversity may enhance the probability of pest outbreaks but there is limited quantitative data based on site-specific studies to substantiate this. A review of crop rotation studies which include a continuous cropping sequence would provide additional information upon which to assess the hypothesis that monoculture encourages pest outbreaks.

Summerfallow was selected because the traditional reasons for summerfallowing are presently being questioned and reassessed (Alberta Department of Agriculture, 1975b; Ford and Krall, 1979). Traditionally, summmerfallow was practiced to release nutrients, store moisture and control weeds. However, recent research findings have related summerfallow to declining soil nitrogen and organic matter content, inefficient moisture storage, increasing soil salinity, and enhanced soil erosion. A synthesis of these research findings would assist agricultural organizations and farmers to reevaluate a traditional soil management practice.

In order to narrow the investigation further, the dryland farming region of southern Alberta was selected for study primarily because of information availability and particularly data derived from long-term crop rotation studies conducted by the Agriculture Canada Research Station at Lethbridge. The region is characterized by several problems (e.g., declining soil fertility, increasing soil salinity and soil erosion by wind) which could pose significant constraints to long-term agricultural production (Pittman, 1977; Rennie, 1979). Both monoculture and summerfallow are prevalent cropping practices in the dryland farming region of southern Alberta and, because of their possible long-term implications, are timely concerns and particularly appropriate for further analysis in this project.

A general overview of agriculture in the study area is presented in this chapter, followed by a more detailed review of monoculture and summerfallow in chapters six and seven. It must be noted that some information sources are derived from regions outside the study area while other information may be applicable only to specific site conditions within the area. Where this information is reviewed, regional and site-specific variations were considered and caution excerised in making generalizations applicable to southern Alberta.

5.1 Description of Southern Alberta

Southern Alberta is delineated by the 41 cm isopleth of mean annual precipitation which approximates the zone of Brown and Dark Brown soils (Figure 5-1). The Brown soils occur in southeastern Alberta and developed under short-grass prairie vegetation and semi-arid conditions ranging from 25 to 34 cm of annual precipitation. The Dark Brown soils occur in a band north and west of the Brown soils where annual precipitation is slightly higher ranging from 36 to 41 cm (Alberta Department of Agriculture, 1976).

The region occupies approximately 9 million hectares of which 3.8 million hectares are cultivated. Most of the non-cultivated area is classified as native pasture and wasteland. Dryland farming prevails in the region and the major crops are wheat and barley. Other crops include oats, fall rye, rape,

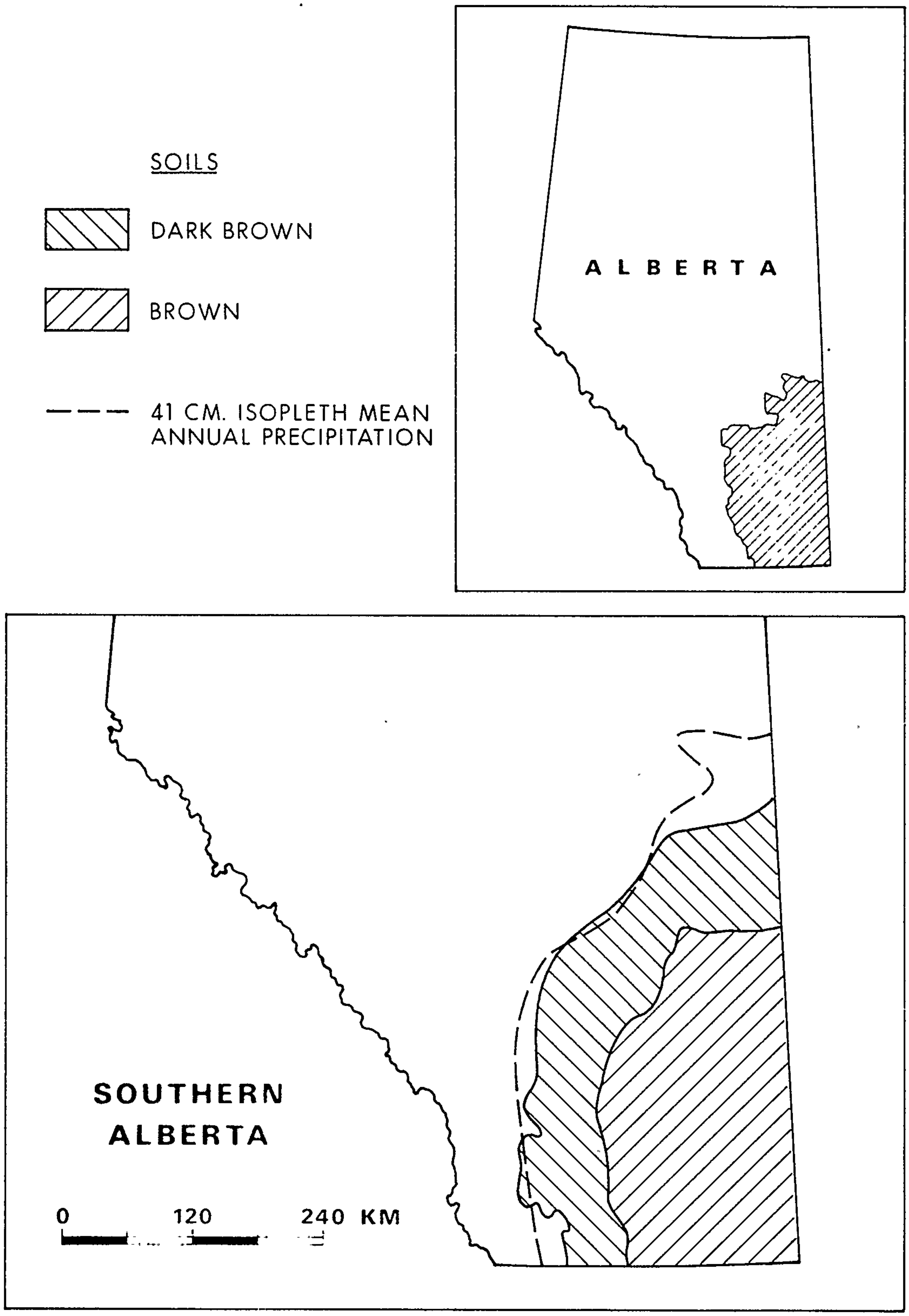


FIG. 5-1. SOUTHERN ALBERTA

flax, mustard, sunflowers, and cultivated grasses and forages. A crop-fallow rotation is the predominant cropping practice in the Brown soil zone whereas a crop-crop-fallow rotation is the predominant cropping practice in the Dark Brown soil zone. The main factor limiting crop production is a lack of available moisture but other factors include solonetzic and saline soils. Soil erosion by wind is a major problem throughout the region (Alberta Department of Agriculture, 1976).

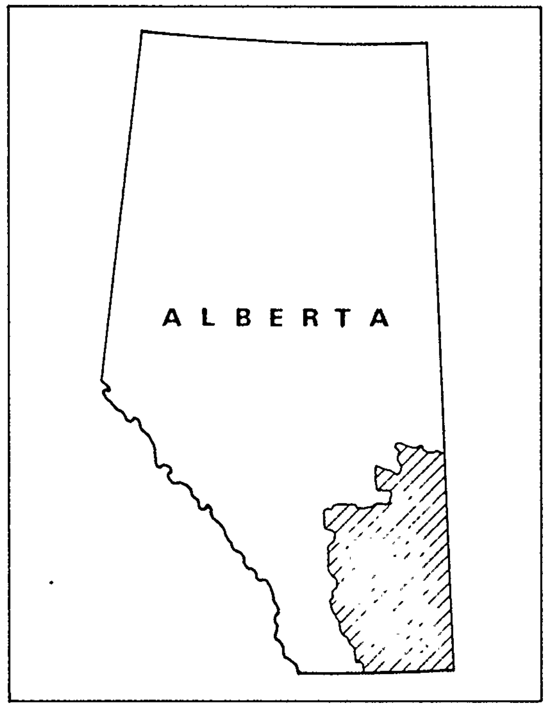
A base for collecting data in southern Alberta was obtained by superimposing a map outlining soil boundaries (Figure 5-1) on a map outlining municipal boundaries. Those municipalities with a significant portion of their area located within the Brown and Dark Brown soil zones are shown in Figure 5-2. These municipalities also form census subdivisions and, therefore, represent basic data units.

5.2 Agricultural Trends

5.2.1 Finite Land Base

Forty-five per cent of the southern Alberta land area is under cultivation (Statistics Canada, 1978). However, this does not necessarily imply that a large land base is still available for expanding crop production, as evidenced in a comparison of the total area of good arable land characterized by a high soil capability for agriculture.

SOUTHERN ALBERTA MUNICIPALITIES



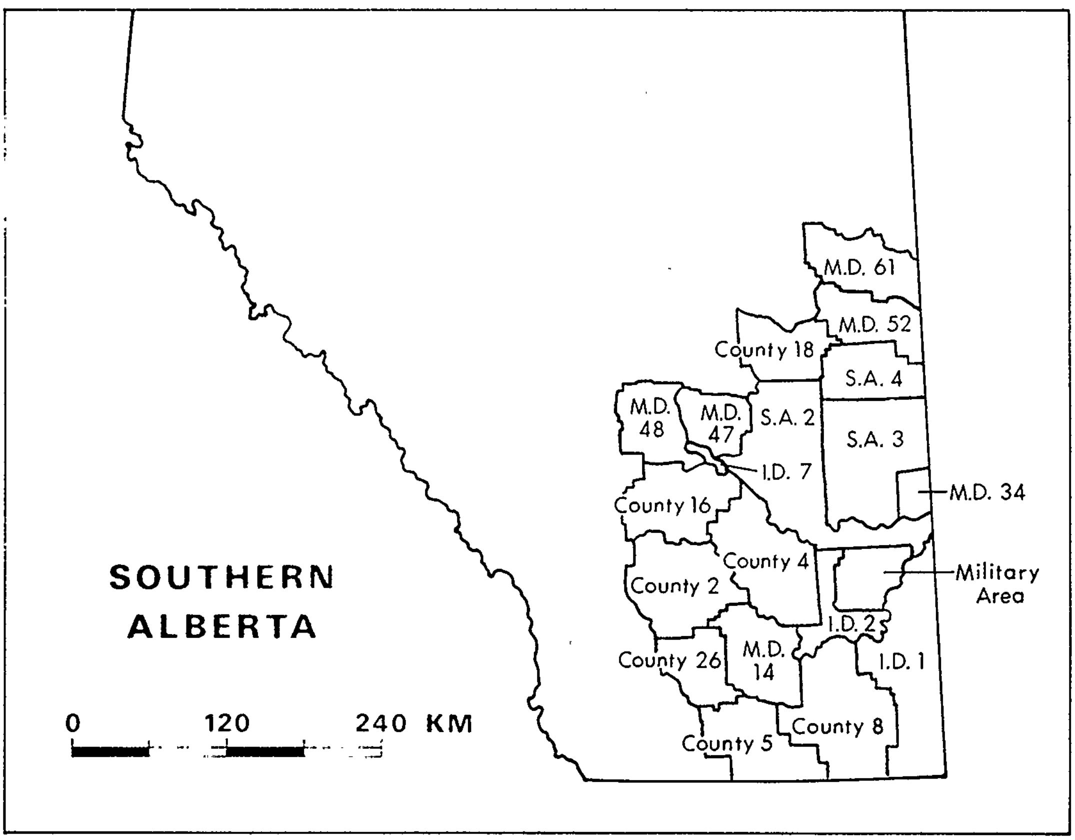


FIG. 5-2. MUNICIPALITIES (CENSUS SUBDIVISIONS) IN SOUTHERN ALBERTA

The Canada Land Inventory (CLI) classification system is commonly employed to specify varying degrees of soil capability. It consists of seven major classes with one representing the highest soil capability and seven the lowest. Each class is briefly described below (Canada Department of the Environment, 1976):

Class 1 - soils with no significant limitations for crop use

Class 2 - soils with moderate limitations that restrict the range of crops or require moderate conservation practices

Class 3 - soils with moderately severe limitations that restrict the range of crops or require special conservation practices

Class 4 - soils with severe limitations that either restrict the range of crops or require special conservation practices or both

Class 5 - soils with very severe limitations that restrict their capability to produce perennial forage crops

Class 6 - soils are capable only of producing perennial forage crops, and improvement practices are not feasible

Class 7 - soils with no capability for arable culture or permanent pasture.

The Canada Department of the Environment (1976) defines good arable land as consisting of those areas characterized by classes 1, 2 and 3. Table 5-1 shows the area of each CLI capability class for both the Brown and Dark Brown soil zones in southern Alberta. The cultivated area for each zone is also shown. From this data, it is evident that the total amount of good arable land (classes, 1, 2, and 3) is 2.9 million hectares. In comparison, the total cultivated area is 3.8 million hectares implying that cultivation has extended onto soils with lower capability for agriculture. This assumes that almost all class 1, 2, and 3 soils are under cultivation; an assumption verified by Pettapiece (1979). Soils with the highest capability for agriculture are already under cultivation. Therefore, crop production cannot rely on a significant expansion of its area without merging onto soils characterized by severe limitations.

5.2.2 Intensification

A finite quantity of arable land has led to more intensive use of resources. This trend is evident in the increasing significance of energy subsidies, particularly fossil fuel and inorganic fertilizer (Figure 5-3). Although the graphs depict provincial trends it is assumed that similar trends exist in southern Alberta. Fuel and fertilizer use may actually be higher in southern Alberta because of irrigation and intensive production of specialty crops (e.g., sugar-beets). Jenson and Stephanson (1975) showed that fuel and fertilizer represented the major en-

Table 5-1. Soil Capability for Agriculture and Cultivated Area in Southern Alberta (Alberta Land Use Forum, 1974)

Class	Limitation to Range of Crop	Brown Soils (ha)	Dark Brown Soils (ha)	Total Area (ha)
1	none	86,089	113,200	199,289
2	moderate	213,168	686,433	899,601
3	moderately severe	442,707	1,354,014	1,796,721
4	severe	1,597,707	1,003,833	2,601,540
5	very severe	1,559,422	668,710	2,228,132
6	non-improvable	608,911	457,962	1,066,873
7	non-agricultural	140,734	72,574	213,308
0			259	259
unclassified		583		583
area of soil zone		4,649,321	4,356,985	9,006,306
cultivated area		1,720,317	2,094,613	3,814,930

FIG. 5-3a DIRECT USE OF GASOLINE AND DIESEL FUEL 1974-1978

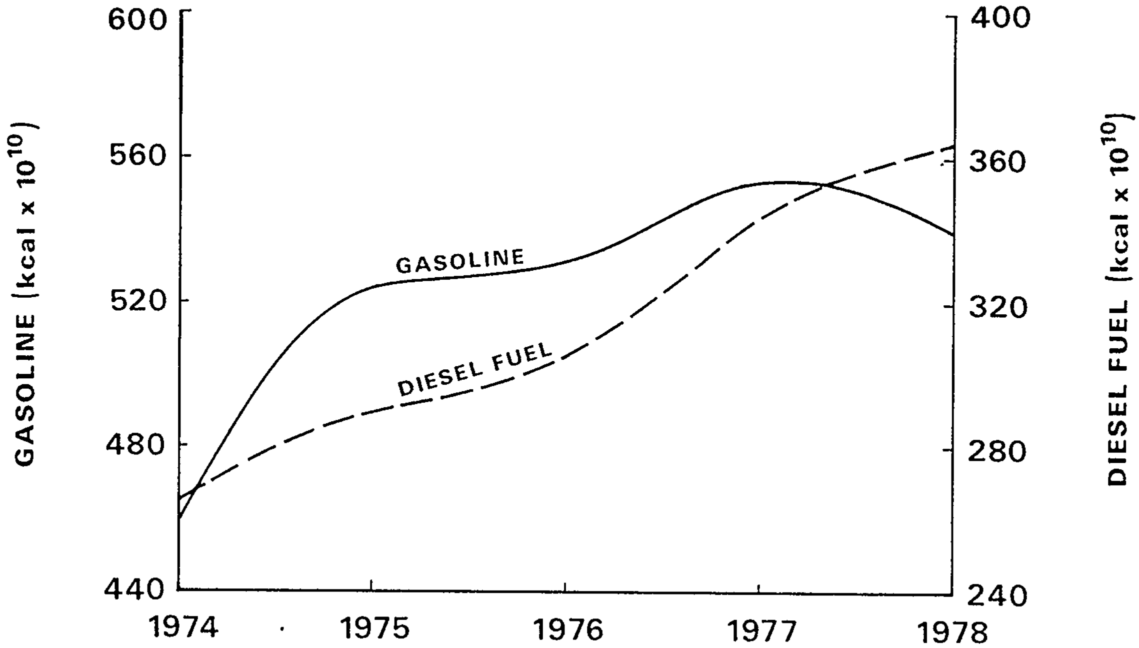


FIG. 5-3b FERTILIZER USE 1940-1978

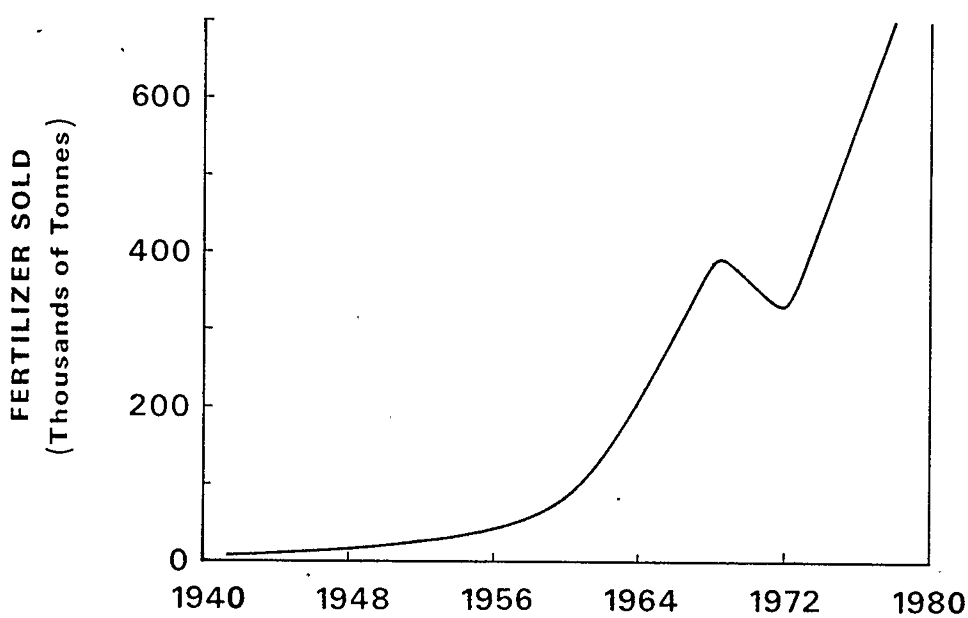


FIG. 5-3. FUEL AND FERTILIZER USE BY AGRICULTURE IN ALBERTA (ADAPTED FROM BOWN, 1979 AND MOTIUK, 1979)

ergy inputs into farms in southern Alberta.

Fossil fuel use by agriculture from 1974 to 1978 is shown in Figure 5-3a. Even for this short period, an increase in energy input is evident in the form of direct use of gasoline and diesel fuel. Gasoline input increased 20.6 per cent from 1974 to 1977 declining slightly in 1978. Diesel fuel input increased steadily during the four-year period with an overall increase of 25.7 per cent. Total direct fuel inputs intensified 26.9 per cent during this period.

Increasing increments of inorganic fertilizer also exemplify the trend toward intensification. Figure 5-3b reveals a dramatic 195-fold increase in the quantity of fertilizer sold between 1941 and 1978. A rapid increase did not occur until the early 1960's climbing to the 400,000 tonne mark in 1968. Consumption during the two subsequent years declined because of depressed international markets which resulted in low cash receipts for Alberta farmers. In 1978, fertilizer use reached almost 700,000 tonnes.

Although fuel and fertilizer inputs are much more intensive in other areas (e.g., southern Ontario, Japan, Netherlands), they contribute a significant proportion of the total energy inputs on farms in southern Alberta. Jenson and Stephanson (1975) calculated the energy ratios for three grain and two forage farm units in southern Alberta. Results indicate that fuel and fertilizer inputs contributed up to 70 per cent of the total energy input into the grain farm units and up to 83 per cent into the forage farm units. Similar results were found by Thompson and Gimby

(1979) who conducted a parallel study in Saskatchewan.

5.2.3 Production

More intensive use of energy inputs has led to an impressive increase in Alberta's agricultural production (Figure 5-4). Production is measured by the index number of physical volume of agricultural production which expresses the gross output of agricultural products as a percentage of the gross output in a base period (Statistics Canada, 1977). The intensity of energy input is measured in kilograms of inorganic fertilizer per cultivated hectare. The graph reveals that agricultural production increased as the intensity of fertilizer inputs also increased. The index of agricultural production rose three-fold from 1945 to 1976 but variations within this period are evident. These are attributed to climatic factors such as the widespread early frost in 1967 and below average annual precipitation in 1974 (Science Council of Canada, 1976).

During the same period that agricultural production increased three-fold, the intensity of fertilizer use increased approximately 30-fold. The reason for this is shown theoretically in Figure 5-5. This graph is similar to that of Figure 5-4 and reveals the typical response curve of crop yield to fertilizer input, known as Mitscherlich's law (Watt, 1973). As fertilizer inputs per unit area increase, increments in yield also increase until an optimum is reached. This optimum is represented by the curve's inflection point, beyond which increasingly larger inputs

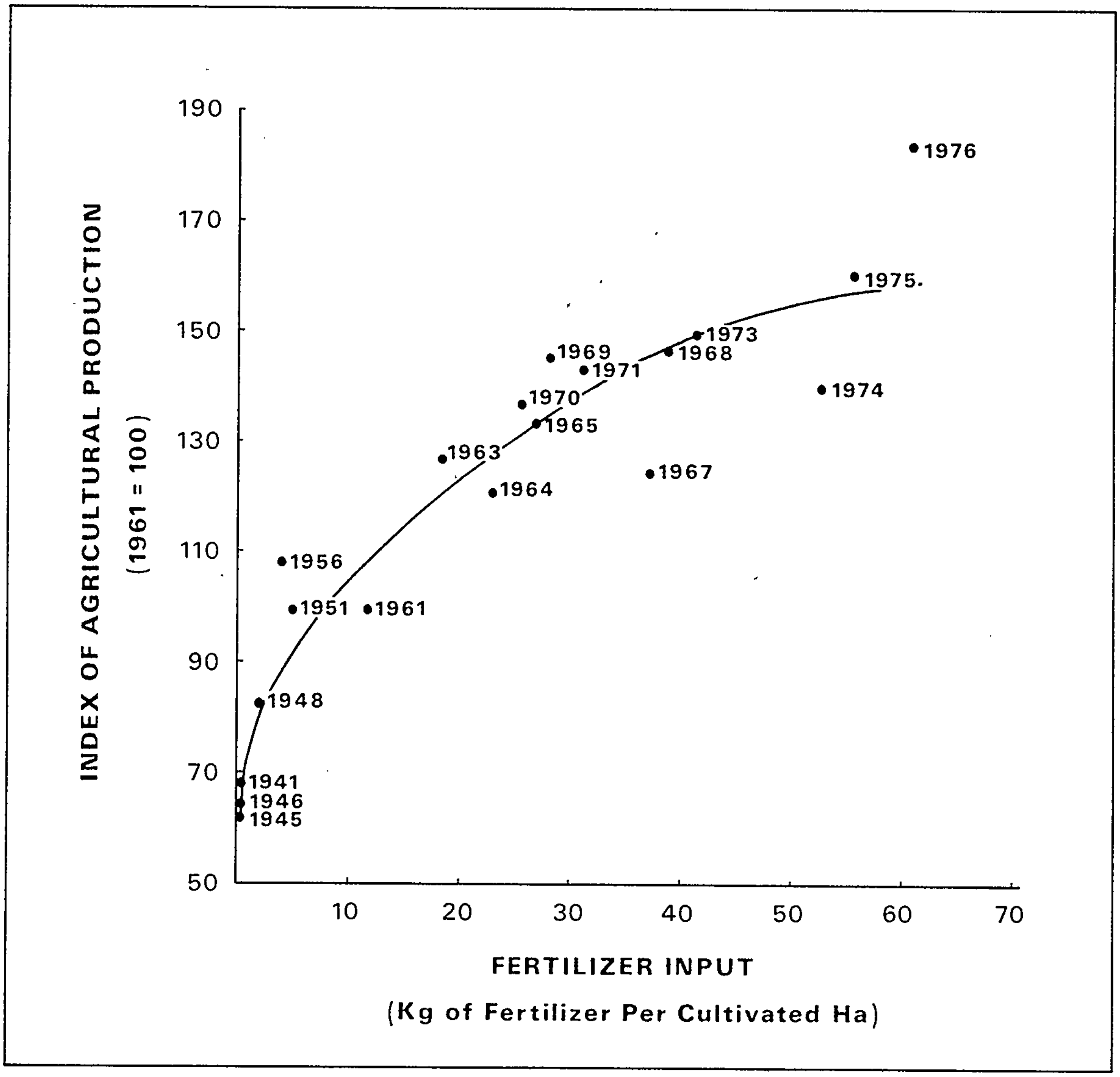


FIG. 5-4. AGRICULTURAL PRODUCTION AND FERTILIZER INPUT IN ALBERTA (ALBERTA DEPARTMENT OF AGRICULTURE, 1971, 1973, 1975A, 1977; ALBERTA LAND USE FORUM, 1974; STATISTICS CANADA, 1977)

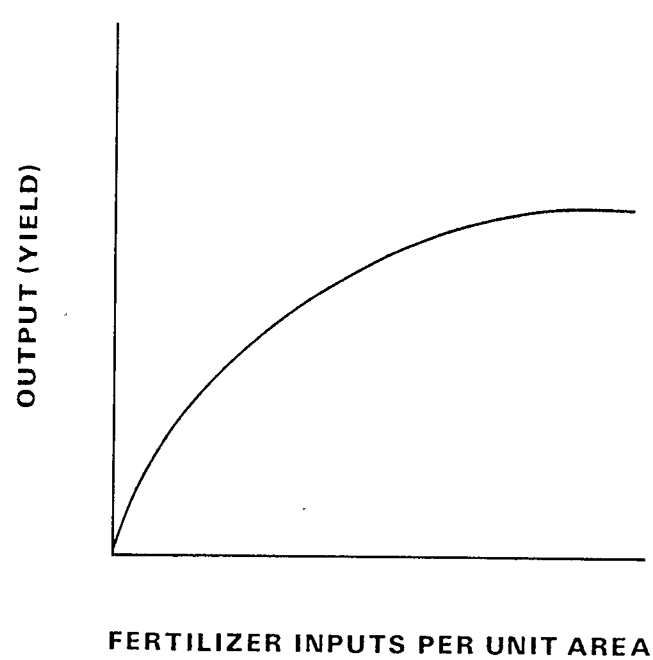


FIG. 5-5 RESPONSE CURVE OF CROP YIELD TO FERTILIZER INPUT (WATT, 1973)

of fertilizer are necessary to obtain an additional unit of crop yield. Therefore, if substantial increases in Alberta's agricultural production are to be achieved, huge fertilizer inputs are required. However, this is likely to increase the rate of soil acidification (see section 5.3.2) and, in addition, the effect of highly intensive fertilizer use on the rate of decomposition of organic matter, the quantity and type of soil organisms, and soil-borne plant diseases are largely unknown.

5.3 Factors Affecting Long-term Production

Historically, agriculture has not always witnessed the success evident in recent decades. Agricultural history points to many failures. These are exemplified in the sedimentation of irrigation channels and accumulation of salts in the irrigated soils of ancient Mesopotamia; the widespread fungal blight, encouraged by a highly vulnerable potato monoculture, of the Irish potato famine during the mid-1800's; the quickly-forgotten experiences of the dust-bowl thirties; and the nearly disasterous corn leaf blight in the United States during 1970.

Factors suggesting that long-term production of agricultural goods and services could be affected are evident in southern Alberta. Climatic factors and a finite quantity of arable land are important limitations to future production but other factors also pose significant constraints. These include the expansion of saline soils, increasing acidity of cultivated soils, declining soil fertility, and soil erosion.

5.3.1 Dryland Salinity

Dryland salinity is a major problem in southern Alberta. The Canada Department of Agriculture (1977) states that this condition occurs when water in excess of the water-holding capacity of the soil accumulates salts by downward seepage and lateral movement of the watertable to a discharge area. The salinized water rises to the surface of the discharge area by capillary action where it evaporates leaving an accumulation of salts. Saline soils affect yields and the type of crop grown because crops have a limited tolerance to salt. Generally, forage crops are more salt tolerant than cereals because perennials provide greater ground surface cover reducing evaporation. In addition, salts can delay germination, reduce microbial activity which affects the availability of plant nutrients, and remove water from the plant roots by osmosis causing their cells to collapse (Canada Department of Agriculture, 1977).

Dryland salinity was not a major problem on the prairies prior to agriculture because excess moisture provided by precipitation was readily absorbed by natural prairie vegetation (Alberta Department of Agriculture, 1975b). Agriculture contributed to the expansion of dryland salinity by increasing the quantity of moisture available for seepage and evaporation. Annual moisture use by cereal crops is less than that of natural prairie vegetation because cereals have a shorter period of moisture use. Plant species in natural prairie vegetation grow, flower, and mature in a series of successive stages throughout the entire growing season resulting in prolonged and more continuous moisture use. Summerfallow accumulates moisture which contributes to increased seepage. Also, shelter belts, fence lines, and buildings located on a recharge zone trap winter snowfall providing additional sources of excess moisture. Tillage operations expose a greater surface area to evaporation which increases the accumulation of salts on the soil surface.

Dryland salinity in southern Alberta is increasing and becoming more difficult to control. The Alberta Department of Agriculture (1979c) estimates that 101,200 hectares of dryland are seriously affected and an additional 405,000 hectares are affected to a lesser degree. The total area affected is increasing by about 10 per cent annually. McCracken (1973) states that the most severe salinity problems occur where the mean annual precipitation ranges between 26 and 46 cm. In Lethbridge County, a ten-fold increase in the extent of dryland salinity occurred between 1960 and 1970. Sixteen per cent of the arable land in that County is affected. These figures do not include salts contributed by irrigation which would further increase the total area affected by salinity.

5.3.2 Soil Acidity

Penny and Henry (1976) identify soil acidity as a major problem in the cultivated soils of Alberta. Throughout the province, approximately 2.4 million hectares are characterized by a pH of 6.0 or less. An additional 3.1 million hectares exhibit a pH in the range of 6.1 to 6.5. Limitations posed by acidic soils include the occurrence of toxic concentrations of aluminum and manganese, reduced nitrogen fixation, and a restricted range of suitable crops, particularly alfalfa (Canada Department of Agriculture, 1974a).

The distribution of cultivated acid soils (pH of 6.0 or less) varies across the province (Penny et al. 1977). Regionally, the highest proportion (31 per cent) occurs in the Peace River area. The percentages found in the Brown and Dark Brown soil zones of southern Alberta are shown in Table 5-2. About 5 per cent of the cultivated area in the Brown soil zone has a pH of 6.0 or less. The same percentage exists in the Dark Brown soil zone south of the Bow River. The high proportion (13.8 per cent) of cultivated acid soils in the Dark Brown soils north of the Bow River is associated with the solonetzic soils of that zone. (Despite alkaline subsoils, the pH of the Ap horizon (plowed A soil horizon) is often below 6.0 in Solonetzic soils). Regionally, this constitutes the third highest proportion of cultivated acid soils in the province (Penny et al. 1977).

Table 5-2. Percentage of Cultivated Acid Soils in Southern Alberta (Penny *et al* 1977)

Soil Zone	< 5.0	5.1-5.5	5.6-6.0	6.1-6.5
Brown	0.0	0.7	4.7	9.0
Dark Brown				
south of Bow River	0.0	0.4	4.7	11.7
north of Bow River	0.4	5.7	13.8	21.6

Table 5-2 also shows that a substantial proportion (e.g., 21.6 per cent north of the Bow River) of the cultivated areas in Southern Alberta exhibit a pH of 6.1 to 6.5. Penny et al. (1977: 163) suggests that "... a moderate decline in soil pH would cause a large increase in the severity and extent of the soil acidity problem." They maintain that a gradual decline in soil pH can be expected from the continued use of nitrogen fertilizers. This observation is supported by McCoy and Webster (1977) and Penny and Henry (1976).

5.3.3 Soil Fertility

A problem of rapidly rising concern which could exert a very significant effect on dryland agriculture is the declining fertility of prairie soils. Shutte (1925) observed a serious reduction in soil nitrogen content since the breaking and cultivation of virgin soils. In a period of 22 years of cultivation, the soil lost 30 per cent of its original nitrogen content. After 38 years, the loss of nitrogen reached 40 per cent.

Newton, Wyatt and Brown (1945) sampled numerous cultivated and non-cultivated plots of prairie soils. Cultivated plots were under cultivation for an average of 22 years. Nitrogen losses were not as great as those determined by Shutte (1925) but trends were similar. Loss of nitrogen from Brown and Dark Brown soils constituted about 18 per cent of the original nitrogen content of each soil group. From one-third to one-half of the nitrogen loss was removed by crops. These figures are averages and mask large variations in local losses of nitrogen between the sampled plots, ranging from no apparent loss to 40 per cent of the original nitrogen content.

Employing the data obtained from these plots, Rennie, Racz and McBeath (1976) subsequently calculated an average annual nitrogen loss of 76 kg/ha/yr for the first 22 years of cultivation. However, the rate of depletion was much more rapid during the first two decades of cultivation, declining gradually thereafter. They suggest an average nitrogen loss of 47 kg/ha/yr over a 60-year cultivation period. Rennie (1977) estimates that the current average loss of nitrogen is 42 kg/ha/yr for the prairies. Of this, 14 kg are removed by crops, 11 kg leach below rooting depth, 10 kg are denitrified, and 7 kg are lost by erosion.

The above data discredits the observation of earlier authors that nitrogen losses are not important because of the immense nitrogen reserve capacity of prairie soils. The addition of inorganic nitrogen fertilizer is an inadequate substitute for these losses because the annual loss of available nitrogen in Alberta exceeds that applied as fertilizer (Nyborg, Malhi, and Timmermans, 1977). The nutrient content of prairie soils is expected to reach an equilibrium level but this has not occurred after 75 years of cultivation (Campbell, Paul, and McGill, 1976). Further, it is not known whether this equilibrium level is sufficient for sustained agricultural production over the long-term. Continued depletion of plant nutrients could restrict future crop production.

The organic matter content of prairie soils has also declined significantly. Shutte (1925) determined a 24 and 16 per cent loss of organic matter in the Black soils of Manitoba and Saskatchewan, respectively, after 25 years of cultivation. Newton, Wyatt, and Brown (1945) observed that the loss of organic carbon in plots located throughout the Brown and Dark Brown soil zones averaged 20 per cent of their original content after 22 years of cultivation. Hill (1954) studied the effect of six short and long-term crop rotations on organic matter content in the top 15 cm of a Dark Brown soil at Lethbridge over a 43-year period. Results indicate that an average loss of 19 per cent occurred for for all the rotations. Losses ranged from 6 per cent in a ten-year rotation including alfalfa and manure application to 36 per cent in a three-year rotation of wheat-wheat-fallow. Pittman (1977) conducted a similar study and found that the average organic matter content of all rotations decreased 15 per cent in the top 15 cm of soil and 24 per cent in the 15 to 30 cm soil layer after twenty years of cropping.

These losses of organic matter are important because they represent a significant decrease in a major source of nitrogen, sulphur, and micronutrients (Rennie, 1979). Further decline in the organic matter content of many prairie soils may necessitate significant increases in inorganic fertilizer use. In addition to reducing the supply of available nutrients, a low organic matter content also alters soil tilth and structure, properties which enhance microbial activity and the moisture-holding capacity of the soil.

5.3.4 Soil Erosion

Despite the lessons of recorded history and decades of voluntary soil conservation measures, erosion is still a major problem in southern Alberta.

The severity of soil erosion by water is guised by conflicting reports. Toogood (1963) generalized from experimental plots near St. Albert that soil erosion by water is not a major problem in Alberta. However, these plots were recently broken from their virgin state and it is unlikely that they adequately represented the numerous variations found in actual field conditions throughout the Province. The Canada Department of Agriculture (1974b) states that soil erosion by water is a major problem in southern Alberta citing 77,000 hectares of extensively eroded soils in the Lethbridge and Pincher Creek areas as evidence. These conflicting reports probably reflect the varying degrees of susceptibility of different soils to water erosion throughout the province.

Soil erosion by wind is a recognized problem in southern Alberta. Erdman (1942) found that the area in Alberta where wind erosion is most prevalent is in the Brown and Dark Brown soil zones. In this area twice as much wind occurs as in the central portion of the Province. Most of the winds occur in the late fall, winter, and early spring when large areas of cultivated land are exposed and, as a result, serious drifting can occur.

The Alberta Department of Agriculture (1979a) estimates that more than 100,000 hectares were affected by soil drifting in 1976 and 1977. Soil drifting is intensified by several agricultural practices. First, removal of crop residue prevents a protective cover on the soil surface. Second, excessive tillage associated with seed bed preparation and summerfallow removes any remaining surface cover and pulverizes the soil. Third, a trend toward larger dryland fields, in order to accomodate larger machinery, reduces the effectiveness of soil conservation measures such as shelterbelts and strip-cropping.

A finite quantity of good arable land (CLI classes 1, 2 and 3) in southern Alberta has resulted in an intensification of inputs such as fossil fuel and inorganic fertilizer. Although production has increased significantly, several constraints suggest that the long-term production of agricultural goods and services may be adversely affected. These constraints include expanding soil salinity, increasing acidity of cultivated soils, declining soil fertility, and intensified soil erosion.

CHAPTER 6

AN ECOLOGICAL APPRAISAL OF MONOCULTURE IN SOUTHERN ALBERTA

Monoculture is a cropping practice characterized by the growth of a single crop species in an area at a given point in time. This definition implies a spatial and temporal dimension. The former is apparent in the concentration of a crop within an area, whereas, the latter is apparent in the period of time that a crop occupies that area. Both dimensions form part of a continuum as shown in Figure 6-1. The spatial dimension (y-axis) is measured by the number of crop species per unit area and differentiates monoculture from polyculture. The temporal dimension (x-axis) is measured by the number of growing seasons that a given crop species is present and differentiates rotational cropping from temporal or continuous cropping. Both dimensions distinguish the four cropping practices displayed in Figure 6-1.

Rotational monoculture is characterized by relatively low spatial and temporal values indicating species homogeneity and frequent crop rotation. A three-year rotation of wheat-barley-oats exemplifies a rotational monoculture because at any point in time there is a single crop species present but over time the species grown are rotated. Temporal monoculture is also portrayed by species homogeneity but the length of time that a crop occupies an area is relatively high. Year-to-year production of a single crop, such as continuous wheat, exemplifies a temporal

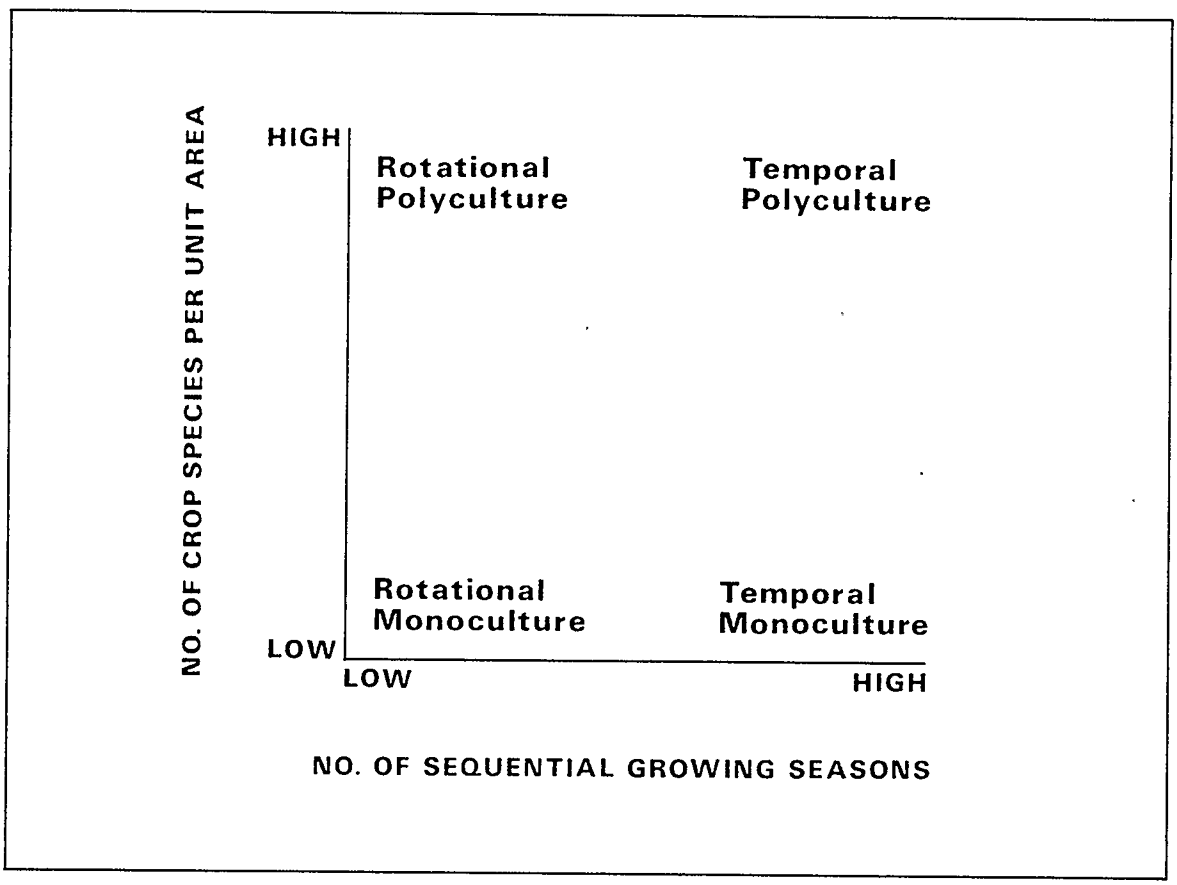


FIG. 6-1. MONOCULTURE IN A CONCEPTUAL FRAMEWORK

monoculture. In temporal polyculture a crop also occupies an area for a relatively long period of time but the number of species per unit area is greater than that of monoculture. This situation is more easily recognized in natural ecosystems (e.g., tropical rainforest) but it is approximated in agricultural ecosystems by native grassland, abandoned fields, and forest-grazing reserves. A rotational polyculture refers to a comparatively diverse number of crop species and frequent rotation of these species over time. This is evident in rotations which include grasses for pasture, legumes for green manure, and mixed cropping for grain production.

Three notes regarding Figure 6-1 merit attention. First, boundaries between the four cropping practices are not delineated but rather a continuum is implied. Second, in reality cropping practices can become very complex alternating between one or more of the four practices over time. Third, the interaction between a cropping practice and scale is not taken into account. This interaction is related to the size of a given area and the diversity of crop species within that area. For example, an area comprised of several farm units, each equal in size and growing a different but monoculture crop, would have a higher diversity relative to any one of the farm units growing only one crop.

6.1 Extent of Monoculture

Census data reveal that wheat, barley and oats are the three main cereal monocultures in southern Alberta occupying 56, 18 and 5 per cent of the total crop area, respectively, in 1976 (Statistics Canada, 1978). Figure 6-2 indicates the percentage of the crop area occupied by wheat in southern Alberta by census subdivisions (i.e., municipalities) for the year 1976. Wheat is grown on a significant proportion of the crop area in most census subdivisions although variations are evident. For example, County 8 and Municipal District 34 have more than 70 per cent of their crop area in wheat. Of the 20 municipalities present in southern Alberta, 13 have more than 50 per cent of their crop area in wheat and seven have less than 50 per cent of their crop area in wheat.

The above data indicate that cereal monoculture, particularly wheat, is a common cropping practice in southern Alberta. This has occurred in part because of a trend away from crop rotation and a trend toward continuous cropping (Siemens, 1963; Ledingham et al. 1973). Crop research has also influenced the shift toward monoculture because the benefits of this research (e.g., plant breeding, nutrient and moisture utilization) are applicable primarily to growing crops in monoculture (U.S. Department of Agriculture, 1973). Further, technological advances facilitate planting, pest and disease control, and harvesting of a single crop species.

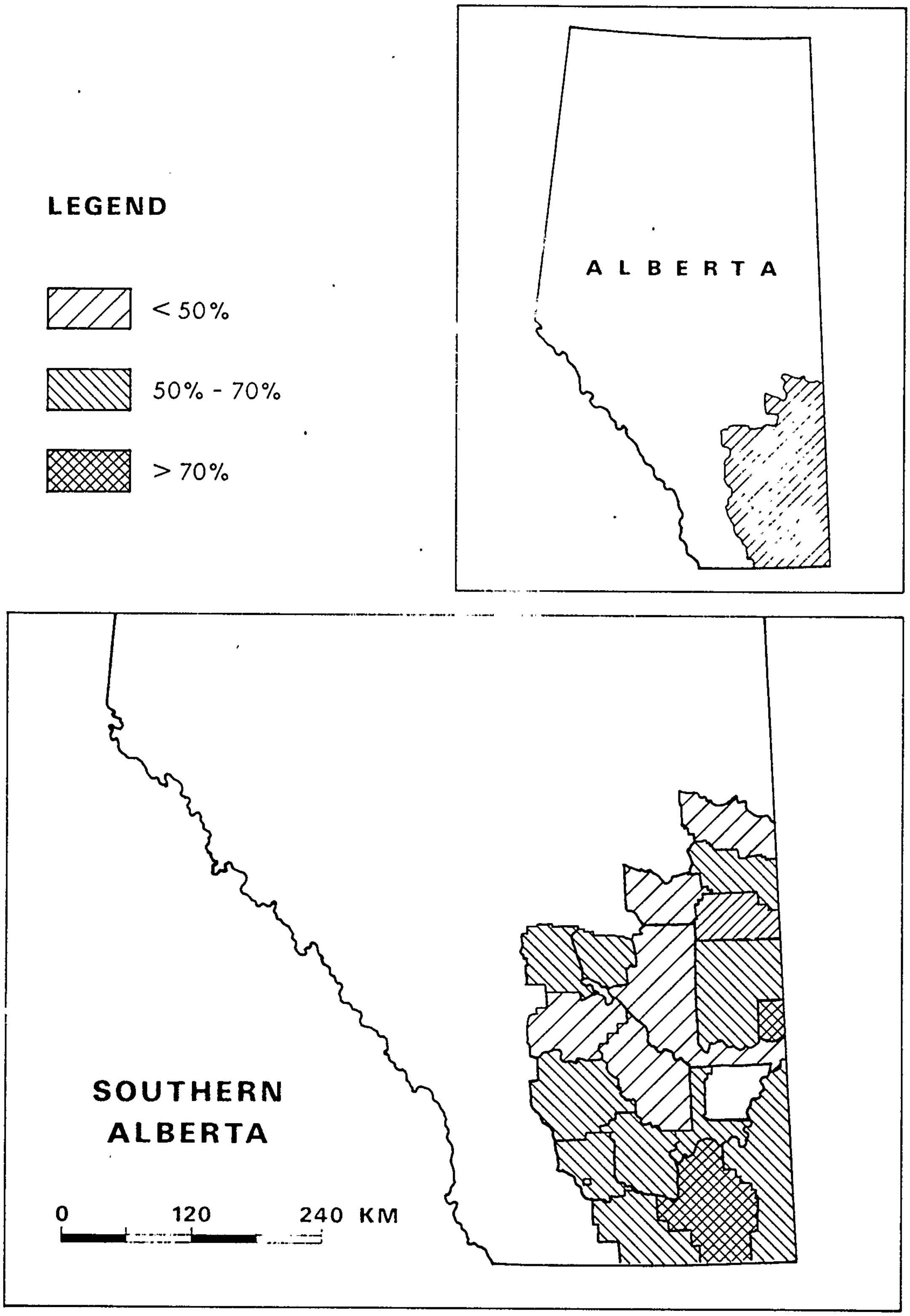


FIG. 6-2. PERCENTAGE OF CROP AREA IN WHEAT BY CENSUS SUBDIVISION, 1976 (STATISTICS CANADA, 1978)

6.2 Problems of Monoculture

A discussion of the problems of monoculture may lead to the premature conclusion that monoculture is a detrimental practice under all circumstances at all times. This is not necessarily the case. Growing a single crop per unit area may have several short-term production and economic benefits. These include:

1. minimized interspecific competition for resources (e.g., water, nutrients, light)
2. improved control of soil fertility and growth conditions because these can be more precisely adjusted for one crop than several (Siemens, 1963)
3. greater adaptation to certain limiting factors, for example, a salt-tolerant crop on saline areas
4. increased facilitation of mechanical operations because of synchronized seeding, rates of growth, and maturation
5. concentration of labour and capital into a single crop.

Lack of quantitative information is the main factor limiting a detailed discussion of the problems of monoculture in southern Alberta. Therefore, the approach is to review research findings which document problems associated with monoculture and, if possible, evaluate their applicability to southern Alberta. Caution must be excercised in applying these findings to specific sites because of site-specific variations in environmental conditions and management practices. The three main problems reviewed are the effect of monoculture on soil fertility, incidence of pest insects, and disease incidence.

6.2.1 Soil Fertility

The Rothamsted classical field experiments in England provide valuable information to assess the long-term effect of monoculture on soil fertility. Jenkinson and Rayner (1977) summarize data on changes in soil organic matter and nitrogen content for two exceptionally long experiments initiated in the mid-1800's. A continuous barley experiment started in 1852, representing an extreme form of temporal monoculture, consists of three plots: 1) unmanured, 2) manured annually, and 3) manured annually only from 1852 to 1871. The organic matter content of the manured plot has increased steadily whereas in the unmanured plot it declined during the first decade and remained unchanged thereafter. The organic matter content of the plot that received manure during the first 20 years increased during this period but subsequently declined. Although this plot's organic matter content is approaching a balanced state, it is still higher than that of the unmanured plot.

A continuous wheat experiment, started at Rothamsted in 1843, consists of 1) manured, 2) unmanured, and 3) fertilized (inorganic NPK) plots. The manured plot has a significantly higher nitrogen content than either the unmanured or fertilized plots, however, it has not changed since about 1900. Similarly, the nitrogen content of both the fertilized and unmanured plots have varied very little since 1881. Thus, in both experiments, organic matter and nitrogen content of all plots studied have reached equilibrium with the exception of increasing organic matter content in the manured plot of the barley experiment. These experiments show that appropriate long-term management practices, particularly the use of manure, can reduce the adverse effects on soil fertility under conditions of continuous cropping, even after exceptionally long periods of time.

In southern Alberta, the effect of various crop rotations on soil organic matter and nitrogen content has been measured on plots established in 1912 at the Agricultural Research Station in Lethbridge (Hill, 1954). Three rotations consist of wheat as the only crop. These are:

A - continuous wheat

B - a two-year rotation of wheat-summerfallow

C - a three-year rotation of wheat-wheat-summerfallow.

Three mixed rotations, also established in 1912, serve as a basis for comparing the effect of the wheat rotations on soil fertility. These rotations are:

D - a six-year rotation of fallow-wheat-oats-fallow (manured)-peas and oats for hay-oats

E - a nine-year rotation of fallow (manured)-corn for ensilage-winter rye-fallow-wheat-wheat-fallow-peas and oats for hay-wheat

F - a ten-year rotation of fallow (manured)-winter wheat-oats-alfalfa seeded without a nurse crop-alfalfa seed-alfalfa seed-alfalfa seed-fallow-corn for ensilage-wheat.

After 43 years of cropping, a consistent decrease in the percentage of nitrogen in the top 15 cm of soil occurred on each plot (Figure 6-3). Losses averaged 24 per cent for all six rotations. The smallest decrease (14 per cent) occurred in the ten-year rotation which included three years of alfalfa implying that mixed rotations containing legumes exert the least affect on soil nitrogen content. Losses of nitrogen from the continuous wheat, two-year, and three-year rotations were 18, 24, and 34 per cent, respectively, suggesting that a monoculture crop alternated with summerfallow contributes to a greater nitrogen decline than continuous cropping (see chapter 7.0). The largest decrease (35 per cent) occurred in the nine-year rotation which included three years of wheat in monoculture and three years of summerfallow.

Similar declines were reported by Hill (1954) for organic matter content (Figure 6-4). The six rotations averaged a loss of about 18 per cent. The ten-year alfalfa rotation lost six per cent, whereas the plot of continuous wheat lost nine per cent. Highest losses of organic matter were recorded for the two (11 per cent), three (36 per cent), and nine (33 per cent) - year rotations which all included summerfallow.

Pittman (1977) also studied the effect of several rotations on organic matter and nitrogen content of soils after 20 years of dryland cropping in southern Alberta. The rotations are as follows:

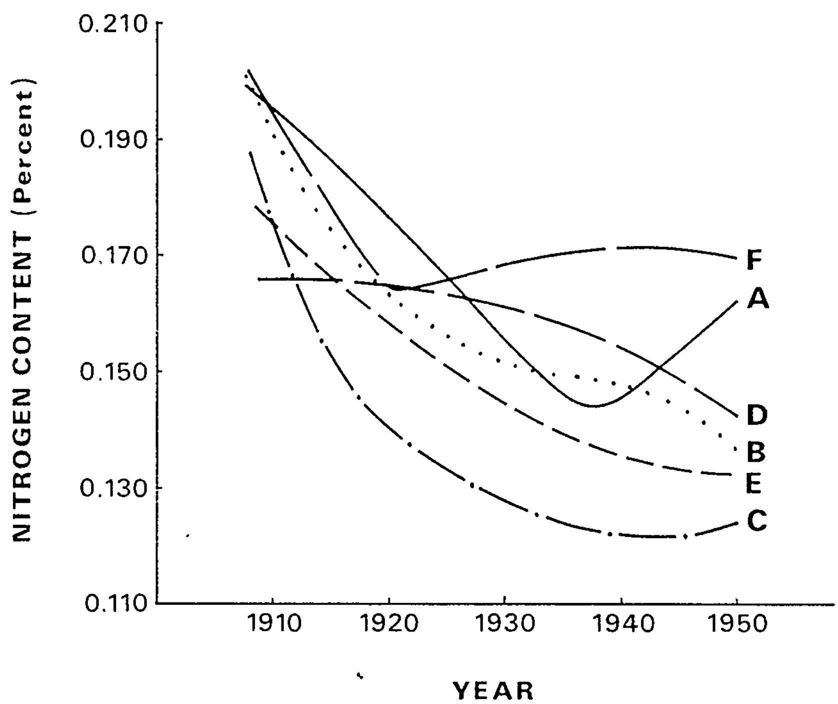


FIG. 6-3. LOSS OF NITROGEN IN THE TOP 15 CM. OF SOIL AS AFFECTED BY VARIOUS CROP ROTATIONS (HILL, 1954)

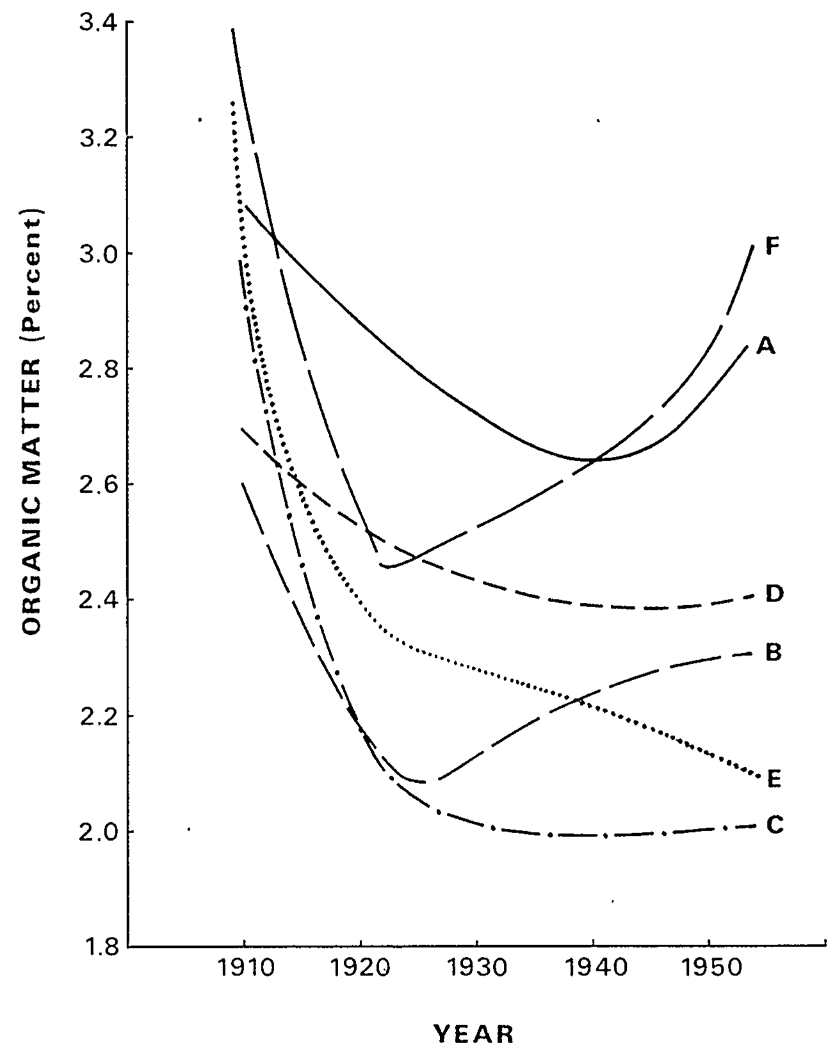


FIG. 6-4. LOSS OF ORGANIC MATTER IN THE TOP 15 CM. OF SOIL AS AFFECTED BY VARIOUS CROP ROTATIONS (HILL, 1954)

A - spring wheat continuously

B - fallow-spring wheat

C - fallow-spring wheat-spring wheat

D - fallow (manured)-spring wheat-spring wheat

F - fallow-winter wheat-winter wheat

H - fallow-spring wheat-spring wheat-crested wheatgrass and alfalfa-crested wheatgrass and alfalfa-crested wheatgrass and alfalfa

K - fallow-spring wheat-spring wheat-crested wheatgrass and alfalfa.

Both soil organic matter and soil nitrogen decreased in all rotations from 1954 to 1974 (Table 6-1). However, Pittman (1977) found that the annual rate of decrease differed throughout this period; it was lower from 1954 to 1967 than from 1967 to 1974. Smaller losses of organic matter occurred in the surface soils (0-15 cm) than the subsurface soils (15-30 cm) of all rotations because of shallow tillage which incorporated more straw and residue into the surface soil. Loss of soil organic matter was slightly lower in rotations which included grass (rotation K) or grass and alfalfa (rotation H) than in rotations where only a single crop was grown. Total nitrogen losses from the upper 30 cm of soil were highest in the fallow-spring wheat-spring wheat rotation (rotation D), closely followed by continuous wheat (rotation A). The smallest losses occurred in the longer-term rotations which included a hay crop (rotations H and K). Pittman (1977) states that crop yields have been maintained because plant

Table 6-1. Percentage Decrease of Soil Organic Matter and Soil Nitrogen in Various Rotations, 1954-1974 (Pittman, 1977)

Rotation	Depth (cm)	Organic Matter	Total Nitrogen
A	0-15	-11.9	-9.6
	15-30	-26.4	-16.6
B	0-15	-17.1	-9.6
	15-30	-24.7	-15.3
C	0-15	-19.0	-14.6
	15-30	-25.4	-15.3
D	0-15	-14.6	-6.7
	15-30	-24.5	-11.5
F	0-15	-11.9	-12.9
	15-30	-25.8	-17.1
H	0-15	-13.3	-7.6
	15-30	-19.7	-8.6
K	0-15	-13.4	-9.8
	15-30	-22.1	-8.8

nutrients have not yet reached critically low levels and that future crop yields will probably be restricted because of further depletion of plant nutrients from the soil.

6.2.2 Incidence of Insect Pests

Outbreaks of insect pests are frequently attributed to a low diversity of plant species. For example, forestry studies have shown that pest outbreaks are more frequent in pure stands of trees than in mixed stands (Graham, 1959). Murdoch, Evans, and Peterson (1972), studying abandoned field sites in Michigan, compared the diversity of plant-sucking insects with the diversity of plants and determined a positive correlation between them.

The relationship between insect and plant species diversity has been employed to explain pest outbreaks in monoculture of agricultural crops; it is generally thought that the incidence of pest outbreaks is higher in monoculture because of low crop diversity (van Emden and Williams, 1974; Geno, 1976; Science Council of Canada, 1976). However, this is supported by only a few documented field studies. For example, Pimental (1961), examined differences in insect species diversity between cabbage in a single-species stand and as a component of a mixed-species stand. Results indicate that insect pests, especially aphids, were scarce in the mixed-species stand but reached outbreak levels in the single-species stand. Potts and Vickerman (1974) documented outbreaks of cereal aphids in monoculture of winter wheat and spring barley. In 1970, their study area (West Sussex, Britain) contained an average arthropod density of 1850 per square metre of which 70 per cent were aphids. This study related aphid outbreaks to an increase in the area of cereal monoculture which has intensified since the mid-1900's because of hedge removal and geographic concentration of crops. During this period, cereal aphid density increased approximately five-fold in Britain.

Quantitative data relating outbreaks of insect pests to cereal monoculture have not been documented for southern Alberta. Several reasons may explain this deficiency. First, insecticides frequently mask the relationship between insect and plant species diversity by maintaining insect population levels below the threshold of economic damage. Second, when outbreaks do occur, they are usually related to factors other than crop diversity such as climate. For example, Smith and Holmes (1977) determined that the area in southern Alberta most consistently infested with grasshoppers coincides with the area that averages between 100 and 120 frost-free days and with annual precipitation between 36 and 46 cm. Third, policy priorities contribute to the lack of quantitative data by directing funds and expertise to other areas of research.

Although quantitative data relating outbreaks of insect pests to cereal monoculture are lacking, Turnock (1977) has qualitatively examined the population behaviour and life systems of native phytophagus (plant-eating) insects during the development of Canadian prairie agriculture. Factors such as grazing by domestic herbivores, reduced prairie fires, cultivation, introduction of non-native species, and intensified use of chemicals have developed a situation whereby native insects had to adapt to agricultural practices. For example, the migratory grasshopper (*Melanoplus sanguinipes*) has almost entirely abandoned native grassland to oviposit and feed in cereal fields. Similarly, the clear-winged grasshopper (*Camnula pellucida*) now depends entirely on cereal crops for nymphal and adult food. One grasshopper species (*Melanoplus spretus*) which was not able to adapt to agricultural practices is now extinct, despite being the predominant species in grasshopper outbreaks until 1874.

A native insect which has shown a remarkable adaptation to agriculture is the wheat stem sawfly (*Cephus cinctus* Norton). Turnoch (1977) states that the abundance and suitability of wheat stems (upon which the larval stage feeds) in wheat monoculture contributed significantly to the adaptability of the wheat stem sawfly. Its adaptation began after an enormous outbreak on native grasses in 1906. The pest continued to invade wheat fields culminating in an almost permanent outbreak from 1926-1949. Since this period the use of resistant varieties, characterized by a more solid stem, have greatly reduced populations of the wheat stem sawfly. However, populations increased again during the early 1970's because the area seeded to susceptible wheat varieties increased from 53 percent in 1972 to 63 per cent in 1973 and 1974.

Turnoch's (1977) study demonstrates qualitatively that outbreaks of insect pests in prairie cereals are related to low crop diversity. However, the significance of this relationship relative to other factors (e.g., climate) which affect pest outbreaks is unknown. Also, the importance of increasing crop diversity, or the spatial diversity of surrounding non-crop habitat for reducing the frequency and magnitude of pest population outbreaks is inclusive. For example, greater spatial diversity in the form of shelter belts, hedges, and uncultivated land may concentrate insect pests (T. Lewis, 1965) as well as beneficial insects (van Emden, 1965). Both van Emden and Williams (1974) and Murdoch (1975) state that increasing diversity per se by expanding the number of species (e.g., multiple cropping) or the number of spatial barriers (e.g., shelter belts, strip-cropping) is notan adequate basis for pest control. Reliance on one variable (e.g., number of species) while ignoring others (e.g., type of species and interactions) may result in further outbreaks. For example, infestations of the two-striped grasshopper (Melanoplus bivittatus) which oviposit along field edges may increase in strip-cropping because the edge forms a large proportion of the total crop area (York, 1951). Thus, much quantitative research is necessary before planned diversity can be used, on a site-specific basis, to maintain insect pests at desired population levels.

6.2.3 Disease Incidence

Several studies have investigated the incidence of disease organisms in cereal monoculture. In England, Shipton (1972) studied the incidence and severity of take-all, a fungal root disease, in monocultures of wheat and barley cropped successively for seven years. The intensity of the disease increased during the first three to five years, peaked one to two years later, and declined thereafter. The reason for this decline is not known although antagonism and mycoparasitism are suggested. Mundy and Selman (1973) observed that yields of winter wheat grown in monoculture tended to vary inversely with the percentage of plant roots severely infested with take-all. This disease contributed with other factors (weeds, soil fertility) to a 25 to 30 per cent decline in yield after three to five years of cropping and subsequently remained steady or improved slightly. In Denmark, Jensen (1975) also determined an inverse relationship between the incidence of take-all and yield of barley grown in monoculture for nine years. This relationship was most significant after the first three years of successive cropping.

In southern Alberta, field studies specifically designed to quantify the relationship between cereal monoculture and the incidence of disease are lacking. However, there is evidence to show that disease organisms are prevalent and that these have caused substantial damage to cereal crops grown in monoculture. For example, Tinline, Ledingham and Sallans (1975) state that the fungal disease common root rot is endemic in the prairies, annually affecting almost all wheat fields. Ledingham et al. (1973) estimate that loss of wheat yields due to common root rot in Alberta were 2.5, 6.8, and 5.1 per cent in 1969, 1970, and 1971, respectively. Areas with the highest incidence of disease and yield loss coincided with the Brown soil zone. Piening et al. (1976) estimate that loss of barley yields due to common root rot in Alberta were 11.1, 8.4 and 10.0 per cent in 1970, 1971, and 1972, respectively. These estimates demonstrate the effect of common root rot on yield but do not quantify the effect of cereal monoculture on the incidence of this disease. Field studies designed to investigate this relationship are required.

Two cropping practices which can act as disease control measures are crop rotation and mixed cropping. Ledingham (1961) showed the incidence of common root rot was lower in crop rotations with a long rotation period. This is because the disease host is removed for a length of time reducing the innoculum potential of an area. However, Ledingham et al. (1973) state that long crop rotations are not practical on the prairies (presumably because of economic factors). Hence, cereal crops are seldom planted on land with a low innoculum potential.

Johnston, Sanderson, and MacLeod (1978) demonstrated that mixed cropping reduced the incidence of pea diseases in Prince Edward Island. The severity and incidence of disease increased as the percentage of pea plants increased toward monoculture. Although this study was undertaken in an area dissimilar to the prairies, the concept of mixed cropping may be applicable as a disease control measure for cereal crop production, particularly in areas with a high innoculum potential. More long-term data is required to comprehensively evaluate the effect of cereal monoculture, crop rotation, and mixed cropping on disease incidence.

6.2.4 Other

Other problems of monoculture include the narrowing of the genetic base of many crops, modified populations of animal organisms, and reduced environmental quality.

Most crops grown in monoculture are the result of intensive plant-breeding programs which tend to narrow the crop's genetic base (U.S. Department of Agriculture, 1973; Science Council of Canada, 1976). The danger is that if one gene is incorporated into many varieties and a pest or parasite exists with a preference for the trait controlled by that gene, then, an epidemic could occur (Wade, 1972). Adams, Ellingboe, and Rossman (1971) cite several examples where disease epidemics have occurred because of a narrow genetic base. A classic example is the Irish potato famine (1845-1852) which occurred because large areas were planted with a potato variety highly susceptible to the fungus responsible for late blight disease. In the 1930's, good resistance to stem rust of wheat was obtained by the "Hope gene" which was rapidly incorporated into wheat varieties grown in Canada and the United States. However, by the late 1940's, a new strain of stem rust known as race 15B, highly pathogenic to varieties carrying the "Hope gene", seriously affected wheat production. A more recent example is the corn leaf blight epidemic which occurred in the United States in 1970 because the fungus responsible for the blight displayed a very high preference for a type of cytoplasm that had been incorporated into 80 per cent of the corn hybrids planted that year.

In the prairies, epidemics due to a narrow genetic base have been largely avoided because of climatic conditions unfavourable to many pests and diseases and because agricultural research has developed many resistant varieties (Science Council of Canada, 1976). However, climate and research have not always acted advantageously. For example, periods of drought generally increase the incidence of common root rot in wheat (Ledingham et al. 1973) and plant-breeding research developed two wheat cultivars which are resistant to the wheat stem sawfly but are highly susceptible to common root rot (Tinline and Ledingham, 1979). The federal government has recently established a plant gene pool to halt the loss of genetic stock used in breeding programs.

Changes in populations of soil organisms can also occur because of monoculture. Just as pest and disease organisms are affected by the type of cropping practice, it can be expected that soil organisms such as invertebrates (e.g., earthworms) are also affected. Although this has been documented elsewhere (Aleinikova and Utrobina, 1975), there is no evidence from southern Alberta to verify modified populations of soil organisms due to cereal monoculture. Mills and Alley (1973) comprehensively reviewed the effect of cropping practices on soil biota and generalized that modifications are possible but give no quantitative evidence to substantiate this.

The U.S. Department of Agriculture (1973) states that monoculture can adversely affect environmental quality. Monoculture is associated with increased sedimentation because of higher rates of soil erosion; greater nutrient loss because of increased runoff and leaching of inorganic fertilizers; and intensified pesticide use because of greater pest control requirements. Data specifically relating these findings to monoculture in southern Alberta are not available.

Cereal monoculture is a common cropping practice in southern Alberta. Comprehensive data derived from site-specific studies designed to assess the long-term effects of monoculture are lacking in this region. Data from long-term crop rotation studies conducted at the Agriculture Canada Research Station at Lethbridge indicate that monoculture may contribute to a decline in soil nitrogen and organic matter content. Limited quantitative evidence suggest that monoculture may increase the potential for outbreaks of insect pests and intensify the incidence of disease. Long-term data is needed to evaluate the effectiveness of crop rotations, mixed cropping,and planned diversity as insect pest and disease control measures. It would be inaccurate to conclude that monoculture is a detrimental practice under all circumstances at all times. The Rothamsted experiments demonstrate that nitrogen and organic matter content of soils under such extreme conditions as continuous cropping (i.e., temporal monoculture) for more than a century can be adequately controlled by appropriate management techniques.

CHAPTER 7

AN ECOLOGICAL APPRAISAL OF SUMMERFALLOW IN SOUTHERN ALBERTA

Summerfallow is the practice of tilling but not seeding or cropping an area of land for at least one growing season. The fallow period is the interval between harvesting a crop and planting the succeeding crop. During the summer months of the fallow period, tillage operations are carried out to break up and disturb the soil. Traditionally, summerfallow has been practiced for the following reasons:

1. greater release of nutrients, particularly nitrogen because of an increase in the rate of nitrification
2. increased accumulation of soil moisture because of enhanced infiltration of annual precipitation
3. decreased transpiration and growth of weeds because of intermittent cultivation which prevents uptake of moisture and nutrients stored during the fallow period.

7.1 Extent of Summerfallow

Summerfallow significantly affected the settlement of the Canadian prairies during the late 1800's by reducing the risk of crop failure due to drought. Summerfallow was first practiced in Canada in 1885 near Indian Head, Saskatchewan, where a local farmer planted wheat on a field cultivated the preceding year (Ford and Krall, 1979). The practice was quickly extended to Alberta where the area of summerfallow reached 1.2 million hectares in 1921, 3.0 million hectares in 1961, and 2.6 million hectares in 1976 (Alberta Department of Agriculture, 1971; Statistics Canada, 1978).

In southern Alberta, summerfallow is frequently alternated with a monoculture crop such as wheat or barley, over a two or three-year sequence depending on annual precipitation. The two-year crop-fallow sequence is more prevalent in the drier Brown soil zone whereas the three-year crop-crop-fallow sequence is more prevalent in the Dark Brown soil zone. During periods of above average annual precipitation, soil moisture conditions may permit an area to be recropped rather than summerfallowed.

Summerfallow occupied 1.4 million hectares in southern Alberta in 1976 representing 53 per cent of the total summerfallow area in the province during that year (Statistics Canada, 1978). The distribution of summerfallow in southern Alberta by municipality (i.e., census subdivision) is shown for 1976 in Figure 7-1. This is measured by the percentage of cultivated area occupied by summerfallow in each municipality. Summerfallow oc-

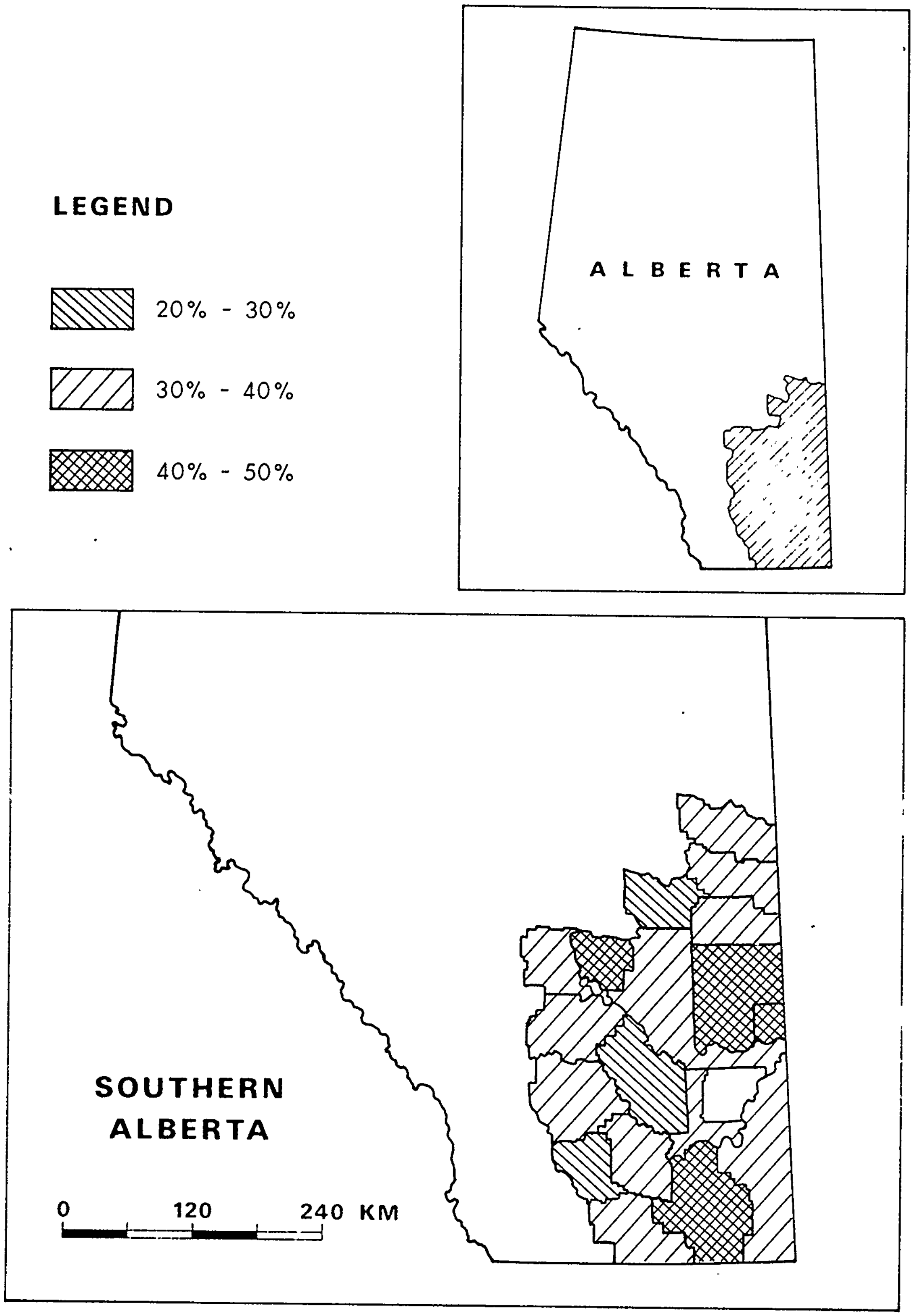


FIG. 7-1. PERCENTAGE OF TOTAL CULTIVATED AREA IN SUMMERFALLOW BY CENSUS SUBDIVISION, 1976 (STATISTICS CANADA, 1978)

cupies between 30 and 40 per cent of the cultivated area in most municipalities but variations among them do occur. Generally, the extent of summerfallow tends to decrease toward the western boundary of the region where annual precipitation is slightly higher. For example, within the Dark Brown soil zone, summerfallow occupies between 20 and 30 per cent of the cultivated area in three municipalities but only one municipality occupies between 40 and 50 per cent. Conversely, within the drier Brown soil zone, summerfallow occupies between 40 and 50 per cent of the cultivated area in three municipalities but only one municipality occupies between 20 and 30 per cent.

7.2 Effects of Summerfallow

Summerfallow is practiced to release nutrients, store moisture, and control weeds in order to increase yields. For example, Smika (1970) reported that average wheat yields of a wheat-fallow rotation were three times that of continuous wheat over a 27-year period in Nebraska. However, long-term data from the Agricultural Research Station at Lethbridge indicate that similar increases in yield have not occurred in southern Alberta. Hill (1954) showed that average yields of a wheat-fallow rotation were only 10 per cent higher than that of continuous wheat over a 43-year period. Pittman (1977) found that average yields of continuous wheat were actually four per cent higher than that of a wheat-fallow rotation over a 20-year period. These long-term findings suggest that alternatives to summerfallow need to be examined. Additional evidence which supports the need for examining alternatives include the effect of summerfallow on soil nitrogen and organic matter content, efficiency of moisture storage, dryland salinity, and soil erosion.

7.2.1. Soil Nitrogen and Organic Matter

Soil nitrogen and organic matter are affected by the frequency of summerfallow, declining more rapidly on frequently fallowed land. Ridley and Hedlin (1967) found that soil nitrogen content of continuous wheat, wheat-fallow, wheat-wheat-fallow, and wheat-wheat-wheat-fallow rotations averaged 0.27, 0.19, 0.26 and 0.25 per cent, respectivly, after 37 years of cropping on Black soils in Manitoba. Soil organic matter content averaged 7.2, 3.7, 4.9, and 4.7 per cent, respectively over the same period.

Chapter six presented data from Hill (1954) and Pittman (1977) which compared losses of nitrogen and organic matter in soils under various crop rotations in southern Alberta. Generally, those rotations which included a fallow period every second or third year showed higher losses of soil nitrogen and organic matter. Hill (1954) determined that nitrogen losses in the top 15 cm of soil under continuous wheat, wheat-fallow, and wheat-wheat-fallow averaged 18, 24, and 34 per cent, respectively, over a 43-year period. Pittman (1977) found that organic matter losses in the top 15 cm of soil under continuous wheat, wheat-fallow, and wheat-wheat-fallow averaged 12, 17, and 19 per cent, respectively, over a 20-year period. In both studies, soil nitrogen and organic matter were generally higher in rotations which included manure, grasses and alfalfa than in rotations which included a high frequency of summerfallow.

The soil nitrogen content of summerfallow fields in southern Alberta has recently been analysed from the numerous soil samples submitted by farmers to the provincial soil and feed testing laboratory. Results indicate that the average soil nitrogen content of summerfallow fields is declining. This is shown for the Brown and Dark Brown soils for two periods (1975-1977, and 1978) in Table 7-1. The average nitrogen content of summerfallow fields in 1978 is lower than that of the previous three-year average for both soil zones. The largest decrease (29.4 per cent) occurred in the Brown soils. The Alberta Department of Agriculture (1979b) states that, given adequate moisture reserves and a favourable growing season, lower soil nitrogen content in summerfallow fields could become a serious limiting factor for crop growth in southern Alberta.

7.2.2 Soil Moisture

Soil moisture conservation by summerfallow is an inefficient practice. Mathews and Army (1960) studied the effect of summerfallow on moisture storage efficiency in the Great Plains of the western United States. Results from 25 locations indicate that moisture storage efficiency was lower in crop-fallow rotations than in continuous cropping. On crop-fallowed soil an average of

Table 7-1. Average Nitrogen Content of Summerfallow Fields in Southern Alberta (Alberta Department of Agriculture, 1979b)

Soil Zone	1975-1977 Average Nitrogen Content (kg/ha)	1978 Average Nitrogen Content (kg/ha)	Per cent Decrease
Brown	45.9	32.4	29.4
Dark Brown			
Above Bow R.	48.9	35.8	26.8
Below Bow R.	39.2	31.3	20.2

16.3 per cent of the precipitation was stored during the fallow period, whereas, on continuously cropped soil 23.6 per cent of the precipitation was stored between harvest and subsequent seeding. Moisture loss in both cropping systems was attributed mainly to evaporation.

Staple and Lehane (1952) investigated the moisture storage efficiency of a wheat-fallow rotation after 11 years of cropping in southern Saskatchewan. The efficiency of moisture storage for seven fallow periods averaged 21 per cent of the precipitation. In each fallow period moisture storage efficiency was generally higher during the first fall and winter when the fields were in stubble and lower in summer and the following winter when the fields were bare. The authors recognized the inefficiency of summerfallow in storing moisture but concluded that it is a necessary practice because the quantity of water stored is necessary, in addition to annual precipitation, in order to adequately supply the moisture requirements of cereal crops.

The findings of the previous study are comparable to that of the Alberta Department of Agriculture (1975b) which reported that summerfallow is also an inefficient practice for storing soil moisture in southern Alberta. Data showing the quantity and percentage of moisture stored in 1.5 metres of soil under summerfallow at Lethbridge are shown in Table 7-2. The average moisture storage efficiency for the 21-month fallow period is 25 per cent of the precipitation. Most moisture is stored between harvest and spring and the least during summer although precipitation is

Table 7-2. Average Amount of Moisture Stored in 1.5 meters of Soil under Summerfallow, Lethbridge (Alberta Department of Agriculture, 1975b)

Lethbridge (1969-1974)	Harvest to Spring	Fallow Season	Fall to Spring	Total
Precipitation (cm)	18.3	18.0	16.5	52.8
Stored (cm)	8.7	1.5	3.0	13.2
Percentage Stored	47	9	19	25

nearly equivalent during both periods. Moisture losses occur primarily through evaporation but also runoff and deep percolation. The Alberta Department of Agriculture (1975b) also concludes that, despite the inefficiency of moisture storage, summerfallow is necessary in some instances to insure a crop.

7.2.3 Dryland Salinity

Dryland salinity is caused by excess moisture which redistributes and accumulates soil salts. Summerfallow may affect dryland salinity by providing this excess moisture. Moisture stored during the fallow period may percolate downward and seep laterally collecting salts and, then, rise to the surface by capillary action where it evaporates leaving an accumulation of salts.

Ford and Krall (1979) maintain that the crop-fallow cropping sequence is the principle cause of dryland salinity in Montana. The Alberta Department of Agriculture (1975b) also identifies summerfallow as an important cause of dryland salinity because of the inefficiency of this practice in storing soil moisture (Table 7-2). Deep percolation provides the moisture necessary for saline seepage to occur and tillage exposes more soil moisture to evaporation allowing salts to accumulate near the surface.

7.2.4. Soil Erosion

A report by the Soil Research Laboratory (1949) concluded that the type of farming practiced during the agricultural history of the prairies has caused a considerable increase in the erodibility of many soils. Summerfallow contributed significantly to this problem by exposing large areas of cultivated soils to winds of relatively high velocity. The erodibility of these soils is increased because tillage operations carried out during the fallow period adversely affected soil-binding properties such as surface roughness, vegetation cover, organic matter, and soil moisture.

Strip-cropping was strongly advocated as an effective erosion control measure during the early part of the century. Farmers in southern Alberta narrowed the width of fallowed fields, alternated strips of crop with strips of fallow, and positioned strips at right angles to the wind (Ford and Krall, 1979). These practices reduced wind erosion because the intensity of soil drifting decreases toward the leeward edge of a stripped area (Soil Research Laboratory, 1949). However, the effectiveness of strip-cropping as an erosion control measure is currently being reduced because of a trend toward wider strips (Alberta Department of Agriculture, 1979a).

7.3 Alternatives to Summerfallow

The above discussion suggests a need to examine alternatives to summerfallow. However, the practice is not likely to be eliminated because of the advantages of weed control and total moisture storage (despite its inefficiency) during the fallow period. Thus, modications to summerfallow as currently practiced merit consideration. These include minimum tillage, chemical fallowing, and flexible cropping.

Lindwall (1978) has documented the findings of ten years of minimum tillage research in southern Alberta. He studied summerfallow treatments involving conventional tillage, combinations of tillage and herbicides, and herbicides alone. Results indicate that the fallowed plot treated with herbicides alone consistently conserved more moisture over the ten-year period. The fallow treatment producing the highest wheat yield was the plot treated with herbicides and one tillage operation. Higher yields in this treatment were attributed to nitrogen released by the tillage operation. More than one tillage operation did not increase nitrogen signficantly. In addition to moisture and yield benefits, minimum tillage also improved crop residue cover to prevent soil erosion.

Minimum tillage can improve moisture conservation and reduce soil erosion but the need for weed control is increased because tillage operations are reduced. This necessitates chemical rather than mechanical control of weeds. Anderson (1971) compared mechanical and chemical weed control during five fallow periods in southern Saskatchewan. Results indicate that chemical summerfallow was effective in controlling weeds during the fallow periods but an average of five applications were necessary compared to four tillage operations. Chemical summerfallow also increased crop residue and soil temperature and reduced the percentage of erodible soil (less than 1 mm in diameter) at the end of summer. Further, moisture conservation equalled that achieved through conventional summerfallow tillage.

Implementation of minimum tillage and chemical summerfallow would probably reduce but not eliminate summerfallow as conventionally practiced. Reasons for this are largely economic (e.g., cost of herbicide and application) but also technical (e.g., specificity of weed control agent), and/or environmental (e.g., residue breakdown). An alternative to conventional summerfallow is flexible cropping. This concept implies that summerfallow is practiced only when and where conditions are such that recropping is not practical. The cropping sequence in flexible cropping is not fixed, as in a rigid crop-fallow rotation, but rather determined by site-specific conditions. For example, in dryland agriculture the decision to seed or fallow an area is based primarily on stored soil moisture at seeding time. If soil moisture content is high the area would be cropped, if it is low, the area would be fallowed. The Alberta Department of Agriculture (1976) recommends recropping when soil moisture at seeding time reaches a depth of 100 cm in sandy soils, 70 cm in loam soils, and 50 cm in clay soils. Moisture is the most important factor in a decision to recrop or fallow but other factors requiring consideration include the incidence of weeds, plant diseases, and insect pests, and socio-economic factors.

Summerfallow has been the focus of several research studies in southern Alberta. Research findings indicate that summerfallow can decrease soil nitrogen and organic matter content, increase soil salinity, and intensify soil erosion. Despite these findings, summerfallow is still commonly practiced throughout the region. Summerfallow is also characterized by a low soil moisture storage efficiency but the total quantity of moisture stored may necessitate this practice when and where soil moisture reserves are inadequate for crop growth. Alternatives to summerfallow requiring further feasibility studies include minimum tillage, chemical fallow, and flexible cropping.

CHAPTER 8

SUMMARY AND FUTURE RESEARCH REQUIREMENTS

The preceding study has provided a review and synthesis of current literature in the developing field of agricultural ecology and has attempted to evaluate the effects of a few selected practices on the long-term production of agricultural goods and services in southern Alberta. By understanding the structure and dynamics of agricultural ecosystems, agricultural ecology attempts to provide management guidelines which will assist man to sustain the yield of agricultural goods and services over a long time frame.

Throughout the course of this study, it has become apparent that the literature is permeated with inconsistencies and inadequacies concerning the nature and properties of agricultural ecosystems. Although there is a wealth of pertinent information in the formal disciplines of agriculture and ecology, the philosophical and theoretical links are still weak or absent. On the basis of the present study, several summary statements can be made about the general nature and properties of agricultural ecosystems and specifically those in southern Alberta.

1. An agricultural ecosystem can be defined as a geographical unit in which abiotic and biotic resources are channeled, directed, and/or arranged by various forms and degrees of agricultural activities into an ecological structure or system for the production of agricul-

tural goods and services. Agricultural ecosystems can be distinguished from natural ecosystems on the basis of continuity, selection of vegetation, species diversity, intra-specific diversity, nutrient and water supply, and pest and disease outbreaks.

2. Energy-subsidized agricultural ecosystems are characterized by auxiliary energy flows which minimize energy allocated for internal maintenance and maximize energy allocated for production.
3. Open cycles of nutrient transfer are prevalent in agricultural ecosystems and these are prone to losses by crop removal, leaching, denitrification, and soil erosion.
4. The structure of agricultural ecosystems is analogous to the developmental or early successional stage of ecosystem development in natural ecosystems. Energy subsidies are required to maintain this structure and to retard or halt the progression into a natural ecosystem.
5. Ecological concerns associated with energy-subsidized agricultural ecosystems include increased energy inputs to obtain additional units of energy output, disruption of nutrient cycles which result in increased nutrient loss, and reducion of species diversity which may increase the potential for pest outbreaks.
6. In southern Alberta, a finite quantity of good arable

land (CLI classes 1, 2 and 3) has resulted in an intensification of energy and fertilizer inputs which, in turn, has increased production significantly over the past several decades.

7. Trends which suggest that the long-term production of agricultural goods and services may be adversely affected in southern Alberta include expanding dryland salinity, increasing soil acidity, declining soil fertility, and intensified soil erosion.
8. Limited quantitative evidence suggest that monoculture may contribute to declining soil fertility, increased incidence of insect pest outbreaks, and greater disease incidence. Management practices such as crop rotation, mixed cropping, and planned diversity could, in many cases, reduce the severity of these problems.
9. Summerfallow has a low moisture storage efficiency, reduces soil nitrogen and organic matter content, contributes to dryland salinity, and increases the total area exposed to soil erosion. Alternatives to summerfallow include minimum tillage, chemical fallow, and flexible cropping sequences.

The site-specific component of this study focused on monoculture and summerfallow, which represent a very limited area where evaluation is necessary. Several problems currently faced by agriculture suggest that other areas also require evaluation.

Finite energy supplies and high costs make it apparent that, as prices rise and conventional energy sources diminish, future agriculture will have a different and, at least, more diversified energy base. Many options are open for future energy sources but research must be conducted now so that, as alternative energy technologies are put into place, they will make the transition from conventional to alternative energy sources smoother and, thus, prevent major disruptions in food production during that period. Some energy sources which offer significant potential at the farm unit level are solar energy for space heating and grain drying, vertical axis windmills for power generation and pumping irrigation water, and the conversion of manure and other sources of biomass into combustible fuels. These will require the development of low-cost, simple on-farm technologies and initially the technology to convert existing farm machinery and equipment to new energy sources. A likely area of development is refining the technology to convert farm manure into methane by microorganisms and modifying existing combustion engines to use this new fuel.

In the short-term, research efforts must be directed toward increased energy conservation and efficiency of use to maximize the time-span available to develop and implement alternative energy technologies. Two promising research areas relate to increasing biological and technological efficiency. Biological efficiency can be increased by developing cultivars which enhance photosynthetic efficiency (e.g., improve plant architecture for better light reception) and reduce vulnerability to limiting factors (e.g., drought resistance). Technological efficiency can be increased by designing adaptive technologies capable of utilizing a variety of combustible fuels, developing energy conserving tillage practices, and determining energy efficient types of irrigation and pest and disease control.

An area requiring major investigation is the rapid depletion of nitrogen and organic matter from many soils because of current tillage and cropping practices. Theoretically, soil nitrogen and organic matter levels are expected to reach an equilibrium but whether these levels are adequate for sustained agricultural production is a crucial concern. Research efforts should be directed toward determining how to balance nutrient budgets so that the rate of nutrient depletion is diminished. This implies an emphasis on nutrient recycling and increasing the efficiency of nutrient use; thus reducing the dependence on energy-intensive inorganic fertilizer production and application. Encouraging opportunities to achieve balanced nutrient budgets are evident in recycling farm-generated wastes by slurry systems and wastewater irrigation, transporting and applying wastes from municipal treatment plants to agricultural lands, developing crop cultivars which are more efficient in nutrient uptake and utilization, developing slow-release fertilizers, and developing nitrogen-fixation capability on non-leguminous plants.

Declining soil fertility, erosion, and the incidence of pest and disease outbreaks indicate that it is necessary to determine appropriate long-term management practices to reduce these problems on a site-specific basis. Recommended practices derived from general trends based on non-specified or poorly defined site conditions are inadequate for long-term management at the farm unit level. Site-specific management practices should emphasize local soil and water conservation needs, maintenance of soil fertility, and long-term control of insect pests and disease organisms. There are several favorable options to improve long-term management on a site-specific basis. Minimum tillage is a promising technique which can help maintain soil tilth, reduce moisture evaporation, and prevent soil drifting but the problem of weed control needs to be resolved. Crop rotation schedules based on balancing nutrient input and output, and tillage equipment designed to handle and retain crop residue in the soil, can improve and sustain soil fertility. Adequately spaced and designed vegetation patterns (e.g., shelterbelts, strip-cropping, cover crops) serve as effective erosion control measures. Planned diversity, crop rotations, and mixed cropping are potential short and long-term pest and disease control measures.

The high energy demands, disrupted nutrient cycles, and long-term management concerns associated with conventional farming practices suggest a need to develop long-term agricultural policies and research priorities. Studies into alternative types of farming systems should be carried out to compare energy intensiveness, nutrient budgets, effect on soil fertility, and incidence of pest and disease outbreaks. Examples of comparative studies include the examination of mixed versus monoculture grain or specialized livestock farming, organic versus conventional farming, and high technology versus labour intensive agriculture.

A major challenge is the identification and establishment of ways to implement research findings. Efforts should be directed toward shortening the time-lag between obtaining research findings and implementing these findings at the farm unit level. This suggests the need to conduct socio-economic studies focused on assessing educational and information dissemination services, evaluating current regulatory and voluntary programs, and examining present institutional arrangements so that the time-lag can be reduced.

There is a continuing need to analyse, evaluate, and forecast trends in the long-term stability of agricultural ecosystems so that farming practices may be modified when and wherever necessary. Research directed toward this end requires a long-term perspective which recognizes that, if production of agricultural goods and services are to be reliable and persistent over time, long-term degradation of the productive capacity of the agricultural ecosystem must be prevented. This long-term perspective needs to be integrated into overall agricultural policies, and mechanisms need to be established to implement these policies and the latest research findings into the day-to-day decision-making process at the the farm unit level.

REFERENCES

Adams, M., Ellingboe, A., and Rossman, E. 1971. Biological Uniformity and Disease Epidemics. Bioscience. 21: 1067-1070.

Alberta Department of Agriculture. 1971. Alberta Agriculture: A History in Graphs. Publication No. 1850-1. Edmonton.

Alberta Department of Agriculture. 1973. Agriculture Statistics Yearbook 1972. Agdex 853-8. Edmonton.

Alberta Department of Agriculture. 1975a. Agriculture Statistics Yearbook 1974. Agdex 853-8. Edmonton.

Alberta Department of Agriculture. 1975b. Dryland Salinity. Agdex 518. Edmonton.

Alberta Department of Agriculture. 1976. Alberta Farm Guide. Edmonton.

Alberta Department of Agriculture. 1977. Agriculture Statistics Yearbook 1976. Agdex 853-8. Edmonton.

Alberta Department of Agriculture. 1979a. Soil Drifting and its Control. Agri-News. February 19: 10-12.

Alberta Department of Agriculture. 1979b. Nitrogen Content of Fallow and Stubble Fields. Agri-News. April 23: 1-3.

Alberta Department of Agriculture. 1979c. Dryland Saline Seepage Control. Agri-News. April 30: 5-7.

Alberta Land Use Forum. 1974. The Future of Land Needs for Alberta Agriculture. Technical Report No. 5. Edmonton.

Aleinikova, M. and Utrobina, N. 1975. Changes in the Structure of Animal Populations in Soil under the Influence of Farm Crops. in Progress in Soil Zoology. Proceedings of the 5th International Colloquim on Soil Zoology. Academia, Prague. pp: 429-435.

Anderson, C. 1971. Comparison of Tillage and Chemical Summerfallow in a Semiarid Region. Canadian Journal of Soil Science. 51: 397-403.

Apple, J.L. 1977. Integrated Pest Management: Philosophy and Principles. in Ecology and Agricultural Production. L.Seatz (ed.). Symposium Proceedings. University of Tennessee, Knoxville. pp: 89-97.

Auclair, A.N. 1976. Ecological Factors in the Development of

Intensive-Management Ecosystems in the Midwestern United States. Ecology. 51: 431-444.

Azzi, G. 1956. Agricultural Ecology. Constable, London.

Black, J.N. 1971. Energy Relations in Crop Production - a Preliminary Survey. Annals of Applied Biology. 67: 272-278.

Blaxter, K. 1974. Power and Agricultural Revolution. New Scientist. 61: 400-403.

Bormann, F.H. and Likens, G.E. 1970. The Nutrient Cycles of an Ecosystem. Scientific American. 224: 92-101.

Bown, E.A. 1979. Personal Communication. Alberta Department of Treasury, Fuel Oil and Tobacco Tax Division. Edmonton.

Brady, N.C. (ed.) 1967. Agriculture and the Quality of our Environment. AAAS Publication 85. Washington, D.C.

Burwell, R.E., Schuman, G.E., Heineman, H.G., and Spamer, R.G. 1977. Nitrogen and Phospherous Movement from Agricultural Watersheds. Journal of Soil and Water Conservation. 32: 226-230.

Caborn, J.M. 1971. The Agronomic and Biological Significance of Hedgerows. Outlook on Agriculture. 6: 279-284.

Campbell, C.A., Paul, E.A., and McGill, W.B. 1976. Effect of Cultivation and Cropping on the Amounts and Forms of Soil N. in Proceedings of the Western Canada Nitrogen Symposium. Alberta Soil Science Workshop, Alberta Department of Agriculture. Edmonton. pp: 7-101.

Canada Department of Agriculture. 1974a. Farming Acid Soils in Alberta and Northeastern British Columbia. Publication 1521. Ottawa.

Canada Department of Agriculture. 1974b. Soil Erosion by Water. Publication 1083. Ottawa.

Canada Department of Agriculture. 1977. Management of Saline Soils. Publication 1624. Ottawa.

Canada Department of the Environment. 1976. Canada Land Inventory: Land Capability for Agriculture. Preliminary Report. Ottawa.

Central Office of Information. 1979. Britian 1979: An Official Handbook. London.

Cox, G.W. and Atkins, M.D. 1975. Agricultural Ecology. Bulletin of the Ecological Society of America. 56: 2-6.

De Soet, F. 1974. Agriculture and the Environment. Agriculture and Environment. 1: 1-15.

Downing, C. and Feldman, M. 1974. Energy and Agriculture. Canadian Farm Economics. 9: 24-31.

Duckham, A.N. and Masefield, G.B. 1969. Farming Systems of the World. Praeger, New York.

Dvoskin, D. and Heady, E.O. 1976. Farming Practices, Environmental Quality, and the Energy Crisis. Agriculture and Environment. 3: 1-13.

Eckholm, E.P. 1976. Losing Ground: Environmental Stress and World Food Prospects. W.W. Norton, New York.

van Emden, H.F. 1964. The Role of Uncultivated Land in the Biology of Crop Pests and Beneficial Insects. Scientific Horticulture. 17: 121-137.

van Emden, H.F. and Williams, G.F. 1974. Insect Stability and Diversity in Agro-Ecosystems. Annual Review of Entomology. 19: 445-475.

Erdman, R.L. 1942. Effects of Wind Erosion on the Composition and Fertility of some Alberta Soils. Canadian Journal of Agricultural Science. 22: 533-545.

Ford, G.L. and Krall, J.L. 1979. The History of Summerfallow in Montana. Bulletin 704. Montana Agricultural Experiment Station, Montana State University. Bozeman.

Frink, C.R. 1969. Water Pollution Potential Estimated from Nutrient Budgets. Agronomy Journal. 61: 550-553.

Frissel, M.J. (ed.) 1978. Cycling of Mineral Nutrients in Agricultural Ecosystems. Developments in Agriculture and Managed-Forest Ecology, 3. Proceedings of the First International Environmental Symposium of the Royal Netherlands Land Development Society. Elsevier Scientific, Amsterdam.

Geno, E. 1976. Ecological Agriculture: the Environmentally Appropriate Alternative. Alternatives. 5: 53-63.

Graham, S.A. 1959. Control of Insects through Sivicultural Practices. Journal of Forestry. 57: 281-283.

Groth, E. 1975. Increasing the Harvest. Environment. 17: 28-39.

Harper, J.L. 1974. Agricultural Ecosystems. Agro-Ecosystems. 1:

1-6.

Harris, D.R. 1969. The Ecology of Agricultural Systems. in Trends in Geography: An Introductory Survey. R.U. Cooke and J.H. Johnson (ed.). Permagon, Oxford. pp: 133-142.

Heichel, G.H. 1976. Agricultural Production and Energy Resources. American Scientist. 64: 64-72.

Hill, K.W. 1954. Wheat Yields and Soil Fertility on the Canadian Prairies after a Half Century of Farming. Soil Science Society of America Proceedings. 18: 182-184.

Hirst, E. 1974. Food-Related Energy Requirements. Science. 184: 134-138.

Jenkinson, D.S. and Rayner, J.H. 1977. The Turnover of Soil Organic Matter in some of the Rothamsted Classical Experiments. Soil Science. 123: 299-305.

Jensen, A. 1975. Danish Experiences with Cereals in Monoculture. European and Mediterranean Plant Protection Organization Bulletin. 5: 181-191.

Jenson N. E. and Stephanson, B.T. 1975. Energy Budgets for Crops Grown in Western Canada. Engineering Research Service Project. University of Alberta, Edmonton.

Johnson, H., Sanderson, J., and MacLeod, J. 1978. Cropping Mixtures of Field Peas and Cereals in Prince Edward Island. Canadian Journal of Plant Science. 58: 421-426.

Laster, M. 1974. Increasing Natural Enemy Resources through Crop Rotation and Strip Cropping. in Proceedings of the Summer Institute on Biological Control of Plant Insects and Diseases. F.G. Maxwell and F.A. Harris (ed.). University of Mississppii, Jackson. pp: 137-149.

Leach, G. L. 1976. Energy and Food Production. IPC Science and Technology. Guildford, Surrey.

Ledingham, R. 1961. Crop Rotations and Common Rootrot in Wheat. Canadian Journal of Plant Science. 41: 479-486.

Ledingham, R., Atkinson,T., Horricks, J., Mills, J., Piening, L., and Tinline, R. 1973. Wheat Losses due to Common Root Rot in the Prairie Provinces of Canada, 1969-71. Canadian Plant Disease Survey. 53: 113-122.

Lewis, T. 1965. Effects of Shelter on the Distribution of Insect Pests. Scientific Horticulture. 17/18: 74-84.

Lindwall. C.W. 1978. Minimum Tillage Research in Southern Alberta. Agriculture Canada Research Station, Lethbridge.

Lockeretz, W. (ed.) 1977. Agriculture and Energy. Academic, New York.

Loehr, R.C. 1977. Pollution Control for Agriculture. Academic, New York.

Loucks, O.L. 1977. Emergence of Research on Agro-Ecosystems. Annual Review of Ecology and Systematics. 8: 173-192.

MacKinnon, J.C. 1976. Design and Management of Farms as Agricultural Ecosystems. Agro-Ecosystems. 2: 277-293.

Major, J. 1969. Historical Development of the Ecosystem Concept. in The Ecosystem Concept in Natural Resource Management. G.M. Van Dyne (ed.). Academic, New York. pp: 9-21.

Mathews, O and Army, T. 1960. Moisture Storage on Fallowed Wheatland in the Great Plains. Soil Science Society of America Proceedings. 24: 414-418.

Mayer, A. and Mayer, J. 1974. Agriculture, the Island Empire. Daedalus. 103: 83-95

McCoy, D.A. and Webster, G.R. 1977. Acidification of a Luvisolic Soil Caused by Low-Rate, Long-term Application of Fertilizers and its Effects on Growth of Alfalfa. Canadian Journal of Soil Science. 57: 119-127.

McCracken, L.J. 1973. The Extent of the Problem. in Proceedings of the Alberta Dryland Salinity Workshop. Lethbridge.

Mills, J. and Alley, B. 1973. Interactions between Biotic Components in Soil and their Modifications by Management Practices in Canada: A Review. Canadian Journal of Plant Science. 53: 425-441.

Moore, B. 1920. The Scope of Ecology. Ecology. 1: 3-5.

Motiuk, K. 1979. Personal Communication. Alberta Department of Agriculture, Statistics Branch. Edmonton.

Mundy, E. and Selman, M. 1973. Intensification of Cereals: Cereal Monoculture Duration and Nitrogen Rate, Part I, Winter Wheat. Experimental Husbandry. 25: 22-40.

Murdoch, W. 1975. Diversity, Complexity, Stability and Pest Control. Journal of Applied Ecology. 12: 795-807.

Murdoch, W., Evans, F., and Peterson, C. 1972. Diversity and

Pattern in Plants and Insects. Ecology. 53: 819-828.

National Academy of Sciences. 1974. Productive Agriculture and a Quality Environment. Committee on Agriculture and the Environment. Washington, D.C.

Neal, O.R. 1944. Removal of Nutrients from Soil by Crops and Erosion. Agronomy Journal. 36: 601-607.

Newton, J.D., Wyatt, F.A., and Brown, A.L. 1945. Effects of Cultivation and Cropping on the Chemical Composition of some Western Canada Prairie Province Soils. Part III. Scientific Agriculture. 25: 718-737.

Nyborg, M., Malhi, S.S., and Timmermans, J. 1977. Losses of Crop-available Nitrogen from Soils. Agriculture and Forestry Bulletin. No. 33: 33-39.

Odum, E.P. 1968. Energy Flow in Ecosystems: a Historical Overview. American Zoologist. 8: 11-18.

Odum, E.P. 1969. The Strategy of Ecosystem Development. Science. 164: 262-270.

Odum, E.P. 1971. Fundamentals of Ecology. 3rd edition. W.B. Saunders, Philadelphia.

Odum, H.T. 1971. Environment, Power, and Society. Wiley-Interscience, New York.

Penny, D.C. and Henry, J.L. 1976. Reaction of Fertilizer Nitrogen with Soil Components. in Proceedings of the Western Canada Nitrogen Symposium. Alberta Soil Science Workshop, Alberta Department of Agriculture. Edmonton. pp: 275-298.

Penny, D.C., Nyborg, M., Hoyt, P.B., Rice, W.A., Siemens, B., and Laverty, D.H. 1977. An Assessment of the Soil Acidity Problem in Alberta and Northeastern British Columbia. Canadian Journal of Soil Science. 57: 157-164.

Pettapiece, W. 1979. Personal Communication. Alberta Research Council, Soil Survey Branch. Edmonton.

Piening, L., Atkinson, T.G., Horricks, J., Ledingham, R., Mills, J., and Tinline, R. 1976. Barley Losses due to Common Root Rot in the Prairie Provinces of Canada, 1970-72. Canadian Plant Disease Survey. 56: 41-45.

Pimental, D. 1961. Species Diversity and Insect Population Outbreaks. Annals of the Entomological Society of America. 54: 76-86.

Pimental, D., Hurd, L.E., Bellotti, A.C., Foster, M.J., Oka, I.N., Sholes, O.D., and Whitman, R.J. 1973. Food Production and the Energy Crisis. Science. 182: 443-449.

Pittman, U.J. 1977. Crop Yields and Soil Fertility as Affected by Dryland Rotations in Southern Alberta. Communications in Soil Science and Plant Analysis. 8: 391-405.

Potts, G.R. and Vickerman, G.P. 1974. Studies on the Cereal Ecosystem. Advances in Ecological Research. 8: 107-197.

Rappaport, R.A. 1971. The Flow of Energy in an Agricultural Society. Scientific American. 224: 116-132.

Rennie, D.A. 1977. Soil, the Threatened Resource. in Challenges and Opportunities in Saskatchewan Agriculture. Saskatchewan Science Council. Background Study 1. Regina. pp: 17-27.

Rennie, D.A. 1979. Intensive Cultivation: the Long-term Effects. Agrologist. 8: 20-22.

Rennie, D.A., Racz. G.J., and McBeath, D.K. 1976. Nitrogen Losses. in Proceedings of the Western Canada Nitrogen Symposium. Alberta Soil Science Workshop, Alberta Department of Agriculture. Edmonton. pp: 326-353.

Ridley, A. and Hedlin, R. 1967. Soil Organic Matter and Crop Yields as Influenced by the Frequency of Summerfallowing. Canadian Journal of Plant Science. 48: 315-322.

Ryszkowski, L. (ed.) 1974. Ecological Effects of Intensive Agriculture (first attempt at a synthesis). Polish Academy of Sciences. Institute of Ecology, Warsaw.

Science Council of Canada. 1976. Food Production in the Canadian Environment. Study on Population, Technology and Resources. Supply and Services Canada, Ottawa.

Shipton, P.J. 1972. Take-all in Spring-Sown Cereals under Continuous Cultivation: Disease Progress and Decline in Relation to Crop Succession and Nitrogen. Annals of Applied Biology. 71: 33-46.

Shutte, F.T. 1925. The Influence of Grain Growing on the Nitrogen and Organic Matter Content of the Western Prairie Soils of Canada. Bulletin No. 44-NS. Dominion of Canada Department of Agriculture.

Siemens, L.B. 1963. Cropping Systems: An Evaluative Review of Literature. Faculty of Agriculture and Home Economics, University of Manitoba. Winnipeg.

Singh, B. and Sekhon, G.G. 1978. Nitrate Pollution of Groundwater from Farm Use of Nitrogen Fertilizers - a Review. Agriculture and Environment. 4: 207-225.

Smika, D.E. 1970. Summerfallow for Dryland Winter Wheat in the Semi-Arid Great Plains. Agronomy Journal. 62: 15-17.

Smith, D.S. and Holmes N.D. 1977. The Distribution and Abundance of Adult Grasshoppers (Acrididae) in Crops in Alberta, 1918-1975. Canadian Entomologist. 109: 575-592.

Smith, R. and van den Bosch, R. 1967. Integrated Control. in Pest Control: Biological, Physical, and Selected Chemical Methods. W. Kilgore and R. Doutt (ed.). Academic, New York. pp: 295-340.

Smith, R.L. 1974. Ecology and Field Biology. 2nd edition. Harper and Row, New York.

Snaydon, R.W. and Elston, J. 1976. Flows, Cycles and Yields in Agricultural Ecosystems. in Food Production and Consumption: the Efficiency of Human Food Chains and Nutrient Cycles. A.N. Duckham, J.G.W. Jones and E.H. Roberts (ed.). North-Holland, Amsterdam. pp: 27-41.

Soil Research Laboratory. 1949. Soil Moisture, Wind Erosion, and Fertility of Some Canadian Prairie Soils. Canada Department of Agriculture. Swift Current, Saskatchewan.

Southwood, T.R.E. and Way, M.J. 1970. Ecological Background to Pest Management. in Concepts of Pest Management. R.L. Rabb and F.E. Guthrie (ed.). Proceedings. N.C. State University, Raleigh. pp: 6-28.

Spedding, C.R.W. 1975. The Biology of Agricultural Systems. Academic, London.

Spurr, S.H. 1969. The Natural Resource Ecosystem. in The Ecosystem Concept in Natural Resource Management. G.M. Van Dyne (ed.). Academic, New York. pp: 3-7.

Staple, W. and Lehane, J. 1952. The Conservation of Soil Moisture in Southern Saskatchewan. Scientific Agriculture. 32: 36-47.

Statistics Canada. 1975. Canada Year Book 1974. Information Canada, Ottawa.

Statistics Canada. 1977. Index of Farm Production. Catalogue 21-203. Ottawa.

Statistics Canada. 1978. Agriculture: Alberta. Catalogue

96-809. Ottawa.

Steinhart, J.S. and Steinhart, C.E. 1974. Energy Use in the U.S. Food System. Science. 184: 307-316.

Tansley, A.G. 1935. The Use and Abuse of Vegetational Concepts and Terms. Ecology. 16: 284-307.

Thompson, D. and Gimby, M. 1979. A Study of the Energy Consumption of Different Agronomic Practices in Saskatchewan: Year II. Saskatchewan Research Council, Saskatoon.

Timbers, G.E. 1977. Present use of Energy on Canadian Farms. Engineering Research Service. Agriculture Canada, Ottawa.

Tinline, R. and Ledingham, R. 1979. Yield Losses in Wheat and Barley Cultivars from Common Root Rot in Field Tests. Canadian Journal of Plant Science. 59: 313-320.

Tinline, R., Ledingham, R., and Sallans, B. 1975. Appraisal of Loss from Common Root Rot in Wheat. in Biology and Control of Soil-Borne Plant Pathogens. G.W. Bruehl (ed.). American Phytopathological Society. St. Paul. pp: 22-26.

Toogood, J.A. 1963. Water Erosion in Alberta. Journal of Soil and Water Conservation. 18: 238-240.

Turnoch, W.I. 1977. Adaptability and Stability of Insect Pest Populations in Prairie Agricultural Ecosystems. Minnesota Agricultural Experiment Station Bulletin. 310: 89-101.

U.S. Department of Agriculture. 1973. Monoculture in Agriculture: Extent, Causes, and Problems. Report of the Task Force on Spatial Heterogeneity in Agricultural Landscapes and Enterprises. Washington, D.C.

U.S. Department of Commerce. 1978. Statistical Abstract of the United States: 1978. 99th edition. Washington, D.C.

Van Dyne, G.M. 1969. The Ecosystem Concept in Natural Resource Management. Academic, New York.

Van Dyne, G.M. and Abramsky, Z. 1975. Agricultural Systems Models and Modelling: an Overview. in Study of Agricultural Systems. G.E. Dalton (ed.). Applied Science, London. pp: 23-106.

Wade, N. 1972. A Message from Corn Blight: the Dangers of Uniformity. Science. 177: 678-679.

Watt, K.E.F. 1973. Principles of Environmental Science.

McGraw-Hill, New York.

Winburne, J.N. 1962. A Dictionary of Agricultural and Allied Terminology. Michigan State University Press.

York, G.T. 1951. Oviposition by the Two-Striped Grasshopper in a Strip-Farming Area. Journal of Economic Entomology. 44: 119-120.