Staff Paper

THE ECONOMIC IMPORTANCE OF CROP ROTATION SYSTEMS: EVIDENCE FROM THE LITERATURE

Berhanu Gebremedhin
Gerald Schwab

Staff Paper No. 98-13 **August 1998**

Department of Agricultural Economics
MICHIGAN STATE UNIVERSITY
East Lansing, Michigan 48824

THE ECONOMIC IMPORTANCE OF CROP ROTATION SYSTEMS:

EVIDENCE FROM THE LITERATURE

by

Berhanu Gebremedhin
E-Mail: gebremed@pilot.msu.edu

Gerald Schwab
E-Mail: schwab@pilot.msu.edu

AEC Staff Paper No. 98-13

August 1998

The financial support for this research was provided by the Michigan Department of Agriculture, Grant No. 97-BG4700, under the Michigan Energy Conservation Program. We would like to thank Dr. Richard Harwood, C.S. Mott Foundation Chair for Sustainable Agriculture at Michigan State University, for his support of this work. We are also grateful to Dr. Scott Swinton for his valuable comments on an earlier version of the paper. We also thank participants at the Michigan Sustainable Agriculture Network (MSAN) for their comments following our seminar presentation.

ABSTRACT
(30 pages)

Agricultural sustainability requires that the individual farm firm be competitive and profitable while simultaneously enhancing environmental quality and the natural resource base upon which the farm firm and agricultural economy depends. The reliance of conventional agriculture systems on purchased inputs external to the firm presents possible challenges to the long-term sustainability of the system. Crop rotation systems are one cropping system alternative that can reduce agriculture's dependence on external inputs through internal nutrient recycling, maintenance of the long-term productivity of the land, and breaking weed and disease cycles. Decision criteria to choose among competing crop rotation systems can include impact on soil quality and fertility, environmental quality, and farm profitability. However, most of the comparative economic analysis work reviewed for this paper considered only farm profitability as a criterion to rank alternative crop rotation systems. Most rotation research is focused around a target crop that is the foundation for the crop rotation system. When corn is the target crop, comparative profitability performance of continuous corn vs. corn grown in rotation showed that neither system is consistently more profitable than another. Corn yield in Michigan does respond favorably to crop diversity. Wheat as the target crop in rotation tends to outperform continuous wheat both in terms of profitability and income risk. Sugar beet prices hold the key in determining the profitability ranking of alternative sugar beet-based crop rotations. Potato in rotations tends to outperform continuous potato both in terms of yield and profitability. Future studies addressing the economic performance of crop rotations need to consider the environmental benefits/costs both on and off the farm site that accrue to society.

Key words: Agricultural sustainability, external inputs, soil quality and fertility, environmental quality, crop rotations, comparative economic analysis, farm profitability.

TABLE OF CONTENTS

LIST OF TABLES

1. INTRODUCTION

The need for agricultural producers and agricultural systems to be sustainable is a generally acceptable statement that has many meanings and interpretations. In the context of this paper, sustainability suggests the need for the individual farm business firm to be competitive and profitable while simultaneously enhancing the environmental quality and natural resource base upon which the farm firm and agricultural economy depends. The increasing reliance of conventional agricultural production systems upon purchased inputs external to the firm raises lingering questions about long-term sustainability of the system. If productivity of the soil resource is dependent upon purchased chemical and fertilizer inputs, the sustainable system chain is challenged by this linkage. Additionally, the loading of the soil with chemical and fertilizer inputs provides an environmental risk to the environment beyond the farm firm's boundaries.

Careful selection of crop rotation systems offers one possibility of reducing the tradeoff between maintaining profitability and reducing environmental impact. Crop rotation systems are considered as one major cropping system alternative to reduce agriculture's dependence on external inputs. They do so by internal nutrient recycling, maintenance of long-term productivity of the land, and breaking weed and disease cycles.

The importance of crop rotations has been long recognized. Scientists started to explain the role of legumes in rotations in 1888. The University of Illinois and Kansas State College started rotation studies in 1876 and 1909, respectively (Bray and Schnittker, 1956). Prior to the development of modern farming that increasingly relied on external inputs, crop rotations served myriad purposes including pest control of weeds, diseases, insects, and nematodes; reducing soil erosion; and maintaining soil fertility and enhancing productivity (Guertal et al., 1997; Ikerd, 1991). As reliance on external inputs increased, some believed that the importance of crop rotations would be reduced. However, recent concerns about the environmental impact of chemical inputs, high rates of use of purchased mineral fertilizers, acceleration of soil erosion, uncertainty about the long-term supply or effectiveness of the external inputs, and declining yields have brought crop rotations into the picture again (Ikerd, 1991).

Several advantages of crop rotations have been widely recognized (Bray et al., 1956; Guertal, 1997; Jones, 1996; Christenson, 1991). Crop rotations break weed and disease cycles. Crop rotations can also effectively reduce soil erosion, thereby avoiding the long-term decline in the productive capacity of the land and reducing the non-point pollution that could occur. Crop rotations improve soil quality; i.e., improve soil structure; enhance permeability; and increase biological activity, water and nutrient storage capacity, and amount of organic matter. Farmers can use crop rotations to spread risk and avoid peaks in labor requirements. Crop rotations can increase water use efficiency and uptake of soil nutrients. Moreover, crop rotations can improve soil fertility thereby reducing the reliance on external inputs. Perhaps as a result, Daberkow and Gill (1989), as cited in Guertal et al. (1997), claimed that more than 80 percent of America's cultivated land was under some form of crop rotation.

For purposes of comparative economic studies, agricultural production systems have been classified into conventional, alternative, and organic systems (Fox et al., 1991). Alternative systems are defined to be less reliant on chemical inputs relative to conventional systems. Those production systems that exclude use of chemical inputs altogether have been referred to as organic systems. The results of the comparative economic studies of these production systems indicate that neither system outperforms the other consistently (Roberts, 1996; Fox, 1991).

The classification of farming systems into conventional and alternative is too broad to be of much practical value. Conclusions drawn from such a broad generalization can even be misleading, as farming systems need to be identified based on the specific practices applied. The purpose of this paper is to present evidence on the environmental and economic performance of crop rotation practices as identified by the specific crop sequence and management practices applied. Based on our literature search, research studies addressing the economic importance of alternative crop rotation systems will be discussed. The papers reviewed for this purpose are by no means exhaustive of the literature, but are believed to be reasonably representative.

The paper is organized into five sections. Section two discusses the role of crop rotation systems in reducing agriculture's dependence on external inputs. Section three presents the methods used in the economic analysis of crop rotations and raises issues that need to be emphasized in rotation studies. Section four summarizes the economic studies of crop rotations reviewed for this paper by target crop. Section five presents some conclusions.

2. THE ROLE OF CROP ROTATIONS IN REDUCING THE DEPENDENCE ON EXTERNAL INPUTS

2.1 Economic Reasons for Less Reliance on External Inputs

External inputs are defined as being procured from off-farm sources. Farmers' concern about the increasing dependence of agriculture on external chemical inputs has been growing. The major areas of concern of agriculture's dependence on external inputs can be classified into three broad categories (Ikerd, 1991; Chou, 1993): (1) uncertainty about the long-term availability and effectiveness of the inputs; (2) decreasing internal stability of the production system; and (3) the need to respond to the accruing environmental and social problems.

Most external inputs are produced from depletable, non-renewable energy resources. Evidence to date indicates that the world consumption of such resources exceeds the additions to reserves (Tietenberg, 1992). The decrease in supply of the energy resources is likely to result in a corresponding decrease in the supply of the external inputs available for farm production and/or a rise in their prices if the demand for them remains unchecked. At some point, the prices may become so high as to render them uneconomical for use by farmers. Moreover, the effectiveness of some external inputs may decrease with their continual use. The internal stability of the production system may diminish due to increasing dependence on external inputs jeopardizing the long-term productivity of the natural resource base--soil. Moreover, societies have grown more conscious about the negative environmental and social effects of chemical inputs, exerting considerable pressure on farmers to account for their impact on the environment.

In response to these and other concerns, several methods of reducing the dependence on external inputs have been designed. Three major principles underlying these methods include more efficient use of commercial inputs, substitution of on-farm inputs for external inputs, or redesigning the farming system to resemble the natural ecosystem (Temple et al., 1994). More efficient use of inputs would decrease their use (demand shift) and possibly lower their price, contributing to the simultaneous achievement of competitiveness, profitability, and reduction of environmental problems. Recycling of on-farm inputs should enhance the long-term productivity of the resource base.

Farm practices to reduce use of external inputs include multi-year crop rotations, less use of commercial fertilizer and more on-farm inputs such as nutrient recycling with manure and cover crops, banded fertilizer application, reduced tillage systems, more diversified crop and livestock systems, more integrated crop and livestock systems, and use of mechanical or biological practices rather than chemical inputs to control pests (Pigg, 1994). Some farming systems have totally excluded use of external chemical inputs.

2.2 The Role of Crop Rotations

Crop rotation systems have the potential to integrate the three principles of reducing agriculture's dependence on external inputs. The beneficial agronomic effects of crop rotations can be enhanced by using cover crops. Cover crops can improve soil structure; increase soil organic matter, water percolation, and beneficial insect population; suppress weeds; reduce soil erosion; and fix residual N after grain harvest (Jones, 1996). These benefits from cover crops may increase farm profitability either by reducing cost (e.g., by reducing the need for commercial fertilizer) or by increasing yield through their effect on soil quality and fertility. For instance, Roberts and Swinton (1995) found that in Michigan, application of cover crops in the corn-soybean-wheat rotation reduced the nitrate leaching while maintaining profitability.

The benefits of crop rotations can also be enhanced if used in combination with conservation tillage. Conservation tillage can reduce production expenses for labor, fuel, oil, and repair costs associated with machinery use (Dhuyvetter et al., 1996). Reduced and no-till practices can increase water infiltration and reduce water loss due to evaporation. Conservation tillage can also have a positive impact on yield by reducing soil loss and decreasing soil compaction that could occur due to machinery traffic (Lavoie et al., 1991). Williams (1988), based on his analysis of the effect of alternative tillage systems on wheat and grain sorghum yield in the semi-arid regions of the Central

Great Plains of the U.S., found that wheat and grain sorghum yields were significantly higher from the conservation tillage than from the conventional tillage. Williams also found, based on stochastic dominance analysis, that risk-averse farmers would choose conservation tillage for wheat-grain sorghum rotation rather than the more common conventionally tilled wheat-fallow rotation.

Fallowing has also been used in combination with crop rotation systems. Fallowing the soil has been a practice to conserve soil moisture, reduce the need for commercial fertilizer, reduce weed and pest population, stabilize yield and farm income, and increase seasonal distribution of work (Schoney and Thorson, 1986; Johnson and Ali, 1982). Schoney and Thorson further claim that a summer fallowed field may contain twice as much available soil nitrogen as a stubble field. On the other hand, summer fallow can increase soil erosion and nutrient loss, and cause salinization (Johnson and Ali, 1982).

The importance of summer fallow is more prevalent in dryland environments. In such areas, crop choice is more limited than in areas with higher soil moisture unless irrigation is used. Dryland farming also tends to be more risky due to variable rainfall and temperature, occurrence of hail, insect outbreak, and other unpredictable natural conditions. Hence, fallowing can be an important risk management strategy due to its effect on conserving moisture (Bole and Freeze, 1986).

Crop rotations have disadvantages as well. Diversified cropping systems may require more diverse equipment, diverse management skills and knowledge, and hands-on management (Ikerd, 1991). However, the components of a diversified system can have a synergistic effect which may result in higher gains than from a specified system.

3. METHODS OF COMPARATIVE ECONOMIC ANALYSIS OF CROP ROTATIONS

3.1 The Need for Economic Analysis of Crop Rotation Systems

Cropping systems can be defined as the combination of crops grown and management applied of which crop rotation systems are a subset. Crop rotation systems are characterized by a defined sequence of crops grown on a given cultivated land and the associated management practices. Numerous cropping systems can be technically feasible on a given farm. Decision criteria are required to choose from among the technically feasible ones. Decision criteria for the cropping systems choice can include impact on soil quality and fertility, environmental quality, and farm profitability.

Some cropping systems benefit through their impact on soil quality and fertility, and environmental quality accrues to the society as a whole. When interest is directed to the long-term sustainability of the agricultural production system, these social benefits need to be valued and incorporated into the decision criteria used to compare cropping systems.

At the farm level, optimizing farmers choose the best cropping system from among the technically feasible alternatives. When viewed from the individual farmer's standpoint, farm profitability becomes the overriding criterion. In addition to being technically feasible, a cropping system needs to be profitable to enable survival. Annual profits are accumulated over time into retained earnings to enable growth of the farm business. Among the profitable cropping systems, the comparatively more profitable would still be preferred. The profitability of cropping systems can change over time and farmers need to adapt on a continuing basis. As a result, economic analysis of alternative cropping systems has played a vital role in the choice of sustainable agricultural production systems.

Profitability is a function of production costs, output prices, and yield. Different cropping systems can have different implications on production costs and output yield, requiring the use of a common index for their comparison--a measure of return to the farm. In addition to profitability, income variability is a major consideration of risk-averse farmers. Income variability is a function of yield and price variability of both outputs and inputs. Individual farmers will not have significant impacts on industry prices as agriculture approximates the characteristics of a perfectly competitive industry. A change in cropping system can, however, affect individual farm income variability as driven by the variability of crop yields and impact on crop input mix.

In order to conduct a comparative study of cropping systems, identification of each system and its associated practices becomes essential. If the differences between the cropping systems have implications for a major reorganization of the farm operation, a whole farm budgeting approach would be required. However, if the differences are limited to only part of the farm operation, enterprise budgeting would suffice. Caution must be exercised while interpreting the results of comparative static economic analysis of cropping systems as results can be confounded by the production of multiple products, expanded performance criteria which are not easily valued, and use of different technologies. There is a need to analyze cropping systems as they generate their physical and financial performance over time. Different analytical methods also render comparison of results across studies difficult.

Rotation crops compete for land. The opportunity cost of producing a crop on a given land is the foregone value of producing the next best alternative crop. A crop can have higher yield in rotation than when grown under continuous cropping. In this case, the profitability of the rotation system needs to be compared with the profitability of a continuous cropping system taking into account the yield of the new crops in the rotation. Similarly, alternative rotation systems may have different effects on production costs and the yield of crops involved requiring the computation of the comparative profitability of each system. As such, economic analysis has been playing a key role in the evaluation of alternative rotation systems. Such analysis is by necessity based on a long-term cropping system study and should be conducted on a continuous basis.

While conducting economic analysis of rotation systems, one needs to identify between a crop sequence (a specific rotation), rotation length (one complete repetition of a crop sequence), and rotation phase (the entry crop of one cycle of a crop sequence) (Guertal et al., 1997). Moreover, the effect of differences in soil types and other natural factors needs to be held constant. Complete randomized block design experiments could solve the confounding effects of differences in soil type in a given experimental field. The confounding effect of climatic and other natural factors could be solved by growing each phase of a rotation every year. If each phase of a rotation system is not grown every year, it would be impossible to isolate the yield effect of the rotation system from that of variable weather factors.

The comparison of rotation systems also needs to explicitly consider the planning horizon of farmers. In the short run, farmers are interested in maximizing return over variable costs; i.e., the gross margin. In the long run, however, consideration of total economic costs would be required to compute net profit over total economic costs as costs considered fixed in the short run could account for a major part of production costs in the long run. Schoney and Thorson (1986) showed that fixed costs of machinery and building ownership charges and land costs associated with cereal grain production in Saskatchewan farms, Canada, accounted for 60-75 percent of total costs. However, the use of gross margin or net return over variable costs may not have different effects on the profitability ranking of crop rotation systems. Paudel et al. (1998) compared gross margin and net return to management criteria in ranking the profitability of weed control practices on peanut production in Alabama and found that the two criteria were consistent in ranking the practices.

3.2 Analytic Methods of Economic Analysis of Crop Rotation Systems

Several different analytical techniques have been used to compare the profitability of crop rotation systems including enterprise budgeting, break-even analysis, whole farm budgeting, linear programming, multiperiod programming, and stochastic dominance analysis. Statistical significance of the differences in profits needs to be ascertained whenever possible.

Enterprise budgeting is by far the most common analytical technique (Roberts and Swinton, 1996). Enterprise budgeting can be used to evaluate the contribution of an individual crop to a rotation system (Jones, 1996; Christenson et al., 1995). Enterprise budgeting can also be used to compare the contributions to profitability of the same crop under different rotation systems (Jones, 1996; Christenson et al., 1995; Zentner et al., 1988; Johnson, 1984). Based on enterprise budgeting, a specifically defined measure of returns (e.g., gross margin, accounting profit, economic profit) can be used to rank the profitability of rotation systems. The preparation of an enterprise budget in a crop rotation system requires the identification of cultural operations and their associated costs, the identification and valuation of production inputs, and the proper valuation of output. Different levels of inputs may be required for a given crop depending on its position in a rotation. All costs and benefits need to be expressed in constant dollars whereby nominal dollars are indexed for inflation.

When evaluating the effect of a rotation system on the profitability of the total farm system, whole farm budgeting is required. Depending on the time horizon considered, whole farm budgeting may be limited to the consideration of variable costs only (Bole and Freeze, 1986) or may include total costs (Schoney and Thorson, 1986; Zentner et al., 1988; Johnson, 1984). In the former case, return to fixed costs becomes the criterion of comparison, while in the later case net returns to management and/or land is used.

Break-even analysis helps determine the level of the variable considered most uncertain that would make the choice between two rotation systems indifferent (Johnson, 1984; Zentner et al., 1988; Johnson and Ali, 1982). In most cases, the two variables considered to be most uncertain are yield and price.

Linear programming models have been used to select the rotation system or a combination of rotation systems that yields the highest return over variable or total costs under certain resource limitations (Marshal et al., 1991; Lavoie et al., 1991; Hesterman et al., 1986; Nazer and McCarl, 1986; Musser et al., 1985; Lazarus et al., 1984; Roberts, 1996). In most cases, each rotation system is considered as an activity. Usually the analysis is conducted under the assumption of a representative farm in a given area. Multiperiod linear programming models are used to capture the carryover effects of rotation systems on soil fertility and terminal land value over time (Baffoe et al., 1986).

Partial budgeting, a technique used to evaluate the impact on profitability of a change in cropping practice, could be used to evaluate a shift from one rotation system to another when the change does not require a major reorganization of the farm operation. For instance, the effect of replacing one crop with another in a rotation system could well be evaluated by partial budgeting. However, the literature indicates that the technique has not been used in rotation studies, perhaps because of the complexity of interactions inherent in a crop rotation system. The very fact that crops react differently because of their position in the rotation precludes simple “on paper” substitution. Moreover, little emphasis seems to have been given to the question of how the yield of a particular crop in a given rotation system varies with time.

Producers’ choice of cropping system can be affected by risk attitude. Generally, higher income with low variability is preferred by farmers (Anderson et al., 1977). Crop rotations spread machinery and labor requirements across a season and may reduce risk due to yield and price variations [Hoskins, (1981) as quoted in Christenson et al., (1995)]. Stochastic dominance analysis, a technique used to rank two cumulative distributions in terms of risk preference, has been widely used in the analysis of risk associated with crop rotation systems (Poe et al., 1991; Williams, 1988; Klemme, 1985; Zacharias and Grube, 1984). Simple techniques such as sensitivity analysis of budgeting and programming results by varying price ratios of inputs and outputs have also been used (Jones, 1996; Zentner et al., 1990). In fact, relative prices are more important than absolute prices in analyzing differences between rotation systems. Computation of measures of variability like the coefficient of variation also gives indications about the relative stability of yield or income in alternative cropping systems.

The techniques based on the mean-variance trade-off criteria are based on measures of location and scale parameters and assume that the measured variable is normally distributed. Normal distribution of yield or income data in agriculture is not common, however. On the other hand, stochastic dominance analysis takes the parameters of the total distribution of the variable of interest into consideration and does not require normal distribution of the variables of interest.

4. SUMMARY OF ECONOMIC STUDIES OF CROP ROTATIONS

To adequately conduct comparative economics of alternative crop rotation systems, it is necessary to not only identify differences in crop yields and associated variable costs of production but to also address such issues as different lengths or years for a complete rotation cycle and the complementarities that each crop provides to a succeeding crop in the rotation. To avoid confounding from uncontrolled weather events, it is also necessary that the experimental design permits each crop to be grown each year. Additional complicating issues are the differences in capital investments in machinery and possible infrastructure on the farm plus the off-site, beyond the farm boundaries, impacts that might alter the optimal crop rotation system from a societal welfare position. It is difficult for all of these economic issues to be addressed in any one research study on crop rotation systems.

Most rotation studies appear to be based around a target crop that is the foundation for the crop rotation system. The research question then is reduced to identifying yield and variable cost differences of the target and rotation crops in alternative crop rotation systems. This problem specification has the advantage of narrowing the agronomic boundaries of the research study but does suggest that the problem may not be adequately specified from a social welfare standpoint. The following discussion is structured by the crops identified as the target crops in the studies reviewed for this paper.

4.1 Corn

Corn contributes to many field crop systems and is the most widely grown crop in Michigan. The corn-soybean rotation has developed as the standard cropping system in the Midwest due to its being a profitable rotation. However, the corn-soybean combination has been increasingly troubled by increases in disease and insect problems (Harwood, 1998). These pest management problems have increased incentive to return to a third crop in the corn-soybean rotation. Oats, alfalfa, and wheat have been used in the past, and are being revisited for their potential to solve the problem. Inclusion of wheat with red clover can increase first-year corn yield by up to 17 percent over continuous corn while corn-soybean raises corn yield by only up to 6 to 10 percent (Harwood, 1998).

Corn is believed to be a main beneficiary of non-root crop rotations. A summary of the economic studies of corn-based crop rotations reviewed for this paper is given in Table 1. In most studies, continuous corn was used as a base of comparison.

A study of 34 Michigan fields showed that average corn yields can be increased by 16 percent with multi-crop rotations as compared to continuous cropping, and gross margin increased by 23 percent (Roberts and Swinton, 1995). Jones (1996) analyzed the short-term economic returns from a combination of corn-based rotation and cover crops using treatments of commercial fertilizer or dairy manure compost as fertility sources. He compared the returns over variable costs of continuous corn and corn-corn-soybean-wheat rotation. Based on three-year experimental data from Michigan, he found that the profitability of the crop rotation depended on the prices of wheat and soybeans relative to that of corn. Crop rotation had higher return when corn:soybean and corn:wheat price ratios were low (1:2.7 and 1:1.76, respectively). Continuous corn had higher return when the price ratios were higher (1:2.2 and 1:1.4, respectively). Under 1993-95 average prices, continuous corn resulted in similar or higher gross margin than corn in rotation.

Table 1. Summary of Economic Studies of Corn-based Crop Rotations

Author (Year)	Systems Compared (Place of Study)	Result
Roberts and Swinton (1996)	Continuous corn vs. corn in rotation (Michigan)	16% yield and 23% gross margin advantages over continuous corn.
Jones (1996)	Continuous corn vs. corn-corn-soybean-wheat under cover/no cover and fertilizer and compost fertility treatments (Michigan)	Under 1993-95 average prices, continuous corn produced higher or similar gross margin with corn in rotation. Corn:soybean and corn:wheat price ratios altered the rankings.
Wagger and Denton (1992)	Continuous corn vs. corn-soybean rotation under continuous tillage, no-till, and alternating continuous tillage with no-till (North Carolina)	Corn yield from no-till was higher than continuous tillage but corn yield was not affected by rotation.
Martin (1991)	Continuous corn, corn-soybean, corn-soybean-wheat under no-till, or conventional till (Indiana)	Conventionally tilled corn/soybeans was optimal choice for the most part.
Zacharias and Grube (1984)	Continuous corn, corn-corn-soybean, corn-soybean-wheat (Illinois)	Corn-corn-soybean was most preferred by risk-averse farmers (stochastic dominance analysis).
Baffoe et al. (1986)	Continuous corn, corn-soybean, corn-corn-barley-barley, corn-corn-soybean-oats (Ontario, Canada)	Continuous corn was optimal choice (multiperiod linear programming).

Wagger and Denton (1992) evaluated the effects of continuous conventional tillage, continuous no-tillage, and alternating conventional tillage with no-tillage practices on yields in continuous corn and corn-soybean rotation in North Carolina. Based on 5-year experimental data, they found that corn yield from no-till was higher by 4-27 percent than continuous tillage and the increase in yield was due to higher soil moisture that resulted from higher residue cover. However, their result showed that corn yield did not respond to crop rotation. Martin et al. (1991) applied linear programming to determine the corn-based crop rotation and associated herbicide application that would provide the highest net income for three farm sizes and three alternative tillage systems (moldboard plow, chisel plow, and no-till) in Indiana. The study was motivated by the need to find alternative practices that rely less on herbicide application. Based on eight years of experimental data, they found that conventional tillage (moldboard or chisel plow) had higher net farm income with minimal herbicide use, and profit from no-till was significantly lower than that from conventional tillage because of lower yields and higher herbicide cost. Corn-soybean rotation was the optimal rotation for the most part.

Hesterman et al. (1986) compared the profitability of continuous corn with alfalfa-corn and soybean-corn rotation in Minnesota. Motivated by the increase in fertilizer costs and the development of new alfalfa germplasm that showed better promise as a source of N, they applied linear programming to a two-year experimental data. They found that alfalfa-corn rotation with alfalfa cut thrice was the economically optimum rotation and that forage alfalfa was more profitable than alfalfa used as green manure. However, their results may have been confounded by weather effects as each phase of the rotation was not grown every year, and two years of experimental data may have been inadequate to compare cropping systems.

Poe et al. (1991) investigated how commodity programs affect corn-based rotation choices and if internalization of on-site and off-site costs of soil erosion would induce farmers to choose less erosive rotation systems. Based on budgeting and stochastic dominance analysis results of 11-year experimental data, they concluded that commodity programs favor erosive rotation systems, non-program participants favor less erosive rotations, and continuous corn was the most profitable system for participants even after erosion costs were internalized. On the other hand, Sahs et al. (1986) as quoted in Fox et al. (1991) showed, after comparing the profitability of continuous corn with five corn-based rotations, that rotation systems had higher and more stable net returns than continuous corn. Peterson and Vervel (1989) as quoted in Christenson et al. (1991) showed that corn yields were lower from continuous corn and that less N was needed for maximum yield in rotation.

Zacharias and Grube (1984) conducted a stochastic dominance analysis to 10-year herbicide and corn-based rotation experimental data in Illinois. They compared net returns from continuous corn with those from corn-corn-soybean and corn-soybean-wheat rotations and concluded that irrespective of herbicide application, the corn-corn-soybean rotation was the most preferable to risk-averse farmers.

Baffoe et al. (1986) compared the economic performance and effect on soil erosion of continuous corn with four-year corn based rotations in Ontario, Canada. The rotations considered were corn-soybean, corn-alfalfa, corn-corn-barley-barley, and corn-corn-soybean-oats. The study was motivated by the concern that intensive row-crop production was increasing despite environmental problems such as soil erosion. Based on results derived from multiperiod linear programming of 20 years, they concluded that continuous corn was the most profitable system followed by the corn-soybean rotation and the corn-soybean system resulted in the highest soil loss followed by continuous corn. The result was maintained when the yield reduction due to soil erosion was considered.

4.2 Wheat and Barley

Several economic studies have compared the economic performance of alternative wheat- and barley-based crop rotations. The performance of these crops under continuous cropping was also considered. A summary of results of the studies reviewed for this paper is given in Table 2.

Table 2. Summary of Economic Studies of Wheat- and Barley-based Crop Rotations

Author(s) (Year of Study)	Systems Compared (Place of Study)	Result
Norwood and Currie (1998)	Wheat-corn-fallow, wheat-sorghum-fallow under conventional tillage, no tillage, alternating tillage (Kansas)	Wheat-corn-fallow had higher and more stable return than wheat-sorghum fallow.
Zentner et al. (1990)	Continuous wheat, wheat-wheat-fallow, six-year rotations that included green manure, hay, and canola (north central Saskatchewan, Canada)	Fertilized wheat-fallow, fertilized fallow-canola-wheat, and fertilized fallow-wheat-wheat-hay-hay-wheat had higher and more stable returns; continuous wheat showed the highest income variability.
Zentner et al. (1988)	Continuous wheat , wheat-fallow, wheat-barley-fallow under no-till, and conventional tillage (southern Alberta, Canada)	Wheat-fallow and wheat-barley-fallow performed better as did the no-till treatment.
Brown (1987)	Wheat-fallow vs. other wheat-based systems (Saskatchewan, Canada)	Wheat-fallow performed better under price and yield risk considerations.
Schoney and Thorson (1986)	Wheat-fallow, wheat-wheat-fallow (Saskatchewan, Canada)	Wheat-fallow performed better.
Johnson (1984)	Wheat-fallow vs. wheat-barley-fallow (western Canada)	Wheat-fallow was more profitable.
Johnson and Ali (1982)	Continuous wheat vs. wheat-fallow (western North Dakota)	Summer fallow wheat had higher and more stable net returns.
Bole and Freeze (1986)	Continuous barley, barley-fallow, soil moisture-based barley-fallow rotation (Canadian prairies)	Flexible crop rotation had higher gross margin and environmental benefits.

Norwood and Currie (1998), motivated by farmers' growing interest in dryland corn, compared the profitability of wheat-corn-fallow with wheat-sorghum-fallow under four tillage systems of all conventional tillage, all reduced tillage, all no tillage, and conventional tillage corn and no-till corn or sorghum combinations in Kansas. They applied enterprise budgeting to four-year experimental data to determine which rotation system was more profitable, and whether conventional tillage wheat, no-till sorghum, or no-till corn would increase yield and profits relative to all reduced tillage or no tillage practices. They found that wheat yields did not respond to rotation or tillage but corn yield was higher under reduced tillage and no-tillage practices. The net returns (return to management) from wheat-corn-fallow were higher and more stable (based on coefficient of variation) than the net returns from wheat-sorghum-fallow.

Johnson and Ali (1982) conducted profitability analysis of continuous wheat relative to wheat-fallow rotation systems in western North Dakota in order to evaluate the impact of summer fallow on farm returns. The study was prompted by the need to reduce summer fallow in order to reduce soil erosion and salinization. Based on wheat yield trends computed from a regression analysis, returns to land were computed for the continuous wheat and wheat grown on fallow. Summer fallow wheat was found to perform better when wheat prices were low and N prices were high. Summer fallow also reduced income variability. On the other hand, based on literature review, Dhuyvetter et al. (1996) concluded for the Great Plains in the U.S. that more intensive cropping systems had higher net returns than fallow wheat when reduced tillage or no-till was used prior to summer crops and cropping intensity could reduce income variability.

Profitability studies of wheat-based rotation systems were also conducted in Canada (Zentner et al., 1990; Zentner et al., 1988; Schoney et al., 1986; Brown, 1987; Johnson, 1984). Zentner et al. (1990) used experimental data of 27 years in north central Saskatchewan to compare net returns and income variability from continuous wheat with 2-year fallow-wheat, 3-year fallow-wheat-wheat, and 6-year rotations that included green manure, hay, or canola. They found that fertilized fallow-wheat-wheat, fertilized fallow-canola-wheat, and 6-year rotation of fertilized fallow-wheat-wheat-hay-hay-wheat rotations performed best both in terms of net return and income variability. Continuous wheat showed the highest income variability. Zentner et al. (1988) compared economic returns of continuous wheat with those from 2-year fallow-wheat, and 3-year fallow-wheat-barley rotations under no-till and conventional tillage practices over a 7-year period in southern Alberta. They found that no-till treatments perform better when rainfall was below average as did the 2-year and 3-year rotations.

The study by Schoney and Thorson (1986) was motivated by the need to evaluate the impact of reduced fallow on farm income by comparing the return from 2-year wheat-fallow rotation with 3-year wheat-wheat-fallow rotation. They concluded that the 3-year rotation was unprofitable unless wheat prices increased substantially both in the short-run and the long-run. Similarly, Brown (1987) conducted stochastic dominance analysis to see why Saskatchewan farmers in Canada persisted in using wheat-fallow rotation despite its environmental problems such as soil loss, reduced organic matter, and the availability of other more profitable cropping systems. He found that consideration of production and price risks explained farmers' choice of the wheat-fallow cropping system. Johnson (1984) also found that fallow-wheat systems were more profitable than fallow-wheat-barley rotations.

Bole and Freeze (1986) compared barley yields and economic returns from continuous barley with those from fixed barley-fallow and soil moisture based flexible barley-fallow rotation systems in the Canadian prairies. The study was motivated by the need to analyze the trade-off between minimizing summer fallow in order to reduce soil erosion, salinization and nutrient loss, and reducing crop failure due to the soil moisture reserve that results by maintaining summer fallow. They found that flexible crop rotations had higher gross margins, followed by continuous barley; but barley-fallow rotations had lower income variability, followed by flexible rotations. Yield from continuous barley was three times as variable as yield from barley-fallow rotations. Moreover, the flexible barley-fallow rotation was found to reduce soil erosion, nutrient loss and leaching, and salinization more than the other two systems.

4.3 Sugar Beets, Navy Beans, and Potatoes

Economic studies have also compared the economic performance of high value crops like sugar beets and navy beans, and that of potatoes in alternative rotation systems. A summary of results of the studies reviewed for this paper is given in Table 3.

Table 3. Summary of Economic Studies of Sugar Beet-, Navy Bean- and Potato-based Crop Rotations

Author(s) (Year of Study)	Systems Compared (Place of Study)	Results
Christenson et al. (1995)	12 sugar beet- and navy bean-based rotations (Michigan)	Under long-term equilibrium prices, systems with high proportions of sugar beets that include navy beans had higher net returns.
Guertal et al. (1997)	Continuous sweet potato, sweet corn-sweet potato, soybean-sweet potato, 2-year sweet corn-sweet potato, 2-year bahia grass-sweet potato, soybean-sweet corn-sweet potato (central Alabama)	Rotations had on average 40% higher yield than continuous potato.
Wetsra and Boyel (1990)	Continuous potato vs. potato-based rotations (Aroostook County, Maine)	Most potato-based rotations had higher returns than continuous potato.
Lazarus et al. (1984)	Continuous potato vs. potato-based rotations that included corn, wheat, safflowers, soybeans, dry beans, and cauliflower	Potato-cauliflower was the optimal rotation.

Christenson et al. (1995) analyzed the returns from 12 alternative sugar beet- and navy bean-based rotation systems in Michigan. They computed returns to land and unallocated resources for two farm sizes from alternative rotation systems that included sugar beets, navy beans, corn, oats, and alfalfa. The rotation systems compared included corn-sugar beet, corn-navy bean, navy bean-sugar beet, oats-navy bean, corn-corn-sugar beet, corn-navy bean-sugar beet, navy bean-navy bean-sugar beet, oats-navy bean-sugar beet, corn-corn-corn-sugar beet, corn-corn-navy bean-sugar beet, corn-navy bean-navy bean-sugar beet, and oats-alfalfa-navy bean-sugar beet. Based on 15-year experimental data, they found that sugar beets after corn yielded lower than sugar beets after navy beans and navy bean yields were highest in longer rotations and when not after sugar beets. Yield of corn after corn was lower by 11.9 percent compared to corn following sugar beets or navy beans. Sugar beet price was the key factor in determining the profitability rankings of the systems. When sugar beets were priced at $36/ton, systems with higher proportions of sugar beets and including navy beans had the highest net return. For sugar beet price at or below $18/ton, systems with more proportions of navy beans were preferred. Despite the lower yields of sugar beets and navy beans in shorter rotations, high returns from these crops explain farmers' reluctance to employ longer rotations. In a similar analysis, Christenson et al. (1991) showed that sugar beet yields increased by 23 percent and navy beans by 38 percent when forage legumes or green manure crops were included in the rotation.

Guertal et al. (1997) analyzed the effect of various rotations on yield and quality of sweet potatoes in Central Alabama. The study was motivated by the need to find alternative disease, weed, and pest control methods as choices on fungicides and pesticides became fewer for vegetable growers. The rotation systems considered were continuous sweet potato, sweet corn-sweet potato, soybean-sweet potato, 2-year sweet corn-sweet potato, 2-year bahia grass-sweet potato, and soybean-sweet corn-sweet potato. Sweet potatoes were grown every year in order to remove the confounding effect of years. Based on long-term experimental data, they concluded that sweet potatoes in rotation had on average 40 percent higher marketable yield than continuous sweet potatoes, and sweet potatoes rotated with 2-year bahia grass gave the highest annual yield and as high a cumulative yield as continuous sweet potatoes.

Westra and Boyle (1990) compared the profitability of several potato-based rotations with continuous potatoes in Aroostook County, Maine. The study was prompted by the need to identify a profitable potato-based rotation in order to reverse the declining trend in total potato farms and potato output in the county which would have an adverse effect in the economies of the county and the state. The rotations included in the study were three years of potato and one year of oats, two and three years of potato-one year of oats underseeded with clover, potato-oats underseeded with clover-potato-processing peas, three years of potato-barley, two and three years of potato-barley underseeded with clover, potato-barley underseeded with clover-potato-processing pea, and three years of potato-processing pea. Based on data generated from annual samples of 800 field plots over 3 years, they found that except the 3-year potato-oats and 3-year potato-barley rotations, all other potato-based rotations had higher returns than continuous potatoes. Three years of potato-processing pea rotation had the highest return ($1,198.24), almost twice the return from continuous potatoes of $642.73.

Lazarus et al. (1984) conducted a study in Long Island fields, New York to determine the economic impact of crop rotations that reduce potato acreage. The environmental concern due to continuous potatoes' heavy use of pesticides gave the impetus for the study. They compared the return from continuous potatoes with those from potato-based rotations that included corn, wheat, safflowers, soybeans and dry beans, and cauliflower. Based on results of linear programming analysis, they found that potato-cauliflower would be a viable alternative to continuous potatoes.

5. CONCLUSIONS

Crop rotations provide a wide range of agricultural and environmental benefits. The direct benefit of crop rotations is the increase in crop yield. By reducing soil erosion, crop rotations help maintain the long-term productivity of land and reduce negative environmental externalities. By breaking disease and pest cycles, crop rotations reduce the need for herbicides and pesticides, thereby reducing the dependence of agriculture on external inputs and contributing to the reduction of environmental pollution. Crop rotations can also improve soil fertility and quality, thereby reducing the need for purchased fertilizer. As such, crop rotations can help achieve a more sustainable agricultural system.

The results of the comparative profitability performance of continuous corn versus corn in rotation showed that neither system outperforms the other consistently. Corn does seem to respond more favorably in Michigan to crop diversity. The relative prices of the rotational crops in the corn-based rotation with respect to the price of corn appear to be important determinants of the profitability ranking. When wheat is the target crop, wheat in rotation tends to show better performance in terms of both profitability and risk considerations. Sugar beet price appears to be the key factor in the profitability rankings of sugar beet-based crop rotations. Although sugar beet yields tend to be higher in longer rotations, the high return from the crop may induce farmers to use shorter rotations. Potato yield and profitability tend to be higher in potato-based rotations than in continuous potatoes.

Most of the work reviewed for this paper focused on the net return benefits to farmers due to crop rotations. The environmental benefits that accrue to society as a whole were not considered in most of the studies. Similarly, change in capital investment for farm machinery and infrastructure were generally ignored. It is likely that environmental benefits have significant value and need to be considered by policies aimed at encouraging wider use of crop rotations. Future studies of the economic performance of crop rotations should recognize the potential value to the environment of crop rotations.

REFERENCES

Anderson, J.; J. Dillon; and B. Hardaker. *Agricultural Decision Analysis*. Ames, IA: The Iowa State University Press, 1977.

Baffoe, J.; D. Stonehouse; and B. Kay. "A Methodology for Farm-Level Economic Analysis of Soil Erosion Effects Under Alternative Crop Rotation Systems in Ontario." *Canadian Journal of Agricultural Economics* 35(March 1986):55-73.

Bole, J. and B. Freeze. "Modeling the Economic Returns from Fixed and Soil Moisture-Based Flexible Rotations." *Canadian Farm Economics* 20(2)(1986):15-20.

Bray, J. and J. Schnittker. "Legumes or Commercial Fertilizer? Economics of Crop Rotations in Eastern and Central Kansas." Kansas State College of Agriculture and Applied Science, Agricultural Experiment Station Bulletin 384, 1956.

Brown, W. "A Risk Efficiency Analysis of Crop Rotations in Saskatchewan." *Canadian Journal of Agricultural Economics* 35(1987):333-355.

Chou, T. "Energy and Economic Analysis of Comparative Sustainability in Low-Input and Conventional Farming Systems." Unpublished M.Sc. thesis, Department of Crop and Soil Sciences, Michigan State University, 1993.

Christenson, D.; C. Bricker; and R. Gallagher. "Crop Yields as Affected by Cropping System and Rotation." Michigan State University Agricultural Experiment Station Research Report 516, East Lansing, MI, 1991.

Christenson D.; R. Gallagher; T. Harrigan; and R. Black. "Net Returns From 12 Cropping Systems Containing Sugar Beets and Navy Beans." *Journal of Production Agriculture* 8(2)(1995):276-281.

Conservation Information Center. *National Crop Residue Management Survey: 1996 Survey Results*. West Lafayette, IN: CTIC, 1996.

Daberkow, S. and M. Gill. "Common Crop Rotations Among Major Field Crops." In *Agricultural Resources: Inputs Situation and Outlook Report*. USDA-ERS AR-15, Washington, D.C., 1989.

Dhuyvetter, K.; C. Thompson; C. Norwood; and A. Halvorson. "Economics of Dryland Cropping Systems in the Great Plains: A Review." *Journal of Production Agriculture* 9(2)(1996):216-222.

El-Nazer, T. and B. McCarl. "The Choice of Crop Rotations: A Modeling Approach and Case Study." *American Journal of Agricultural Economics* 86(February 1986):127-136.

Ferris, J. "Contributions of the Sugar Beet Industry to the Michigan Economy." Michigan State University Agricultural Experiment Station Research Report 501, East Lansing, MI, 1990.

Fox, G.; A. Weersink; G. Srawar; S. Duff; and B. Deen. "Comparative Economics of Alternative Agricultural Production Systems: A Review." *Northern Journal of Agricultural and Resource Economics* 20(1)(1991):124-142.

Guertal E.; M. Bauske; and J. Edwards. "Crop Rotation Effects on Sweet Potato Yield and Quality." *Journal of Production Agriculture* 10(1)(1997):70-73.

Harwood, R. "Directions for Farm Change: Bringing It All Together." In *Michigan Field Crop Ecology: Managing Biological Processes for Productivity and Environmental Quality*, M. Cavigelli; S. Deming; L. Probyn; and R. Harwood (eds.), Michigan State University Extension Bulletin No. E-2646, 1998.

Hertel, T.; K. Steigert; and H. Vroomen. "Nitrogen-Land Substitution in Corn Production: A Reconciliation of Aggregate and Firm-Level Evidence." *American Journal of Agricultural Economics* 78(February 1978):30-40.

Hesterman, O.; C. Sheaffer; and E. Fuller. "Economic Comparisons of Crop Rotations Including Alfalfa, Soybeans, and Corn." *Agronomy Journal* 78(1986):24-28.

Hill, P. "Use of Rotational Tillage for Corn and Soybean Production in the Eastern Corn Belt." *Journal of Production Agriculture* 11(1)(1998):125-128.

Huang, W. and R. Lantin. "A Comparison of Farmers' Compliance Costs to Reduce Excess Nitrogen Fertilizer Use Under Alternative Policy Options." *Review of Agricultural Economics* 15(1)(1993):51-62.

Ikerd, J. "A Decision Support System for Sustainable Farming." *Northeastern Journal of Agricultural Economics* 20(1)(1991):109-113.

Johnson, L. "Crop Rotation Economics in Western Canada Using Farm Budgeting Criteria." *Canadian Farm Economics* 14(6)(1984):20-28.

Johnson, R. and M. Ali. "Economics of Wheat-Fallow Cropping Systems in Western North Dakota." *Western Journal of Agricultural Economics* 7(1)(July 1982):67-77.

Jones, M. "Enhancing Yield, Profitability and Nitrogen Mineralization in Corn-Based Integrated Cropping Systems." Unpublished Ph.D. dissertation, Department of Crop and Soil Sciences, Michigan State University, 1996.

Klemme, R. "A Stochastic Dominance Comparison of Reduced Tillage Systems in Corn and Soybean Production Under Risk." *American Journal of Agricultural Economics* 67(3)(August 1985):550-557.

Lavoie, G.; K. Gunjal; and G. Raghavan. "Soil Compaction, Machinery Selection, and Optimum Crop Planning." *Transactions of the ASAE* 34(1)(1991):2-8.

Lazarus, S. and G. White. "Economic Impact of Introducing Rotations On Long Island Potato Farms." *Northern Journal of Agricultural Economics* 13(2)(1984):221-228.

Luna, J.; V. Allen; J. Fontento; L. Daniels; D. Vaughan; S. Hagood; D. Tylor; and C. Laub. "Whole Farm Systems Research: An Integrated Crop and Livestock Systems Comparison Study." *American Journal of Alternative Agriculture* 9(1 and 2)(1994):57-63.

Martin, M.; M. Schrieber; J. Riepe; and R. Bahr. "The Economics of Alternative Tillage Systems, Crop Rotations, and Herbicide Use on Three Representative East-Central Corn Belt Farms." *Weed Science* 39(1991):299-307.

Maynard, L.; J. Harper; and L. Hoffman. "Impact of Risk Preferences on Crop Rotation Choice." *Agricultural and Resource Economics Review* 97(April 1997):106-114.

Moore, K. "Crop Rotation Policy: A Report on the Perspectives of Policy Insiders." *The Rural Sociologist* 89(Summer 1989):39-44.

Musser, W.; V. Alexander; B. Tew; and D. Smittle. "A Mathematical Programming Model for Vegetable Rotations." *Southern Journal of Agricultural Economics* (July 1985):169-176.

Novak, J.; C. Mitchelle; and J. Crews. "Risk and Sustainable Agriculture: A Targeted-MOTAD Analysis of the 92-Year 'Old Rotation'." *Southern Journal of Agricultural Economics* 22(1)(1990):145-153.

Paudel K.; N. Martin; G. Wehtje; and T. Grey. "Economic Decision Making Using Enterprise Budgeting and Statistical Analysis: An Illustration in Weed Control Practices in Peanut Production." *Journal of Production Agriculture* 11(1)(1998):48-73.

Peterson, T. and G. Vervel. "Crop Yields as Affected By Rotation and Nitrogen Rate. III: Corn." *Agronomy Journal* 81(1989):731-734.

Phipps, T. "Commercial Agriculture and the Environment: An Evolutionary Perspective." *Northeastern Journal of Agricultural Economics* 20(2)(1991):144-150.

Poe, G.; R. Klemme; S. McComb; and J. Ambrosios. "Commodity Programs and the Internalization of Erosion Costs: Do They Affect Crop Rotation Decisions?" *Review of Agricultural Economics* 13(2)(1991):223-235.

Roberts, W. "Examining Tradeoffs Between the Economic and Environmental Costs of Increased Cropping Diversity." Unpublished M.Sc. thesis, Department of Agricultural Economics, Michigan State University, East Lansing, MI, 1996.

Roberts, W. and S. Swinton. "Economic Methods for Comparing Alternative Crop Production Systems: A Review of the Literature." *American Journal of Alternative Agriculture* 11(1)(1996):10-17.

Roberts, W. and S. Swinton. "Increased Cropping Diversity to Reduce Leaching and Runoff: Economic and Environmental Analysis." Staff Paper No. 95-70. Department of Agricultural Economics, Michigan State University, East Lansing, MI, 1995.

Sahs, W.; G. Helmers; and M. Langemeier. "Comparative Profitability of Organic and Conventional Production Systems in East-Central Nebraska." In *Global Perspectives on Agroecology and Sustainable Agricultural Systems.* Proceedings of the Sixth International Scientific Conference of the International Federation of Organic Agriculture Movements, California, August, 1986. (Published 1988).

Schoney, R. and T. Thorson. "The Economic Impact of Extended Crop Rotations on Saskatchewan Grain Farms." *Canadian Farm Economics* 20(2)(1986):21-26.

Temple S.; D. Friedman; O. Samson; H. Ferris; K. Scow; and K. Klonsky. "An Interdisciplinary Experiment Station-Based Participatory Comparison of Alternative Crop Management Systems for California's Sacramento Valley." *American Journal of Alternative Agriculture* 9(1 and 2)(1994):64-71.

Varvel, G. "Precipitation Use Efficiency of Soybean and Grain Sorghum in Monoculture and Rotation." *Soil Science Society of America Journal* 59(1995):525-531.

Wagger, M. and H. Denton. "Crop and Tillage Rotations: Grain Yield, Residue Cover, and Soil Water." *Soil Science Society of America Journal* 56(1992):1233-1237.

Westra, J. and K. Boyel. "An Economic Analysis of Crops Grown in Rotation with Potatoes in Aroostook County, Maine." Maine Agricultural Experiment Station Bulletin 834, 1990.

Williams, J. "A Stochastic Dominance Analysis of Tillage and Crop Insurance Practices in a Semiarid Region." *American Journal of Agricultural Economics* 70(1)(February 1988):112-120.

Young, D. and K. Painter. "Farm Program Impacts on Incentives for Green Manure Rotations." *American Journal of Alternative Agriculture* 5(3)(1990):99-105.

Zacharias, T. and A. Grube. "An Economic Evaluation of Weed Control Methods Used in Combination with Crop Rotation: A Stochastic Dominance Approach." *North Central Journal of Agricultural Economics* 6(1)(1984):113-120.

Zentner, R.; K. Bowren; W. Edwards; and C. Campbell. "Effects of Crop Rotations and Fertilization on Yields and Quality of Spring Wheat Grown on a Black Chernozem in North Central Saskatchewan." *Canadian Journal of Plant Sciences* 70(April 1990):383-397.

Zentner, R.; K. Bowren; J. Stephenson; C. Campbell; A. Moulin; and L. Townely-Smith. "Effects of Rotation and Fertilization on Economics of Crop Production in the Black Soil Zone of North-Central Saskatchewan." *Canadian Journal of Plant Science* 70(July 1990):835-851.

Zentner, R.; C. Lindwall; and J. Carefoot. "Economics of Rotations and Tillage Systems for Winter Wheat Production in Southern Alberta." *Canadian Farm Economics* 22(1)(1988):3-13.

Zentner, R.; J. Stephenson; P. Johnson; C. Campbell; and G. Lafond. "The Economics of Wheat Rotation on a Heavy Clay Chernozemic Soil in the Black Soil Zone of East-Central Saskatchewan." *Canadian Journal of Plant Science* 63(April 1988):389-404.