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SUSTAINABLE HILLSLOPE FARMING: A CASE STUDY IN SUSTAINABLE AGRICULTURE AT KELLOGG BIOLOGICAL STATION, Michigan State University

BY

John Dixon Smith

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ABSTRACT

SUSTAINABLE HILLSLOPE FARMING: A CASE STUDY IN SUSTAINABLE AGRICULTURE AT KELLOGG BIOLOGICAL STATION, MSU

BY

John Dixon Smith

Farm management strategies need to be designed which conserve soil on hillslopes, while maintaining profitability.

In this study, data from on-site analysis of the study area was incorporated with spatial data from the region and analyzed with the Comprehensive Resource Inventory and Evaluation System, developed at MSU. Knowledge of the physical and social environment, as well as knowledge of land evaluation and sustainable agricultural principles, resulted in presentation of several land use/management scenarios. Each scenario was modeled to provide information regarding yield and erosion levels.

The continuous corn system resulted in excessive amounts of soil erosion as estimated by the USLE. Minimum tillage, no-tillage, contour cultivation, cover cropping, and strip cropping provided decreased amounts of soil erosion. Use of mulching, manure, and agroforestry concepts were discussed as a means of decreasing erosion without adversely impacting yields or profits.

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CHAPTER 1

INTRODUCTION

Proper farm management techniques on hillslopes will help to achieve sustainable agricultural systems. Improper management of sloping lands has contributed to soil erosion throughout the world. Sedimentation is the leading cause of water pollution in the U.S., and a loss of soil productivity due to erosion has had devastating impacts on the health and welfare of a good portion of the non-industrialized world (Troeh et al., 1980). Designing management practices for sloping lands which are competitive in terms of production potential, as well as being environmentally sound, is a challege of paramount importance for researchers and farmers around the world.

The problem melds the skills and knowledge of modern agriculture with the concerns of conservationists. Solutions lie in designing systems which meet present day production needs, while considering the quality of tomorrow's environment. A study initiated on plots at the Kellogg Biological Station of Michigan State University in Hickory Corners, Michigan provides analysis of various hillslope management practices which focus on creation of sustainable systems.

The relation between landscape position and sustainable production systems has great implications for land use planning. It is particularly pertinent in light of the fact that vast tracts of marginal land are being farmed in the "third-world", a practice which continually decreases the production potential of those countries. It is also pertinent for so-called "developed" countries, where concern over pollution has focused attention on the destructive practices of high-input agriculture. Murray (1977) states that population pressure often stimulates some form of adaptation within a society to counteract the stress put on the natural resource base. This adaptation, when migration to arable uncultivated regions is not possible, could take the form of technological improvements in farming methods, increased numbers of crops per land unit, development of labor intensive practices, or more equitable distribution of land.

Problems arise when a society does not or can not adapt to an increase in the man/land ratio. Through resultant practices of overgrazing, overcropping, and deforestation, natural resources become depleted, agricultural yields decrease, and the rate of malnutrition begins to rise. If nothing is done to combat the problem, serious famine can result, as was the case in the Sahelian and Northeast regions of Africa in 1984, and which appears to be occuring again today in the later region. In the Western hemisphere, the country of Haiti provides a glaring example of this process. According to World Bank (1987), Haiti has the unenviable distinction of being the poorest country in the West. The rural population is growing at a rate of 2% a year, and the country has already lost 20% of its arable land due to the effects of deforestation and erosion. An additional 1% is estimated lost each year (Segal and Weinstein, 1984). Clearly new strategies need to be applied in some of the less industrialized nations, but the United States also suffers from inappropriate land use techniques.

Unsustainable agricultural practices which result in large amounts of soil erosion can have detrimental effects on farmers and American society alike. Eroded land will show a decrease in available nutrients, a destruction of soil structure, and a depletion of soil moisture; all of which will result in a reduction in the farmer's producer surplus-- less produce for more input. Off-farm impacts of erosion are even more severe (Clark et al., 1985). They can have a major effect on the quality of water resources, including increased sediment loads in streams and reservoirs, nutrient loading in lakes, and pesticide contamination of groundwater. Fish and wildlife populations can diminish, swimming and boating can become troublesome and even hazardous, and the general aesthetic value of the resource can depreciate. In addition, erosion can have serious implications for human health (Troeh et al., 1980).

There are many complex factors contributing to these global problems. Designing hillslope management practices which are sustainable requires comprehension and consideration of the factors and linkages affecting the local environment. These ecosystems are unique unto themselves, and therefore localized analysis and small-scale solutions are important for sustainable development. Factors which make up these systems include social, cultural, institutional, and economic aspects, as well as the physical components of the land unit in question. Integration of these components and prediction of results due to various management practices can be greatly aided through the use of recent technical advances in decision-support systems for land use planning and agroecology.

One such technology advance is the development of the Geographic Information System (GIS). A GIS is a system which allows a user to organize and analyze spatial data in an ordered fashion. Data may be entered, stored and retrieved from the system, and in addition may be manipulated to create user-specified combinations of variables. Results may be produced in either tabular or cartographic form (Marble and Peuquet, 1983).

Another perspective, agroecology, as its name implies, finds its roots in the disciplines of agriculture and ecology.

The concepts and principles in this field meld those of its parent disciplines. Concern has grown over the philosophy of maximizing production at the expense of the environment. Agriculture often acts as an artificially imposed system on the natural state. Because the natural state resists the imposed system, large quantities of inputs are needed to maintain desired levels of production. This is especially true in the industrialized countries. Such a relationship leads to degradation of the natural system. Gulinck (1986, p. 80) states, "The new message, although not fully adopted, is `adapt agriculture to ecosystems' rather than the reverse".

Thesis Objective

The objective of this research is to compare alternative cropping patterns and crop selection to promote sustainable hillslope farming in the study area of Hickory Corners, Michigan. The null hypothesis is that there is no relation between alternate management strategies and erosion rates. The research hypothesis is that certain alternative land management strategies to the continuous corn system used to provide baseline data will result in lower soil erosion rates.

"Sustainable" for the purposes of this research is defined as "options which conserve resources while not substantially reducing total yields and thus farm income, and which are acceptable to farmers given the physical, social, economic, and political environments in which they exist".

Therefore, alternative land management strategies selected will be practices that are currently being used by some farmers and practices which do not substantially reduce total yield.

A Geographic Information System is a tool which can aid in analysis of management selection. Results of soil and plant sampling along the hillslope are incorporated into the land use recommendations, thus making possible inclusion of any physical variation found at a very fine scale. Use of models to predict crop production and soil loss aid final land use/management suggestions.

The aim of this study can be posed as a research question. What "optimum" management strategies can be developed for the study area which reduce environmental degradation, particularly soil erosion, while maintaining adequate agricultural yields? Soil erosion levels are estimated using the Universal Soil Loss Equation (Foster, 1988; Troeh et al., 1980) and keeping this loss at an acceptable level determined by local tolerance levels (defined as the amount of soil that can be lost while still maintaining in-depth soil productivity due to bio-physical regeneration). An acceptable level of crop yield is determined by comparing projected yields to average yields obtained in the area for similar land units.

The techniques used were to digitize soil and topography maps from the study area and to establish relatively homogeneous zones based on soil types and topography. Climate data is not included in zone formation due to the relatively small study area, and assumed uniform climate parameters. These zones, which will be known as micro-agroecological zones (AEZ's), will be formed with the aid of the GIS. The AEZ will form the basis for developing strategies to achieve the objective. Data collected down the length of the slope on various soil factors which affect crop growth, as well as on crop yield itself serves as background information for the management strategies suggested. The GIS will aid in resource inventory, data management and manipulation, and final report generation.

Thesis Organization

Chapter two of the thesis explores the relevant work published relating to this study. The chapter begins with a description of the basic principles of land evaluation. Following this is a detailed analysis of soil erosion and of agroecology; presented as the rationale for conducting this study. A fourth section describes the basic functions of the Comprehensive Resource Inventory and Evaluation System-GIS (CRIES-GIS) developed at Michigan State University, which is the GIS used in this study. Also included in this section is a discussion of the YIELD Model of the CRIES Agroeconomic Information System, as this model is also used in the study. The concluding section examines the natural and social systems of the study area, and how they affect acceptance of the suggested management strategies.

Chapter three outlines the methods used in the study, while chapters four and five present the results and a discussion of these results respectively. Chapter six contains the conclusions, including a discussion of the applicability of these results, and recommendations for further research.

CHAPTER 2

LITERATURE REVIEW

Land Evaluation

The general purpose of land evaluation is to judge a given region's suitabiltiy to a particular activity. This concept has evolved throughout history. Even today, however, the guidelines to performing land evaluation are not concrete. Land evaluation is a systematic assessment of a land unit's potential for various types of land use, which would meet the expressed needs of the user. The process entails the execution and subsequent interpretation of integrated surveys. These surveys, or resource inventories, examine all natural and human components of the land unit and determine how they interact. Planners and technicians can take the information generated through resource inventories and land evaluation and apply it in trying to formulate optimal use of the land (McRae and Shelton, 1982; Dent, 1981; Beek, 1978).

Mankind has always evaluated land. Locations were selected because they met certain needs; others discarded if they proved inadequate. This was probably originally done on a trial and error basis. A cave provided more protection from the rain and wild animals (as long as it was unoccupied) than did a tree. A forest-savannah transition zone had a greater diversity of wildlife and therefore served well as hunting grounds. Corn produced thicker, healthier stems and more bountiful ears in loamy soil as opposed to either sand or clay. In all of these ways, and many more, man would look at his environment in an evaluative manner and try and decide where a suitable region lay for what he wanted to accomplish.

In the past several decades land evaluation and resource inventory have undergone some dramatic changes. The approach has become increasingly quantitative, especially when measuring physical factors. Since environments and human populations are not static entities, land use began to be looked at over time. This dynamic approach has been incorporated into land evaluation. Improvements in technology have also been applied to this field. The use of remote sensing and geographic information systems has resulted in savings in both time and money for data acquisition, processing and manipulation. In more recent years the relationship between economics and land use has been more clearly defined, and the social aspects have also begun to be examined critically (Bloemer & Needham, 1986; McRae and Shelton, 1982; Dent, 1981; Beek, 1978; Buie, 1961).

Though no one land evaluation method has become universally accepted, the FAO's "Framework for Land Evaluation" probably comes closest (Beek, 1978; FAO, 1976). The framework grew out of years of experience in land evaluation from FAO-assisted development projects in the third-world. It was designed to be applicable throughout the world. There are seven major points to consider when using the FAO's framework. They can be phrased as questions by the evaluator:

- What is the present land use and what will be the effect(s) should this use continue?
- How may present management practices be changed in order to affect improvement within the present land use?
- What are the possible alternate land uses?
- What are the recurring inputs needed to achieve these alternate land uses and minimize the adverse effects?
- Which of these alternate land uses can be sustained?
- What are the benefits of each type of use?

Should a major change in the landscape itself be needed to achieve a desired land use, two additional questions should be answered:

- What changes in the landscape are needed and are feasible, and how can they be achieved?
- What are the non-recurring inputs necessary to achieve this state?

Land can be evaluated for either its capability for a specified use or its suitability for that use. The distinction lies in what factors are incorporated in the analysis. Land capability is based on an analysis of purely physical factors which makeup the land unit. These factors would include such things as soils, topography, climate, and the like. An example is the Land Capability Classification of the USDA which classifies land into eight categories depending on its potential and limitations to support agriculture or permanent vegetation (Klingebiel and Montgomery, 1973).

An analysis of land suitability includes other social factors such as economic, political, and cultural aspects. Suitability classification is an outgrowth of the FAO's Framework for Land Evaluation. Land can be categorized into orders, classes, subclasses, and units based on qualitative, quantitative, and economic characteristics, and on current and potential uses (Dent, 1981).

It has become increasely apparent that land evaluation leading to sustainable development must be a multi-disciplinary approach, which incorporates all physical and socio-economic factors relating to land and its use. Modern technology has made gathering and interpretation of these factors more precise and more cost effective. These tools can be an effective aid in planning for both the present and the future. The whole must be looked at as a process instead of merely a point in time (Easter et al., 1986, Jones, 1985; Rodale, 1985, Hamilton, 1983; Merrill, 1976).

Too much of past evaluation has stressed the physical makeup of land units while neglecting social, cultural, economic, and institutional factors which could affect present and future use. This thesis begins with physical analysis while also emphasizing the importance of these other factors. The hope is to evaluate the land unit so that present benefits can be gleaned without sacrificing future opportunities.

Soil Erosion

To more fully grasp the relation of landscape position and sustainable agriculture it is important to have knowledge of other relationships. One such relationship is the effect of erosion on crop production.

Soils act as a medium for plant growth. Through the soil plants absorb both water and nutrients. The pore space in soils allows for root penetration and movement of oxygen and carbon dioxide. Finally, soils give a plant stability by anchoring it firmly (Foth, 1984).

Soil erosion is an accelerating process. The more a soil erodes; the greater are its chances for further erosion. As the water retention capacity of soil decreases due to erosion, it becomes more prone to the destructive forces of the wind. A loss of organic matter to erosion can decrease soil permeability. Greater runoff means greater erosion. A decline in the quantity of available nutrients leads to a reduction of the vegetative cover. Raindrops are then able to strike the soil surface directly causing detachment of particles or aggregates (Bauer, 1980).

Crosson (1983) claims that a clear quantifiable relationship between the deterioration of individual soil characteristics due to erosion and a reduction in crop yields has not yet been established. Research results in this area have been conflicting and contradictory. Due to the diversity of factors involved, development of generalizations outlining the quantitative effects of erosion on productivity have been difficult to achieve. Individual research results have, however, shown an inverse correlation between erosion and productivity.

Erosion decreases the supply of available nutrients for plant use. This is thought to have the greatest negative impact on productivity in all crops except legumes, which can supplement their nitrogen requirements through biological nitrogen fixation. Generally, loss of fertility is greatest on soils which are initially more fertile. Loss of fertility can be compensated for by additional inputs into the farming system, but the costs to the farmer and the depletion of other resources resulting from mining or use of fossil fuels to manufacture fertilizers must be considered (Schertz et al., 1985; Sampson, 1981; Murdock et al., 1980). Erosion is a selective process and most eroded soils often have lost a great deal of organic matter. Organic matter promotes the development of good soil structure, and also aids in nutrient retention (Schertz et al., 1985; Murdock et al., 1980). Sampson (1981) cites the relationship between organic matter and presence of available nutrients as a reason why the loss of the former can so dramatically affect productivity.

Most eroded soils experience a reduction in water holding capacity (Schertz et al. 1985; Sampson, 1981; English and Heady, 1980; and Murdock et al., 1980). Water is essential for plant growth. Dregne (1983) states that it is water availability, not soil fertility, that is the most limiting factor in agriculture. The USDA concurs with this and adds that a reduction in a soil's water holding capacity due to erosion will have the greatest impact on productivity (Crosson, 1983). Protection of soil properties which affect water holding capacity is therefore important to productivity.

One such property is soil structure. The impact of raindrops can deteriorate soil structure by physically displacing soil particles and breaking up aggregates which make up the structure. A break down of structure leads to a decrease in total porosity and greater runoff. This break down can also affect the ability of roots in penetrating and spreading throughout the soil. All of these factors can result in decreased yields (Sampson, 1981).

Erosion decreases soil depth. Adequate quantities of soil must exist to serve as a proper medium for plant development and root growth. The shallower a soil, the more severe the effects of any erosion. Soils physically support crops. If the soils become depleted, then crop yields will become depleted also (Murdock et al., 1980).

Erosion also alters soil texture. The selective nature of erosion has been described as it pertains to the quantity of organic matter. It also selects out finer particles from the soil body, resulting in a sandier soil with a higher proportion of large particles (Murdock et al., 1980). Schertz et al. (1985) noted a decrease in the quantity of fine clay in eroded soils. This will affect the supply of available nutrients due to clay's ability to hold these cations.

Murdock et al. (1980) describe the effects of erosion on soil tilth. Eroded soils become harder and more compact. Tilling of the soil becomes more difficult requiring more time and energy in land preparation.

English and Heady (1980) say that one way erosion decreases crop productivity is by complete loss of cropland to gully formation or stream bank collaspe. Fields may be divided up and sections lost because it becomes uneconomical or unfeasible to farm them.

Even when cropland is not destroyed, crops may still be lost because of sedimentation. Between November of 1977 and June of 1978, 2.2 million acres of crops were destroyed in the Great Plains by sedimentation. Though natural erosion has overall been beneficial in building up fertile delta regions, this has not held true for man-induced erosion. When sediment is deposited on farmland, that area usually does not increase in productivity. Often the sediment can be of inferior quality to the topsoil that it covers (Sampson, 1981).

Soil erosion can reduce crop yields due to non-uniform removal of the soil from fields. Fields which are extremely heterogenous in nature demand varying degrees of inputs to compensate. This requires more time and money on the part of the farmer to maintain uniform yields throughout the affected field. Failure to alter management will result in a total yield reduction (Crosson, 1983).

Through its negative impacts on the various soil parameters which induce good crop production, erosion has a detrimental effect on yield. As has been shown above, erosion can also become so severe as to mar the land base itself through gully formation or sheet erosion. These factors will eventually lead to a decrease in land rent for the farmer.

The above discussion has examined the effects of erosion on the agricultural sector. But what happens to the soil when it leaves the farm? The following outlines the effects of erosion on the environment and on human health.

Sedimentation has many adverse effects on both water quality and quantity. Sediment can decrease water storage capabilities of lakes and reservoirs and clog streams and drainage channels. In the U.S., as well as many other countries, the lives of major water projects have been shortened due to sedimentation (Peterson, 1984). The Army Corps of Engineers often has dredged the nation's waters of deposited sediment because these loads had raised river beds causing destructive flooding. This sediment, once in the water must be cleared before being used for home consumption, industry, or irrigation. This means that treatment costs will increase (Viessman and Welty, 1985). Sedimentation can also deteriorate water habitat for wildlife. Suspended solids reduce water clarity thus shading prey and predators alike. Fish gills can become blocked, and breeding grounds and eggs can become covered. Land use activities have a major impact on the amounts of sediment released to water bodies. Agriculture has been cited as having a significant impact on water quality in Michigan, and is known to produce more sheer volume of sediment loads than any other single activity in the U.S. Very often sediment stemming from agricultural land carries high loads of nutrients and pesticides which will have further detrimental effects on the environment and human health (Institute of Water Research, 1987; Troeh et al., 1980).

Increased nutrient loads, and particularly increased phosphorus loads, will initially provide a more productive environment for water biota. Increased biomass in waters means more wastes produced. This further enriches waters, accelerating the process. Soon a strain is placed on dissolved oxygen levels and large fish kills may result. If nothing is done to decrease the nutrient loads, eutrophication will occur. Eutrophication is a process of aging and enrichment. Lakes move from an oligotrophic state, to mesotrophic, and finally to eutrophic depending on their degrees of enrichment. Long before water bodies reach the final trophic stage, however, nutrient loads will decrease the recreational value of waters. Algal blooms can be unsightly and can produce unpleasant smells and taint the flavor of fish. Rooted vegetation can impede swimmers and boaters. Overall enjoyment of the resource decreases.

Nutrient loads in water can also have severe effects on human health. Nitrate can enter the groundwater by percolating down through the soil. One source of nitrate is agricultural fertilizers. Nitrate can cause methemoglobinemia in infants, an affliction that has resulted in death. Because of the sandy nature of the soils in the study area this region has been classified as having a high vulnerability to aquifer contamination (Institute of Water Research, 1987).

Use of inorganic fertilizers in agriculture promotes a vicious cycle. Because farmers rely on these inputs rather than on manure or other organic fertilizers, the organic matter content of the soil decreases since the vegetation is removed through harvest and organic inputs are not used. As was mentioned earlier, this will decrease the soil's ability to retain nutrients. This means that the farmer is forced to increase the inputs of inorganic fertilizer to achieve the same yields, and thus even greater quanties are lost in surface runoff or through percolation (Cox and Atkins, 1979).

Another groundwater contaminant originating from agricultural practices is pesticides. Pesticides, when ingested, can be stored in the fatty tissues of both humans and wildlife, and can become toxic when sufficient quantities amass. This can take a destructive toll on wildlife habitat and wildlife itself, as well as on humans. Concern over pesticide use was brought to the public's attention in the late 1950's with the publication of Rachael Carson's Silent Spring. Though use of these substances is now much more closely regulated and studied than it was in the 1950's, contamination problems still exist. This is of growing concern in many non-industrialized countries. These places have become markets for pesticides such as DDT, which have been banned in the United States (Institute of Water Research, 1987).

Agroecology

If one traces the development of science throughout history, one finds a constant effort to redefine and redelineate the boarders of each specific discipline. The study of science itself emerged from religion and was then refined into various new areas of inquiry. The fields of biology, chemistry, and physics were soon subdivided into more precise disciplines, each delving deeper into a specific subject taken from the parent field. As knowledge is gained, a greater need to classify and organize the new material arises. Such is the nature of science, and such is the nature of the relatively new discipline called agroecology (Kemeneny, 1959).

It is difficult to say whether agroecology grew out of the field of ecology or out of some agricultural discipline. There are elements of anthropology, rural sociology, and economics within agroecology as well. It is difficult to say whether it is a true discipline at all, or merely a tiny branch of ecology (Hecht,1987; Naveh and Lieberman, 1984).

Many related fields and practices such as landscape ecology, alternative agriculture, sustainable agriculture, regenerative agriculture, and sustainable development suffer from the same identity crisis. It is not within the scope of this study to argue for scientific recognition of a new discipline, but merely to draw on some of the work and ideas that can be attributed to agroecology and related studies.

Agroecology can be looked at as the interelationship of agricultural systems and the natural ecosystem in which they are found. Man is a dominant force in this relationship, and herein lies both the problem and the solution. Close to one-third of the earth's land area is now directly affected by agriculture. Man has gained a mastery over the land, whereas he should be in a partnership (Cox and Atkins, 1979; Bookchin, 1976).

The study of agroecology is both a "horizontal" analysis, as relations between spatial land units are examined, as well as "vertical", since structure and function of a particular site are also studied. Temporal analysis is also important.

Agroecology studies these phenomena with the aim of understanding the biological and physical processes at work within the agricultural system. One application of this knowledge would be to devise low-input agricultural management systems which are more sustainable and efficient. These systems attempt to bring more harmony to the unnatural state modern agriculutral systems impose on the landscape. Concern over excessive production costs, poorer gross returns in some crops and overproduction of others, decreased species diversity, destruction of wildlife habitat, contamination of soil and water resources, and the physical atlteration of the landscape has resulted in heightened awareness of agroecological concepts.

Agroecology considers strategies to conserve soil, water, and energy, recycle nutrients, and develop better biological pest management systems. Potential benefits of incorporating agroecological concepts include greater long-term return on capital inputs, sustained yields, good soil structure and fertility, increased species diversity, and less pollution (Edwards, 1988; Altieri, 1987; Gulinck, 1986; Naveh and Lieverman,1984; Risser et al.,1984, Cox and Atkins, 1979).

Because agroecology looks at the question of sustained resource use, it serves well as a background for this study. Management of natural resources can be enhanced by considering ecological principles. Past efforts have been site specific rather than based on any unifying theory. Research in this area is beginning to grow, but still more is needed before generalizations can truly be reached (Gulinck, 1986; Risser, 1984).

Recently studies have been conducted which examine the natural structure of land units; identifying components and assessing functional relationships in order to determine the effects on species composition and productivty. Zak et al. (1986) showed a correlation between three different forest ecosystems in Northern Michigan and their respective nitrogen cycles. Turner (1987) measured net primary production (NPP) over various physiographic regions in Georgia and found significant differences. She suggests that spatial and temporal differences in NPP may be useful for land evaluation purposes.

Work has also been done on a finer scale examining attributes of sloping land. Pregitzer et al. (1983) found differences among slope positions and the resulting soil type, depth, moisture, and nutrient availabiltiy, as well as dominant vegetation composition. Schimel et al. (1985) showed a general increase in nutrient availability, soil organic matter, and plant biomass with movement downslope, however, in a later study (1985a.) found no effect of slope position on microbial biomass and mineralization rates-- factors which affect nutrient availability.

A key research need in promoting sustainable agricultural systems is development of innovative technologies. Past efforts to reduce inputs have concentrated on labor, rather than on fuel, fertilizers, and pesticides. There is a growing awareness among agricultural researchers and farmers alike of resource conserving strategies which are environmentally sound, and which contribute to long-term productivity.

It is important to link ecology to economics. That is a language farmers can understand (Gliessman, 1985; Cox and Atkins, 1979). Merrill (1976) states,

> "...what are needed are ecological tools that keep farming productive, and economic incentives that make them practical." p.321

In 1983, the average debt for U.S. farmers was close to $70,000. In non-industrialized countries decreased harvests can mean decreased educational opportunities, increased malnutrition, greater risk of disease, or even starvation and death (Myers, 1984).

Constraints to implementation of such research efforts have been the assumptions that high yields are the goal of agriculture, that fossil fuel will continue to form the backbone of production systems, and that efficiency in agriculture is measured through vertical integration of the farm business. Before research geared towards sustainable agriculture can truly succeed, these assumptions must be altered.

They must reflect the idea that the goal of agriculture is to sustain and nuture the land, that fossil fuels are exhaustible, and that efficiency can be measured by other standards; such as the flow of energy through the ecosystem (Edwards, 1988; Gliessman, 1985; Myers, 1984; Merrill, 1976).

Many practices have been recommended which follow the tenets of agroecological thought. These practices limit the use of synthetic fertilizers and pesticides; protect soil resources by decreasing erosion and nutrient leaching by adding organic matter back to the soil; and promote the diversification of complementary agroecosystems. Adhering to these basic tenets of sustainable agriculture may improve profitability and help ensure that resources are not so degraded as to limit future use (Douglas, 1985).

Specific recommendations center around more efficient use of resources, such as nutrients, energy, and land. They include increasing crop diversity. This practice can limit the impact of damaging insect and disease outbreaks, helps to control weeds through shading or competition, attracts beneficial insects, withstands weather fluctuations better, and can mean a greater variety of food available for a longer period of time.

Other practices include closing off nutrient cycles so that energy flow becomes more efficient. Steps in this direction include no till farming, which returns organic matter to the soil helping to retain nutrients; crop rotation, which utilises different quantities of nutrients from different depths in the soil profile; cover cropping, which protects nutrients from leaching, agroforestry, which can also help with nutrient leaching and organic matter additions, and integrated farming practices, where potential wastes may become inputs for additional activities. All of the above recommendations also help control soil erosion (Altieri, 1985; Gliessman, 1985; Douglas, 1985; Harwood, 1985; Cox and Atkins, 1979; Merrill, 1976).

Edwards (1988) feels there is potential for inclusion of woody perenials in farm production systems. This practice is commonplace on many tropic farms, but has met with little interest in temperate climes. Cox and Atkins (1979) concur with this recommendation and also suggest development of strategies which maximize water and nutrient efficiency, and minimize soil erosion. They advocate use of mixed cropping systems. Francis et al (1986) state that strip cropping of corn and grain legumes can reduce erosion on sloping lands, and increase total yields. Merrill (1976) promotes the use of alfalfa strips in a mixed cropping system to attract pests away from other crops, and to provide shelter for predators of these pests. In addition, this legume has a very high capability to fix nitrogen. These various management strategies will be explored as possible improvements of current practices for the study area.

Future concerns in agroecology will focus on conservative use of inputs to agricultural systems and on coping with the externalities generated by these systems.

> "Agriculutre of the future must be more productive using fewer non-renewable resources and energy and having less adverse environmental impact." (Harwood, p. 64, 1985).

Maximizing gross production is no longer a viable alternative. The difference between costs and harvest value must be maximized, and externalities must be included in the costs. Cox and Atkins (1979) draw attention to the central issue in agricultural resource management.

> "Land must be considered as the basic resource of agriculture, and the protection and effecient use of prime agricultural land a major goal of agricultural policy." (p. 632).

Gulnick (1986) stresses the importance of understanding the ecological processes which affect a given region in order to make the best use of natural and artifactial resources. This thought forms the basis for the present study. Homogeneous regions within the study area will be mapped based on their natural composition (topography and soil type). Data on the productivity of the regions will be gathered and these factors will be analyzed to determine management strategies. Risser et al. (1984) concluded in a workshop focusing on landscape ecology that application of geographic information systems will aid greatly in understanding some of the spatial and temporal relationships involved in this field. In addition, they state that comprehension of these relationships will then facilitate inclusion of ecological principles in geographic information systems used for land use planning. A geographic information system will aid in devising management strategies for the study area, as well as in analyzing the impacts of these strategies.

Geographic Information Systems

Decision making resulting in sustainable solutions must be based on an analysis of a variety of environmental factors. These factors could include topographic, climatic, and soils data from the physical environment, as well as cultural, economic, and institutional data from the social environment. Examples of data from the factors listed under the social system could include land use, access to markets, and delineation of administrative divisions respectively. Handling and analysis of the quantities of data needed for informed decision making can quickly grow to be an enormous burden. Techniques which can aid greatly in this task include application of Geographic Information Systems (GIS).

A GIS provides a very powerful tool for conducting resource inventories and land evaluation. The GIS can handle large volumes of spatial data in an organized, systematic fashion. The data can be input, stored, manipulated, analyzed, and displayed in a relatively quick and inexpensive fashion. Past geographic analysis relied on the analog map and manual techniques. This vastly limited the amount of data which could be considered at any one time; a serious drawback in terms of cost efficiency and effectiveness.

Application of a GIS can greatly reduce storage requirements by transforming spatial data to computer files. These files can be easily and speedily accessed to allow for analytical testing and display. Decision makers can use this tool in assessing and devising options for land use and management. A GIS can take the user specified criteria and evaluate various management scenarios according to physical and socioeconomic factors. It allows incorporation of these various factors into a more holistic approach to problem solving and most importantly relates this data to an exact geographic location. In addition, temporal analysis of various phenomena is also possible using this system (Schultink et al., 1987; Riggins, 1985; Marble and Peuquet, 1983).

One such system is the Comprehensive Resource Inventory and Evaluation System-GIS (CRIES-GIS) developed at Michigan State University. This system was developed with the aim of being applicable to a diversity of resource analysis situations at a relatively low cost. The system can be operated on micro computers and as such provides an opportunity to handle large volumes of spatial data with minimal hardware requirements. CRIES supports land use/management decisions which meet the expressed needs of the user by analysing a multitude of physical and socioeconomic factors . Use of CRIES is limited only by availability of accurate sources of base line data and user articulation of the problem. Two of the numerous examples of use include spatially identifying regions of unrealized agricultural production potential and assessing the comparative advantage of various management scenarios for given land units.

CRIES attempts to develop operational procedures to inventory and classify natural resources, to analyze these resources individually or in aggregate form, and to use this information in development planning. CRIES has three primary objectives:

a) to apply a consistent approach to land resource assessment which is adaptable to many countries and suitable for the transfer of appropriate agrotechnology;

b) to provide assistance in integrated surveys, development of a computer-compatible resource data base and computer-aided analysis software for the analysis of development options and policy initiatives; and

c) to provide the training and technical assistance necessary to develop indigenous capabilities to inventory and classify renewable resources, assess crop production potential, and systematically evaluate development alternatives and derived public and private benefits. Schultink et al., 1989, p. II.

The CRIES-GIS aids in achieving these project objectives through operation of basic GIS functions which include data input, data storage, formatting and retrieval, data manipulation, analysis, and display. CRIES relies on a grid-based system referenced to geographic coordinates such as those of the State Plane System or Universal Transverse Mercator projection.

Spatial data, which can take the form of points, lines, or polygons, is referenced to a coordinate system by assigning it a particular x-y value on the grid. The data once entered into the computer can be transfered to a raster file for manipulation and analysis purposes. As such, the spatial location of each attribute and land unit is known throughout the evaluation. Final results will reflect the contributions of the various attributes of the exact land unit analyzed. Another component of the CRIES project is the CRIES Agro-economic Information System (AIS). The AIS allows users to evaluate performance characteristics of various management options for delineated regions such as communities, administrative districts, or agro-ecological zones. One module of this system is the AIS-YIELD. The yield model can predict production returns for a variety of food and cash crops for user specified regions. Use of this model permits evaluation of various land use/management options with relative ease and at low-cost (Schultink, 1987).

Use of GIS has expanded rapidly during recent years and is continuing to grow. These systems can greatly aid decision makers in analyzing their resources, in identifying regions of overexploitation, and also in identifying those of unrealized production potential. Understanding the linkages between physical and socio-economic factors appears to be very important in sound resource development. The GIS allows intergration of physical and socio-economic data in spatial analysis. These systems will become even more important in future resource management use.

The Environment of the Study Area

The study area is located at Michigan State University's Kellogg Biological Station in Hickory Corners, Michigan at UTM coordinates 4,696,000 m N by 634,000 m E (USGS, 1961). The region, which is part of Kalamazoo County, is characterized by outwash plain and small ground-moraine ridges. Numerous lakes dot the landscape. Of these, Gull Lake is the most important as a recreational resource. Agriculture is prevalent on the moderately and well-drained soils which are primarily sands and sandy loams. Poorly drained soils remain as swamp or marsh (Albert et al., 1986).

Knowledge of the environment is important for sound land use planning. The environment is made up of various factors which can be divided into the general categories of either the "natural system" or the "social system". Factors which comprise the former are geology, climate, topography, vegetation, soils, and hydrology; while those which make up the later include the broadly defined areas of cultural, economic, and institutional influences. The systems are closely intertwined; each providing structure for the other. A change in a single component of one system can affect changes within that entire system. This alteration can also eventually affect the other system as well. Analysis of these systems is needed prior to selection of management strategies (Axinn, 1978a).

Until about 280 million years ago the region was covered by shallow seas and underwent a period of sedimentation. The most important sedimentary rocks formed were sandstone, shale, and limestone. From 280 million to about 1 million years ago the area was subjected to a period of upheaval and erosion. The Pleistocene age followed. This was the time of glaciers-- the most important to the Hickory Corners region being the Wisconsin glacier.

Modern soils have developed during the past 10,000 to 12,000 years from material deposited by the glaciers and reworked over time by the actions of wind and water. Parent material of these soils consisted primarily of glacial till, outwash, alluvium, and organic material. Glacial till is unsorted material ranging in size from clay particles to boulders. It formed rolling plains and was also pushed up in ridges known as moraines. The till found in this region is calcareous. Outwash materials were deposited from the running waters of melting glaciers. The location of deposition was determined by the velocity of the waters. As velocity decreased the coarser particles dropped first. When the melt waters became sluggish, finer particles of silt and clay were deposited. Alluvium is similar to outwash in that it is deposited by running water. The difference is that alluvium is deposited by present day floodwaters. Organic material, which forms the last component of the soil parent material, is made up of the remains of local vegetation. This material accumulated in shallow depressions, thus forming small regions of muck soils, but also accumulates on the surface of other soils forming the surface horizon. This last factor has been important in the formation of the soils at KBS (Foth, 1987; SCS, 1979).

A very powerful influence on the environment is the climate. Climate determines the types of plants and animals which dominate the landscape. It regulates the quantity of moisture available and the temperature, both which affect soil development and weathering. The effects of climate are felt over very broad regions. Variation on the local level may occur due to proximity to water bodies or extreme deviations in topography, but for the most part the climate at KBS is uniform throughout the area.

Kalamazoo County shows an average annual precipitation of 34.40 inches, with seasonal snowfall amounting to 71.4 inches. Winter temperatures average 27 F, while summer values increase to an average of 71.4 F. Relative humidity increases from 62% in midafternoon to 80% by dawn. Winds blow primarily from the southwest at a highest average value of 11.7 mph in January. The growing season usually lasts from early May through late September. The climate of the region can be described generally as being cool and humid (Soil Conservation Service, 1979).

Topography can also be a strong environmental determinant. Topography determines drainage patterns, influences plant species composition, regulates soil erosional processes, and controls soil temperature. Runoff and drainage increase with increasing slope. Runoff may stimulate erosion which can decrease the productivity of a region. Drainage will affect aeration. Generally, poorly drained soils are less productive because they lack oxygen which means that root respiration and ion asorption is restricted (Tisdale, 1985).

The topography of the region was formed primarily through glacial action. The gently rolling plains and small ridges which typify the region have been previously described.

SCS (1979) notes several occurances which were important to soil development of the region. The accumulation of organic material has been previously noted. Also important to regional soil genesis has been reduction and transfer of iron, leaching of calcium carbonate and other bases, and formation and movement of clay particles. The later two processes have been most important to the soils of the study area.

Most soils have been leached to some extent of carbonates and other bases. The degree of leaching usually reflects the age of the soils; greater leaching occuring in older soils. Leaching is important because of its effects on fertility. Generally, a soil that has been highly leached has a lower pH which often means it is less fertile.

Clays result from physical and chemical weathering. They are important in soils for a variety of reasons, most notably for water retention and soil fertility. Presence of clays in a soil will affect the structure of that soil. Average pore size will decrease with an increase in clay quantity, thus allowing less percolation of water. Presence of clay can also increase the cation-exchange capacity (CEC) of soils. The CEC can be defined as the amount of exchangeable cations which can be retained by soil. A high CEC signifies a more fertile soil. Translocation, or the movement of clay particles through the soil profile, will affect soil horizon structure and fertility (Foth, 1984 ; Tisdale et al., 1985).

Soils in the study area typify those found in the general region. They are primarily Oshtemo sandy loam and Kalamazoo loam. These two types make up approximately equal areas of the land unit (Whiteside, date unknown).

In the study area the Oshtemo soil is divided into mapping units with slopes between 1-6% (OsB) and that which slopes 6-12% (OsC). The former is a well drained soil found on sandy upland plains. The surface layer of this soil is made up of about 9 inches of dark brown sandy loam followed by 10 inches of yellowish brown sandy loam. Under this lies 50 inches of subsoil ranging from dark brown sandy loam to yellowish brown sand. Permeability is moderately rapid, runoff is slow or medium, and it is capable of holding a moderate amount of water at field capacity. The soil has a fair potential for agriculture, while its potential for recreation, building, or woodland is listed as good. Suitable crops are corn, soybeans, and small grain, though erosion and midsummer droughtiness are limitations. Management recommendations to conserve the soil base when the use is for cropping include minimum tillage, use of winter cover crops, and returning crop residue or other organic material to the soil. When the use is for pasture, proper stocking rates, adequate rotation schedules, and timely deferment of grazing are all recommended for conservation purposes. The capability subclass is 3s and the Michigan soil management group is 3a.

OsC is a rolling well drained soil of the upland areas. The color of the surface and subsurface layers resembles that of OsB, but these layers are thinner being only 7 and 6 inches respectively. The subsoil is also thinner than that of OsB lasting only 29 inches and having a dark brown color. The substratum continues until about 60 inches and is made up of dark yellowish brown sand. This soil's permeability and water retention capacity is the same as that of OsB, though runoff is greater. Land use potential is the same as that of OsB, with the same limitations and recommendations for conservation. It is classified as 3e under the capability subclass category and 3a under the Michigan soil management system.

Kalamazoo loam (KaB) which is found on 2-6% slopes is a well drained soil of the uplands. The 9 inch surface layer is dark grayish brown loam, followed by 44 inches of dark yellowish brown and dark brown subsoil made up of a top layer of loam and clay loam followed by a layer of sandy loam, and finally by a layer of loamy coarse sand. The substratum of dark yellowish brown gravely sand continues to about 64 inches. Permeability and water retention are both moderate, and runoff is medium. This soil has good potential for a variety of uses including agricultural. Recommended crops are corn, soybeans, and small grain. Limitations, as in the Oshtemo series, are erosion and midsummer droughtiness. The same recommendation for conservation practices are made. KaB is rated at a capability subclass of 2e and the Michigan soil management group is 3/5a (SCS, 1979).

The final component of the natural system which should be examined is the hydrology of the area. The landscape around KBS is dotted with many small lakes. Gull Lake is the largest and most important of the lakes, but also notable are Duck and Wintergreen, as well as numerous other smaller bodies of water on station property. Water is an important resource for the area since primary activities are agriculture and recreation. In fact, these two activities rank second and third respectively in economic order of importance for the entire state, being preceeded only by the automobile industry. Concern for the quality of water in Michigan often is greater than the concern for quantity. Balancing multiple use of a resource can be problematic. Often the competition between various sectors, such as agriculture and recreation, for water is stiff. Gull Lake is still classified as being in an oligotrophic state, meaning having high water quality. Nearby Wintergreen Lake, however, is showing signs of eutrophication, due to a large degree to the bird population maintained on its shores. Agriculture, however, has been cited as one cause of water quality degradation in Southwest Michigan. This is due particularly to the sandy nature of the soils, which makes for greater percolation of nutrients and pesticides down to the groundwater, and higher sediment loads in surface runoff (Institute of Water Resources, 1987).

Though the majority of this study will revolve around examination of the physical factors comprising the natural system, a look at the social system should also prove fruitful. KBS is located in a rural area of Michigan in the Midwest of the United States. As has been previously mentioned, agriculture is of primary importance to the region. Generally, farmers in this type of setting have accepted, established ways of behavior, which influence farm management systems. Change is not something that is readily adapted. This is especially true when the idea may be perceived to be somewhat radical, or if the change may result in a decrease in returns in the immediate future. Axinn (1986) states regarding these phenomena,

> "The success of an agricultural non-formal education program tends to be directly related to the extent to which:
>
> a. the benefit of the recommendations to farmers is high;
>
> b. the costs of recommended practices to farmers are low;
>
> c. recommended practices are relatively simple;
>
> d. the benefit to farmers is immediate;
>
> e. the recommended practices may be tested by individual

> farmers on a trial basis prior to complete commitment;
>
> f. the recommendations fit the type of farming system." (p.3).

All of the components of this statement are applicable to the present study, however, `b' and `d' are particularly pertinent. Studies have shown that with the possible exception of conservation tillage, private costs of soil conservation practices exceed private benefits. Even when the farmer does benefit, these benefits are usually not felt for quite some time after incurring the costs (Harrington et al., 1984).

Agriculture in industrialized nations is committed to mechanized monoculture. The basic trend over the past century has been to become more closely tied to this system rather than the reverse. Approaches, which suggest that this shift was perhaps a mistake, will be viewed somewhat skeptically and will only be adopted slowly. It took many years before the soybean (now an important crop) was accepted in the Midwest. The possibility for adoption of new and varied practices is perhaps higher in non-industrialized nations where the majority of agriculture is not harnessed to a mechanized monoculture system.

Another aspect of the problem, which can be classified under "cultural aspects", is the nature of soil erosion itself, and the relation of technology to it. Erosion is often a slow gradual process, and though many tons of soil may be lost off a single acre over a growing season, this loss may be imperceptible to the farmer. This fact leads to a lack of appreciation as to the magnitude of the effects. To compound this, advances in technology have masked the seriousness of the problem. The development of less expensive and more effective fertilizer, pesticides, farm equipment, and irrigation systems, and improved seed varieties and techniques has increased yields on land that would otherwise have shown a reduction in production. The productive potential of many lands has decreased even if actual yields have not (Schertz et al., 1985; Sampson, 1981; English and Heady, 1980; Murdock et al., 1980).

Institutional aspects of this problem are many. Public Act 297 passed in 1937 established the Soil Conservation Districts. These local organizations develop activities which will promote voluntary soil conservation measures. There are 83 such districts in Michigan working in very close cooperation with the federal Soil Conservation Service. The districts can merely provide technical advice and materials to aid farmers in properly managing their soil resources. They have no power to enforce policy (Troeh, 1980; DNR, 1975).

In 1948 the Water Pollution Control Act was established. This act has been amended many times; most recently in 1977.

Its goal is to control pollution at its source. The act has been quite effective in monitoring and controlling point source pollution, which comes primarily from industry, but has been largely ineffective in dealing with non-point source pollution, such as that coming from farmland (Tietenberg, 1984).

State-wide concern over the effects of sedimentation on precious water resources resulted in the State of Michigan Act 347 of 1972. Because of the difficulty in pinpointing contributers to non-point source pollution and the strength of the farming community, agriculture was made exempt from this act (DNR, 1975).

Most efforts in the past have relied on voluntary reductions of erosion. Such is the nature of the Conservation Reserve Program in Michigan where farmers are paid approximately $40 an acre to take highly-erodible land out of production for 10 years. A major problem with subsidy programs is that they may do more to increase farm production and income than they do to reduce soil erosion. Inputs on non-subsidized land may be increased which reduces the quality of runoff waters from these lands, thus reducing the total benefits of the program (Harrington et al., 1984).

Farmers in Michigan are in the business to make money. Because of this fact, imposing externalities on others makes sound economic sense. Otherwise, farmers would have to pay the costs of decreasing erosion and pesticide contamination of the groundwater themselves. Erosion does have a detrimental effect on farmland by decreasing fertility. A reduction in the quality of land will reduce the farmer's producer surplus (which is equal to his land rent) because he will harvest less for the same amount of inputs, or must increase his other inputs to maintain yields.

Realtors see land rent as a return on the market value of land. A reduction in the land rent means a reduction in the value of the land in a real estate market (Barlowe, 1986). Because of erosion, farmers are realizing less from their efforts and at the same time decreasing the market value of their lands. It seems, then, in the farmer's best interest to reduce erosion. However, the previously mentioned Harrington et al. (1984) study again provides clarity, showing that usually costs of soil conservation practices exceed benefits for the farmer.

Farmers make little enough now in their business. Trying to implement expensive conservation programs would meet with great opposition.

Consideration of the influences of the social system, and the interplay between this system and the natural system are needed for devising sound land management suggestions which have a good chance of being accepted by those affected (Axinn, 1978b; Axinn, 1984).

CHAPTER 3

RESEARCH METHODS

Sample Plot Description

The plot for the transect analysis has approximately an 8% slope and a western aspect. The summit is located at approximately 950 feet elevation (KBS Topographic Map, 1980). Slope was measured at two meter increments using a hand level. The soil in the plot, known as the rain shelter slope, was classified by Whiteside (date unknown) as Oshtemo sandy loam.

During 1987 the rain shelter plot was planted in corn at 29,900 plants/acre and irrigated. The plot was fertilized with 10-40-10 with 2% zinc at 100 pounds/acre and later treated with liquid 28% N at 30 gallons/acre. Roundup, Atrex 4L, Bladex 4L, and Lasso 4EL were applied at 2 quarts, .75 quarts, 1.5 quarts, and 2 quarts/acre respectively.

Sampling Strategy

Sampling was based on a random stratified method as described by Webster (1977). A transect was drawn down the slope of the study plot and divided into 2 meter cells. The VAX mainframe computer generated a list of randomly selected points within each cell, and then generated 10 addition points along the transect. This resulted in 55 sampling points.

Soil Samples

Soil samples were collected with a soil auger. One composite sample was made from three cores taken to a depth of 15 cm. at each designated point along the transect. Replicate subsamples of each sample were then made for analysis.

Samples were analysed for pH in a 1:1 soil/distilled water ratio and measured using a Corning pH meter (Robertson, G. P.; personal communication). Soil moisture values were obtained by oven drying 40 grams of each sample at 60 degrees Celsius for 5 days (Robertson, pers. comm.). Quantities of mineral N were determined by mixing 10 g. of soil with 100 ml. of a 1 N NaCl solution and allowing it to stand overnight (Robertson, 1981). The mixture was then filtered and analysed using a Tecator Flow Injection 5020 Analyzer to determine ug/g of dry soil of nitrate (NO3) and ammonium (NH4) (Technicon 1973). To assess potential mineralization activity, the samples were left to incubate in the dark for 11 days at a constant temperature of 25 degrees C. They were then processed in the same fashion as the original N analysis. (Robertson, pers. comm.). Bulk density was determined by dividing the weight of each sample by the volume of the soil auger times 3 to account for the composite nature of each sample (Robertson, pers. comm.).

Plant Samples

Three plant samples were collected at each sampling point. The grain was separated from the rest of the plant and each portion was dryed for 10 days at 60 degrees Celsius. Biomass was then determined using a Mettler PE 3600 balance (Robertson, pers. comm.).

Statistical Analysis

The slope was divided into three sections based on topography. These sections were called summit, backslope, and footslope. Means and standard errors were calculated for each slope section.

Results from this data analysis were used to select alternate management strategies for the land unit.

Agroecological Zones

Topography and soil type were used in delineating zones of relative homogeneity which are called agroecological zones (AEZ). Topographic data was taken from the USGS Quadrangle, 7.5 minute series. Soil data came from the Kellogg Biological Station Soils Map.

The AEZ represent units of similar environmental makeup. The assumption is that a homogeneous zone, when subjugated to a uniform management practice will respond with a uniform yield. The results of management practices can then be predicted throughout the study area in like AEZ. Delineating AEZ requires identifying prevalent combinations of like components, such as soil type and slope gradient, and locating them spatially. In this study the soil map was divided into three mapping units (KaB, OsB, and OsC). The topography map showed three areas with slopes ranging between 0 - <2%, 5 - <10%, and 10 - <18%.

Delineating AEZ's can be performed with the aid of the Comprehensive Resource Inventory and Evaluation System (CRIES) developed by Michigan State University. This Geographic Information System was used to convert the topographic and soil maps into digital format. Once the maps were in a useable form, the CRIES OVERLAY program was employed to combine the data layers of topography and soil. The resulting attribute values constituted a new digital map of AEZ.

Yield Prediction

Corn yields were predicted for the various AEZs using the CRIES AGRO-ECONOMIC INFORMATION SYSTEM (AIS) YIELD model. Data requirements for this model include local environmental factors such as:

- Altitude in meters,
- Latitude in degrees,
- Hemisphere location,

- Slope class,
- Soil type,
- Total available soil water for different soil texture,
- Soil moisture available at sowing date,
- Monthly mean temperature,
- Monthly mean precipitation,
- Monthly mean relative humidity,
- Monthly mean solar radiation, and
- Monthly mean wind velocity; as well as management and crop management information including:

    - Sowing day,
    - Duration of growth stages (1-5),
    - Fertilizer usage,
    - Mulching rate,
    - Irrigation rates during each growth stage,
    - Crop type,
    - Leaf area index,
    - Root depth for each growth stage, and
    - Crop group.

Data for these inputs was collected from KBS farm and Kalamazoo County weather records. Data input values and sources may be found in Appendix A.

The AIS-YIELD model was used to identify regions of relatively higher and lower productivity. This information was used in designing management alternatives. Land of relatively low productivity could be taken out of corn production with less of a sacrifice to total yield, than could land of relatively high productivity.

It should be noted that the YIELD model was developed and tested on data sets covering a much greater geographic region than in this study. Prior model use has been on a regional or national level where climatic differences produce greater differences in production rates. As this study examines micro-agroecological zones, climate input values were uniform among the AEZs. Differences among the AEZs include soil type, texture, and moisture holding capabilities and slope categories, and as such these factors are the only variables which generate yield differences. Model results are used simply in identifying zones of low productivity, not in trying to predict absolute yield values.

Soil Loss Prediction

Another CRIES data module was used to assess the degree of erosion from the various land units given the land use and management. This data module uses the Universal Soil Loss Equation to predict metric tons of soil eroded per hectare per year. Requirements for this model include:

- Rainfall and runoff,
- Inherent soil erodibility,
- Slope length,
- Slope Steepness,
- Land cover/mamagement, and
- Soil conservation practices.

Each of the model inputs was created in digital map form by using the GROUP phase of CRIES or as in the case of slope length and steepness the TERRAIN module. Data for rainfall, land cover/management, and soil conservation values were calculated from the SCS technical guide. Data for inherent soil erodibility was obtained from the SCS soil survey for Kalamazoo Co. Data input values and sources may be found in Appendix A.

The model was used to assess the degree of harm or protection (in terms of tons of soil lost) different management practices will allow. This provided a comparative advantage of various management systems by estimating soil erosion under each system, and seeing whether one system produces more or less erosion than another. The model is most useful for this purpose, as opposed to predicting absolute values of erosion under any given system of management.

Final Results

The resulting digital maps from the USLE calculations can be used to identify priority management areas. These maps comprise the final land use/management suggestions for the study area.

CHAPTER 4

RESULTS

Mean Values

Appendix B shows a cross section of the slope with its delineations into summit, backslope, and footslope. Appendix C gives the means and standard errors for the parameters measured. Significant differences exist among many of the slope positions and are noted in the appendix. As can be seen from this table, however, high values in the footslope and low values in the backslope, as hypothesized, showed up clearly in only two cases. This trend was observed in the parameters of soil moisture and in grain yields.

Bulk density values, which we hypothesized to show the opposite trend, showed high values in the footslope and low in the backslope. High values, as hypothesized, were only observed in the footslope in one other case. This occurs under pH. In addition, the low values hypothesized in the backslope are observed in two other occurances. These can be found in PNO3 and PMIN. The values in these later cases, however, are not always significantly different from other slope sections.

Agroecological Zones

Use of the OVERLAY and GROUP phases of CRIES resulted in 4 distinct agroecological zones formed from the soil and slope gradient maps of the study area, as can be seen in Figure 1. Half of the land is comprised of an AEZ made up of Kalamazoo loam with slope gradient of 0 - <2%, shown by the area covered with the grid pattern. This AEZ has been assigned the attribute value 3. An attribute value is often an arbitrarily selected number allowing for differentiation among regions whose boundaries have been specified by the user. Approximately a quarter more of the area is made up of Oshtemo sandy loam with slope gradient of 0 - <2%, shown by the broad horizontal lines. An attribute value of 4 has been assigned to this AEZ. The final quarter of land is split between an Oshtemo sandy loam section with slopes ranging between 5 - <10%, shown by the diagonal lines, and a smaller section of Oshtemo sandy loam with slopes ranging between 10 - <18%, shown by the checkerboard pattern. These two AEZs have been assigned attribute values of 12 and 18 respectively.

N ↑

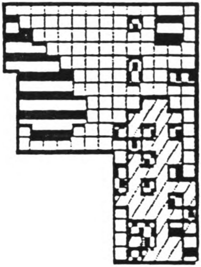


Figure 1 Map of study area showing different AEZs.

Key:

AEZ 3 (Kalamazoo Loam, 0 - <2% slope)

AEZ 4 (Oshtemo Sandy Loam, 0 - <2% slope)

AEZ 12 (Oshtemo Sandy Loam, 5 - <10% slope)

AEZ 18 (Oshtemo Sandy Loam, 10 - <18% slope)

Scale 1:18,000

YIELD Model Results

Eight simulations of yield were run with the YIELD model. Corn yield was estimated in each AEZ employing mulching to conserve water and without any mulching. Appendix C gives the results in kilograms of corn biomass per hectare.

USLE Results

The six different land management scenarios tested with the USLE model resulted in various erosion values. An average tolerance limit of 10 metric tons/hectare/year was calculated for the study area based on T-values as derived from county soil survey data. The management scenarios were compared to this tolerance limit.

The first system examined was a continuous corn cropping system relying on conventional tillage. Analysis of this cropping system provided baseline data for comparison with alternate systems which were proposed. Use of the CRIES HISTOGRAM phase produced the following results. Just over 10 hectares of this land are managed so that erosion will not exceed tolerance levels. This constitutes approximately 18% of the total land unit.

The second scenario modeled employed minimum tillage on a continuous corn system resulting in 11 hectares managed within tolerance limits, or 19% of the total land unit.

The third system modeled included a no-till continuous corn. This system resulted in over 17 hectares or 30% of the land unit being managed so that erosion values do not exceed tolerance limits.

The fourth management scenario, that of a corn system utilizing fall cover crops and contour cultivation with conventional tillage, resulted in vastly improved values. Nearly 35 hectares or 59% of the land unit would be managed so that soil erosion will not exceed tolerance levels.

The fifth system proposed included planting alfalfa strips on some of the most potentially fragile land which is also some of the least productive land for corn as determined by the AIS-YIELD model and on-site sampling analysis. This system of corn with fall cover cropping, contour cultivation, and conventional tillage, including alfalfa strips planted on the area represented by attribute 18 resulted in almost 40 hectares or nearly 70% of the land being managed so that soil loss would be kept at a tolerable level.

The final scenario modeled a system of no-till corn utilizing contour cropping with strips of alfalfa again planted on some of the potentially most fragile land which is shown by attribute value 18. This resulted in nearly 50 hectares or about 85% of the land unit being managed within tolerance limits. Table 1 shows the results in terms of the number of hectares and percentage of the total land unit that is being managed within soil erosion tolerance levels under the six management alternatives.

Final Land Use/Management Recommendations

The maps from these six management scenarios can be used to spatially locate areas which are being managed well and areas which are resulting in erosion values exceeding the tolerance limit. These maps are contained in Appendix E. The maps and results of Table 1 tend not to support the null hypothesis that there is no relation between alternate management strategies and erosion rates.

Table 1 USLE results under different management systems.

	MANAGEMENT SYSTEMS					
	1	2	3	4	5	6
# of ha within tolerance levels.	10.44	11.19	17.18	34.24	39.74	49.10
% of total land area within tolerance levels.	18.11	19.41	29.80	59.38	68.93	85.16

Key to Management Systems:

1. Continuous Corn, Conventional Tillage.
2. Continuous Corn, Minimum Tillage.
3. Continuous Corn, No-Till.
4. Corn/Fall Cover Crop, Contour Cultivation, Conventional Tillage.
5. Corn/Fall Cover Crop, Contour Cultivation, Alfalfa Strips, Conventional Tillage.
6. Corn/Fall Cover Crop, Contour Planting, Alfalfa Strips, No-Till.

CHAPTER 5

DISCUSSION

Mean Values

It is interesting to note that the mean values of the parameters sampled indicating good fertility (i.e. pH, moisture, available N, mineralization rates, and bulk density) do not generally follow the hypothesized pattern, while sampled grain yields do. Perhaps there are other factors at play, such as greater protection from the elements in the footslope, which may induce higher yields. In any case, grain yields among slope positions were only significantly different in the rain shelter slope between the summit and footslope, and backslope and footslope, though not between the summit and backslope. The footslope showed the highest yield as hypothesized. Also interestingly enough, the plant biomass showed no significant differences among slope positions.

Plant samples were collected in late August. Perhaps if these samples had been collected later in the season, results would have been different. This fact became apparent when calculating yields based on sample biomass. These calculations resulted in yields of approximately 50 bushels/acre as oppossed to the 75 to 80 bushels/acre which the SCS says can be expected from this land unit.

In addition, fertilization rates may not have been at optimum levels. This fact may have masked the effects of slope position on yield.

Management Suggestions

When exploring management options to limit soil erosion many different strategies come to mind. Donahue et al. (1983) suggest that terracing and the use of contour tillage systems are the most important conservation measures a farmer can take. Terraces are constructed on sloping land to decrease soil erosion and conserve water. Many different types of terraces exist including graded terraces which allow water to slowly run off into drain tiles or a grassed waterway, and level terraces which trap water and allow it to slowly infiltrate. Terraces reduce slope length and runoff velocity; both important to soil and water conservation. Well maintained terraces may be farmed for thousands of years.

Farmers are often reluctant, however, to construct terraces because of the amount of work involved and the costs. In addition, terraces may hamper the movement of large farm machinery (Troeh et al., 1980). Dregne (1983) warns also that soil erosion may actually exceed levels found on unterraced land should the terraces fall into disrepair.

Alternate tillage systems may provide an easier, cost effective and more readily adoptable strategy. One type of tillage system, contour tillage, refers to the practice of tilling and planting crops along the contour lines of a field rather than up and down in a straight line. This type of tillage traps runoff in the ridges and furrows created. Contour tillage can reduce runoff by up to 50% and improve yields by up to 25% (Troeh, 1980).

Another tillage practice (minimum tillage) also increases infiltration and reduces runoff and erosion (Troeh, 1980; Hayes, 1982). Minimum tillage can refer to several different methods, but the main principles behind the concept are to make as few tractor passes as possible and to leave crop residues, clods, and ridges on the soil surface. Tractors compact the soil thus increasing runoff. Residues and cloddiness help prevent surface crusting and decrease evaporation. Problems can occur with seedling emergence, insects, disease, and delayed warming and drying of the soil, which will lead to later harvests. This delay can affect farmers in the market, if prices have gone down due to an overabundance of the crop. In addition, pesticide use may increase with minimum tillage (Troeh et al., 1980). Sampson (1981) claims, however, that minimum tillage has gained acceptance with farmers because it provides immediate returns in a savings of time and tractor fuel.

A no-till system involves planting crops in a bed which has been prepared only by opening a narrow slot or trench wide and deep enough to allow for proper seed coverage. Weed control occurs through use of herbicides as opposed to mechanical cultivation. A no-till system results in a substantial reduction in tractor use, leading to both decreases in soil erosion and fuel use, but can also increase dependence on herbicides (Young, 1982).

Maintaining good soil fertility is another practice that will help prevent erosion. The resulting lush vegatative cover will decrease the severity of raindrop impact, and help to reduce runoff velocity. Soil fertility can be maintained or improved through nutrient inputs, as well as additions of organic matter, including mulches and manure. The latter two will also help improve soil structure allowing for greater infiltration (World Bank, 1985; Foth, 1984; Donahue et al., 1983).

Use of fall cover crops is another management practice which can reduce erosion and improve soil productivity. These crops help protect the soil surface after harvest and when plowed under in the spring provide a good source of organic matter and nutrients, particularly if the crop is a legume.

Another practice which could result in land producing a crop while still conserving more soil is the use of grass or legume hay strips. These strips act as a trap for eroding soil, may be grazed or harvested as hay, and have been shown to increase total field yield (Troeh et al., 1980; Francis et al., 1986).

Donahue et al. (1983) promote the use of mulch to decrease erosion. Mulches reduce evaporation, increase infiltration, and may add organic matter and nutrients to the soil. Use of mulch is especially important before the crop canopy has had a chance to establish. The mulch will protect the soil surface from raindrop impact and decrease runoff velocity.

Irrigation can be an important tool in increasing yield and in decreasing erosion because proper use can promote formation of lush crop canopies. Application requires careful control to prevent waste of water. Soils must drain well naturally or a drainage system must be put in (Troeh et al., 1980). The economics of such a venture is also of major concern. Studies have shown that though irrigation can increase yields, and at times dramatically, the increase does not always warrant the expense of installing and maintaining a system (Schwab and Black, 1989).

Though many farmers have spent years trying to remove trees from their fields, trees may prove to be useful in some areas. Agroforestry can provide good yields, while at the same time conserve the natural resource base of hillslope farms. Agroforestry is a land management practice where woody perennials are grown together with non-woody crops and/or animals in some spatial mixture or temporal sequence. The practice is a true example of the whole being greater than the sum of its component parts. By combining woody and non-woody crops and/or animals, significant ecological and economic benefits to the system accrue. The goal of agroforestry is not to maximize yield, which has been the motivating force behind modern high-input agriculture in the U.S., but to increase profitability. This implies sustaining that yield over time while minimizing outside inputs. To achieve this, natural resources, and particularly soil resources, must be conserved (Combe, 1982).

Management Selection

Designing sound management systems for hillslope agriculture requires careful planning, a thorough knowledge of the natural and social system, and application of techniques which can serve both a productive and protective function. The systems which were designed based on field level data, assessment of the appropriateness of the management techniques listed above, and the modeling provided by the GIS and AIS meet these criteria.

The effects of various management strategies were modeled through use of YIELD and USLE. Alternate management strategies selected include use of mulch, cover cropping, contour cultivation, minimum tillage, no-till, and strip cropping.

Other recommendations are made, but were not modeled due to lack of input data required by the models to assess the effects of these practices. Some examples include the effects of trees on erosion and on productivity, using manure to decrease erosion by promoting good soil structure, and improving yields through organic matter and nutrient additions.

YIELD Model Results

There was not a substantial difference in estimated yields among the 4 AEZs. The model is probably not sensitive enough to reflect changes in productivity on such a fine scale. As discussed previously, the model is most effective in estimating yield over large regions where climatic values will vary as well as slope and soil types.

The difference between the highest yielding AEZ and the lowest yielding amounted to 91 kg/ha. This figure translates to less than 2 bushels/acre. Whether this is a significant difference or not is relevant to the agricultural system. In some areas of the world 2 additional bushels may be the difference between malnutrition and health. In other areas, 2 bushels an acre multiplied by a vast amount of acreage may also be a significant amount. In still others, 2 bushels an acre may not mean that much.

The differences within the same AEZ between a mulched system and system using no mulch was barely noticeable. The change from no mulch to mulch resulted in less than half a kg/ha increase in yield. A 10% decrease in evaporation was assumed from mulch use. This value could actually be higher, which would result in higher yields. In addition, the effects of using mulch are cummulative because organic matter would increase, soil structure would improve, and, depending on the composition of the mulch, available nutrients would also increase. This would result in gradual annual yield increases.

The lowest yields as hypothesized and as substantiated by the on-site analysis were found in AEZs 12 and 18 respectively. These AEZs represent the more steeply sloping regions in the study area. This is an important finding for designing optimal management strategies, since these regions also generate the most soil erosion.

USLE Results

The USLE has limitations which should be noted here. The present equation has been used over roughly the past 30 years and is developed from equations used since the 1940's. It was developed from years of plot experiments and is most applicable east of the Rocky Mountains. Other equations are being developed, but the USLE is currently the most widely used, documented, and accepted (Foster, 1988).

The equation's greatest strength lies in comparing the effects of various management practices rather than in precisely quantifying soil loss on a given field. This is the use that it has been put to in this research. The importance of the results in Table 1 is in comparing the effects on erosion of the various management systems proposed, rather than in predicting absolute values of erosion under a given system. The same conclusion can probably be made for the YIELD model as well, and for that matter for models in general. Simulated values are useful for comparative analysis. Overconfidence in absolute values can lead to misinterpretation and mismanagement.

A continuous corn system was modeled to provide baseline data to which the other systems could be compared. Table 1 shows the results of the simulations. The continuous corn system results in the worst case in terms of quantities of soil eroded over larger areas.

A second system, that of continuous corn using minimum tillage, resulted in values only slightly better than the first.

The next system modeled, switched to no-till, which resulted in a larger area being managed within tolerance levels. Of the continuous corn systems, the no-till provided the most protection of the tillage systems modeled.

The fourth system modeled included a corn-fall cover crop system employing contour cultivation and conventional tillage. These changes in management practices resulted in substantial savings in soil over large areas of the land unit.

The fifth system modeled was identical to the fourth, but included strips of alfalfa grown on some of the least productive land, which constituted part of the backslope area identified through on-site analysis. Use of YIELD also showed this region, which was contained within AEZ 18, to have the lowest production potential of the various AEZ's. This area was spatially located through use of the CHARMAP phase of CRIES. Approximately 13% of the total land unit would be taken out of corn production, and put into alfalfa.

The final system modeled employed a no-till system on corn/fall cover crop with contour planting and alfalfa strips on AEZ 18. This system resulted in the best management in terms of limiting erosion as compared to the other systems modeled with USLE.

R, K, and LS factors in the USLE were kept constant in each scenario. Alternate management practices were reflected through changes in C and P values. Use of minimum tillage and cover cropping resulted in reduced values in C. C values could be reduced even more through use of minimum tillage which leaves crop residue on the field, but this corn is being harvested for silage, which means that most of the plant is taken off. P values were reduced through use of contour cultivation and strip cropping by 50% and an additional 13% respectively.

Final Land Use/Management Recommendations

The maps contained in Appendix E are meant to be used as tools for designing appropriate management systems. In any of the maps, the darkly shaded regions signify areas which under that management system are meeting soil tolerance levels for erosion. The white cross-hatched areas represent regions which exceed tolerance levels. These areas can be termed priority management areas.

In the sixth map, the management system of corn-fall cover crop employing no-tillage along the contours with alfalfa strips is the best in terms of limiting soil erosion. This system results in a reduction in corn yield, but only land contained within AEZ 18 is affected.

Additional management systems recommended include using manure from the nearby dairy cattle production facility. This will decrease cash outlays for N-P-K and improve soil structure and organic matter quantities, thus also decreasing erosion. Another alternative as discussed previously is agroforestry. It appears as if there is good potential for incorporating trees into the agricultural production system studied at KBS. Potential tree types with good possibilities include alders and poplars. Specific recommendations include European black alder, European gray alder; while some type of fast growing hybrid aspen looks like a reasonable selection of poplar.

A recommendation for spatial arrangement would be along the field perimeter, as well as strips of trees following the contours of the slope in the priority management areas. A spacing of 3m x 6m is recommended to offer some protection from erosion, while not taking away too much of the land from corn production.

Harvesting should be conducted on a fairly short rotation system of 10 to 15 years. It is not the purpose to grow the trees out to saw length, but to produce pulp or fuel wood, as well as protection of the soil.

Incorporation of poplars and alders into the farm system will have multiple benefits. Their use will be both protective and productive in nature. Trees will protect the soil from erosion, and addition of leaves will increase organic matter content and total available nutrient content of the soil when incorporated into the topsoil. Leaves can be collected and composted or simply allowed to decompose where they fall. Additional protective benefits may include a decreased reliance on pesticides through increasing biological diversity in the system.

In their productive role, there are many potential uses for wood products in this region. There currently exists a market for aspen fuelwood. The nearby Tree Source Corporation purchases aspen wood chips for use in industrial wood combustion burners and boilers. In Allegan County, Menasha Corporation is another purchasers of fuelwood, and may be interested in pulp for paper, particle board, and plywood as well.

Other benefits include more effecient use of light, water, and nutrients; a possible reduction in synthetic fertilizer application, and a decrease in risk to the farmer.

The management suggestions presented are part of a system for decreasing inputs and promoting sustainability. The suggestions should be viewed as flexible guidelines, not as a rigid system of steps to follow. In addition, farmers interested in following sustainable agriculture concepts should not make rapid drastic changes in their present systems. Changes need to be made slowly over time, and good records need to be kept on costs, both financial and in terms of time, on inputs and on yields. Clearly, it is quite a leap from planting a fall cover crop to planting alders in farm fields. Farmers need to assess which system will work best for them given their resources and environment. On areas which have been identified as giving lower yields and being the most erosion prone, trees or at least grass or legume strips may prove to be the most productive sustainable management practice.

CHAPTER 6

CONCLUSIONS

Management strategies which minimize erosion without being excessively costly for a farmer to implement are needed for sustainable farming of hillslopes. Though the detrimental effects of farming sloping land have been well documented, they are still farmed throughout the world (Logan and Cooperland, 1987). Over 30% of all agriculture in Latin America can be found on sloping land; in the country of Haiti this figure rises to 65% (Prosner, 1981). In Asia, Nepal serves as an example. A 2.1% increase in annual agricultural production in this country has not kept pace with a population growth of 2.66% (Agricultural Projects Services Center, 1986). This has led to many marginal lands in the hills being placed under cultivation, which has resulted in over a quarter of a million tons of topsoil eroding every year (Myers, 1984). The plight of many African countries received much publicity during the early 1980's. Many of those problems stemmed from improper management of sloping lands (Roose, 1988; Thomas, 1988).

The problem is somewhat different in North America. Sedimentation is the leading cause of water pollution in the

U.S., and the greatest bulk of sediment stems from eroding agricultural lands (Troeh, 1980). In Michigan, "Sediment, by volume, is our greatest pollutant" (DNR, 1975).

Sloping lands are generally more prone to water erosion than lands which are flat, and cultivating slopes exacerbates this situation (Logan and Cooperland, 1987). In addition, erosion has caused a decrease in production potential of many U.S. farmlands. The full extent of these effects are masked through additional inputs into the farming system (Troeh et al., 1980).

There are many factors which often force farmers to move to less desireable hillslopes. These factors include pressure from growing populations for increased food production or for conversion of choice farmland to other uses, inequitable distribution of land and an inflexible land tenure system, and conversion of land that once produced food to land for cash crop production (Murray, 1977; Logan and Cooperland, 1987).

Whatever the reasons that force farmers to cultivate sloping lands, the fact remains that by cultivating them without proper controls they are continuously decreasing the production potentail of these soils and polluting the environment. Strategies must be developed which will allow farmers to farm slopes with minimal environmental damage allowing for sustainable yields. In non-industrialized countries, soil erosion leading to malnutrition and other related problems warrants adoption of new strategies, while in industrialized nations, erosion problems causing pollution and economic hardships should stimulate development of alternative techniques. Alleviation of erosion alone may not be enough of an incentive for adopting alternate strategies. However, decreased environmental degradation coupled with increased or diversified farm output and more efficient resource use makes alternative strategies much more attractive. Much of the work is simply educating farmers about these strategies.

In this study, data from on-site analysis of the study area located at the Kellogg Biological Station of Michigan State University was incorporated with spatial data from the region and analyzed with the aid of a Geographic Information System. Knowledge of the physical and social environment, as well as knowledge of land evaluation techniques and various sustainable agricultural principles, resulted in presentation of several land use/management scenarios. Each scenario was modeled with the aid of the GIS to provide information regarding yields and erosion levels.

The continuous corn system, which provided baseline data for the study, resulted in excessive amounts of soil erosion. Various management practices were proposed resulting in vastly improved erosion levels thus not supporting the null hypothesis that there is no relation between alternate management strategies and soil erosion rates. On the contrary, these findings supported the research hypothesis that certain alternative land management strategies to the continuous corn system will result in lower soil erosion rates. One criteria in selecting management strategies was to limit the reduction to total yield. This was done through identifying regions of low potential productivity and high erosion potential. Management practices which took land out of corn production were targeted for these areas.

Alternate practices such as no-tillage, minimum tillage, contour cultivation, cover cropping, and strip cropping provided decreased amounts of soil erosion when compared to the continuous corn system employing conventional tillage. Use of mulching, manure, and agroforestry concepts were also discussed as a means of decreasing erosion without adversely impacting yields or profits.

Recommendations For Future Research

For even greater comprehension of the impacts of various management systems, a benefit-cost analysis should be conducted. This analysis was beyond the scope of this study. A benefit-cost analysis could be greatly aided by use of the CRIES AIS-MULBUD module adapted from Etherington and Matthews (1984).

Study Limitations

Though this study is site specific, it is hoped that the results can be useful in both Hickory Corners, Michigan and other locations where the problem of sloping land management takes on greater importance. Population pressure and land tenure systems found throughout the non-industrialized world have long since forced farmers onto the marginal lands of the hillslopes. Given this situation, technical solutions must be developed which can at least slow the negative impacts of such a farming practice on the environment, and subsequently on the people. These technical solutions are not the cure-all to the problems of non-industialized nations. Far from it. They merely provide a stop-gap. However, barring massive upheavals in the social systems of many of these countries, the technical solutions provide a more realistic and achievable route to alleviating some of the stress placed on the natural resource base. Technology and physical alterations of the landscape also can eventully affect the social system.

Ideally then, such a study should be conducted on the land area where it could take on greater significance. This would more likely ensure inclusion of any cultural or societal factors that may guarantee the success or failure of the technical solution. It should be stressed here that no technical solution may be imposed on any society. A technical solution must be couched in a cultural package to make it palatable.

Financial and time limitations, however, made it impossible to conduct the study in another country. Therefore, a substitute site was selected which was more accessible and reasonable given the resources. It is hoped that the results of this study will add to the knowledge base for proper agricultural management of hillslopes, and thereby help form a unifying theory on this subject. Perhaps similar methods will be used someday in evaluating land units in other countries. Unified theories developed in this field must utilize the tremendous production potential of modern agriculture, while at the same time consider the functional relationships of natural systems, thus achieving solutions which produce adequate yields and are at the same time ecologically sound.

Knowledge gained from this study, particularly knowledge gained on differences among slope sections, may add to the limited literature base being formed on this subject. The techniques used in analyzing the data are certainly applicable to other areas of the world. This is true even in areas where the same tools, such as the computer hardware and software programs used in the analysis, are not available. Alternate tools, such as field calculations of USLE, may provide useful results. The principle of analyzing both the physical and social environment in a comprehensive fashion prior to designing and implementing management decisions is the key behind this study. Certain tools were used and certain management recommendations have been put forth. Designing sustainable agricultural systems for farming hillslopes requires, above all, thorough knowledge of the total environment and the flexibility to adapt to available resources.

APPENDICIES

APPENDIX A

YIELD Model and USLE Data Input Values

Table 2 Environmental Data Set

Month	Temp. (Celsius)	Precipi- itation (mm)	Wind (ratio) (m/sec)	Humidity (%)	Solar Radiation (hrs./day)
January	24.8	2.10	17.2 (1.2)	71	9.6
February	27.1	1.83	17.0 (1.2)	71	10.7
March	35.6	2.48	16.9 (1.2)	71	11.9
April	48.8	3.77	16.8 (1.2)	71	13.3
May	59.6	3.36	16.7 (1.1)	71	14.4
June	69.4	3.49	16.5 (1.1)	71	15.0
July	73.0	3.56	16.6 (1.1)	71	14.7
August	71.8	2.80	16.6 (1.1)	71	13.7
September	64.4	3.06	16.8 (1.2)	71	12.5
October	54.2	2.74	17.0 (1.2)	71	11.2
November	40.1	2.67	17.1 (1.2)	71	10.0
December	29.1	2.53	17.1 (1.2)	71	9.3

Data Source: All values adapted from Kalamazoo County Soil Survey, 1979 with the exception of solar radiation which was taken from the YIELD Model User's Guide, 1987.

Table 3 Crop Production Parameters

Crop type	4
Avg. root size for growing phases (cm)	35, 90, 135, 165, 185 (Aldrich, 1965)
Leaf Area Index	4
Crop Production Group	10
Crop Water Depletion Group	Default

Data Source: Unless otherwise noted, YIELD Model User's Guide, 1987.

Table 4 Farm Management Parameters

Sowing Date	5/7/87 (KBS Farm Records)
Harvest Date	9/5/87 (")
Duration of each stage of growth (days)	27, 32, 30, 24, set by model (Aldrich, 1965)
Irrigation parameters	Default
Evaporation Reduction	Default or 10% in mulched systems
Fertilizer Usage	Default

Data Source: Unless otherwise noted, YIELD Model User's Guide, 1987.

Table 5 Local Parameters

	AEZ 3	AEZ 4	AEZ 12	AEZ 18
Altitude (m) (USGS, 1961)	283	283	283	283
Latitude (degrees) (")	42.22	42.22	42.22	42.22
Location (")	N	N	N	N
Slope Class	1	1	2	3
Soil Textural Class	2	1	1	1
Soil Moisture (mm/m)	140	60	60	60
Soil Salinity	Not Included			

Data Source: Unless otherwise noted, YIELD Model User's Guide, 1987.

Table 6 USLE Input Values

Management System	R (j/ha)	K Oshtemo (mt/ha)	K Kalamazoo (mt/ha)	LS	C	P
Continuous Corn Conventional Tillage	230	.42	.31	*	.52	1
Continuous Corn Minimum Tillage	230	.42	.31	*	.42	1
Continous Corn No-Till	230	.42	.31	*	.34	1
Corn/Fall Cover Crop Conventional Tillage Contour Cultivation	230	.42	.31	*	.44	.5
Corn/Fall Cover Crop Conventional Tillage Contour Cultivation Alfalfa Strips	230	.42	.31	*	.44	.44
Continuous Corn No-Till Contour Planting Alfalfa Strips	230	.42	.31	*	.34	.44

Data Sources:

All "R" and "C" values were adapted from the Michigan SCS Technical Guide versions 1978 and 1987.

"K" values were adapted from Kalamazoo Co. Soil Survey, 1979.

"LS" values are calculated from the LENGTH and GRADIENT modules of the CRIES-GIS.

"P" values were calculated based on Troeh et al., 1980.

APPENDIX B

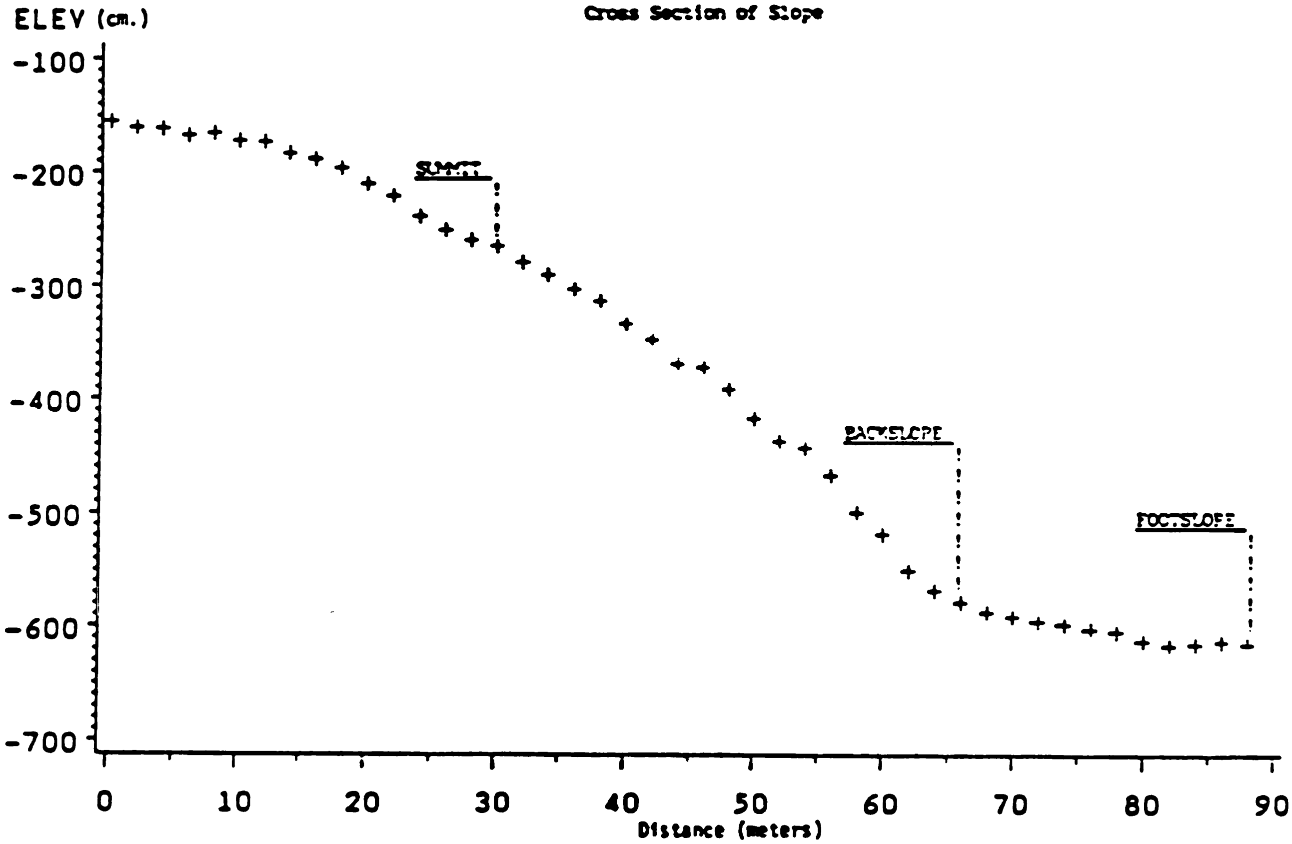


Figure 2 Cross Section of Slope.

APPENDIX C

Table 7 Transect Analysis Of Slope.

Position	Variate	Mean	se	N
Summit		6.96 s	0.06	19
Backslope	pH	7.07 b	0.04	21
Footslope		7.38 f	0.04	15
Summit		9.94 s	0.20	19
Backslope	%H2O	8.73 b	0.41	21
Footslope		10.99 f	0.37	15
Summit	Plant	701.16 sbf	25.97	19
Backslope	Biomass	746.67 sbf	30.03	21
Footslope	(grams)	713.00 sbf	46.65	15
Summit	Grain	261.21 sb	13.15	19
Backslope	Biomass	256.05 sb	11.22	21
Footslope	(grams)	292.27 f	16.80	15
Summit	NO3	6.82 s	0.48	19
Backslope	(ug/g	3.71 bf	0.18	21
Footslope	dry soil)	3.63 bf	0.29	15
Summit	NH4	2.17 s	0.17	19
Backslope	(ug/g	3.19 b	0.36	21
Footslope	dry soil)	1.63 f	0.08	15
Summit	PNO3	1.06 s	0.05	19
Backslope	(ug/g	0.76 bf	0.02	21
Footslope	dry soil)	0.78 bf	0.07	15
Summit	PMIN	0.99 s	0.05	19
Backslope	(ug/g	0.58 b	0.02	21
Footslope	dry soil)	0.69 f	0.07	15
Summit		1.55 sb	0.02	19
Backslope	Bulk	1.53 sb	0.04	21
Footslope	Density	1.64 f	0.03	15

Key: S A single letter means the value is significantly different from the other two.

SB Two letters mean there is no significant difference between those two positions.

SBF Three letters mean there is no significant difference among those three positions.

APPENDIX D

Table 8 Estimated corn biomass production for each AEZ.

	Agroecological Zones.			
YIELD Model Yield kg/ha	**3**	**4**	**12**	**18**
Without mulching	4895	4940	4888	4849
With mulching	4895	4940	4889	4849
YIELD Model Yield bu/acre				
Without mulching	78	79	78	77
With mulching	78	79	78	77
SCS (1979) Estimates Yield bu/acre				
	95	80	78	70

APPENDIX E

Maps Showing Results of USLE According to Various Management Systems.

N ↑

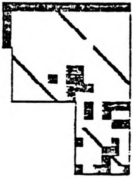
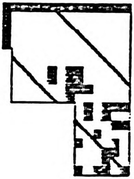


Figure 3



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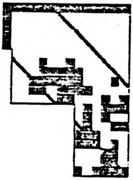

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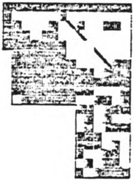

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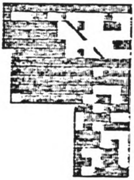

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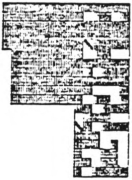

Figure 8

Scale: 1:24,000

Legend: Within Tolerance Limit.

Exceeds Tollerance Limit.

Description of Management Systems:

Figure 3	Continuous Corn, Conventional Tillage.
Figure 4	Continuous Corn, Minimum Tillage.
Figure 5	Continuous Corn, No-Till.
Figure 6	Corn/Fall Cover Crop, Contour Cultivation, Conventional Tillage.
Figure 7	Corn/Fall Cover Crop, Contour Cultivation, Alfalfa Strips, Conventional Tillage.
Figure 8	Corn/Fall Cover Crop, Contour Planting, Alfalfa Strips, No-Till.

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