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ENVIRONMENTAL CONSERVATION ON AGRICULTURAL WORKING LAND:
ASSESSING POLICY ALTERNATIVES USING A SPATIALLY
HETEROGENEOUS LAND ALLOCATION MODEL

By

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B.A. University of Virginia, 2001

A THESIS

Submitted in Partial Fulfillment of the

Requirements for the Degree of

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(in Resource Economics and Policy)

The Graduate School

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December, 2004

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LAND: ASSESSING POLICY ALTERNATIVES USING A SPATIALLY
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By Kelly M. Cobourn

Thesis Advisor: Dr. Timothy J. Dalton

An Abstract of the Thesis Presented
in Partial Fulfillment of the Requirements for the
Degree of Master of Science
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December, 2004

Multifunctionality refers to the ability of agricultural systems to produce an array of non-market goods and services in addition to market commodities. This thesis focuses explicitly on the provision of environmental benefits, through reduced soil erosion and fertilizer applications, by agricultural producers. Soil erosion and nutrient contamination from agricultural production are the foremost contributors to ground and surface water degradation in the United States. Reducing their production implies gains in social welfare, but may generate significant private losses to producers. The objective of this analysis is to quantify the tradeoff between environmental improvements and producer welfare and to examine the extent to which public policy can influence that tradeoff.

To address this objective, a land use allocation model is constructed using slope to reflect terrain heterogeneity. The model is formulated as a mathematical programming problem, with the objective of maximizing producer welfare subject to an exogenous land

endowment and a series of production constraints. The model developed in this thesis differs from previous empirical models in several substantive ways. First, crop and livestock production activities are explicitly modeled as either separable or nonseparable activities. The advantage to doing so is that it gives the model the flexibility to choose the optimal degree of integration between the two. The model also diverges from previous studies by incorporating a common set of variables that affect the economic and environmental aspects of commodity production. Specifically, the spatial allocation of land use practices impacts economic and environmental outcomes via a yield damage function and differentiated rates of soil erosion. These two aspects are expected to improve the model's predictive ability.

One of the primary benefits of the model is that it can be used to identify the economic factors driving landscape-level production patterns. The analysis demonstrates that the land use allocation is relatively insensitive to changes in commodity prices. Therefore, altering the level of commodity-based income support payments is insufficient to attain environmental improvements. Several hypothetical "green" policy instruments are simulated to estimate the cost to producers of reducing environmental damages. The results indicate that limiting soil erosion to an environmentally acceptable level with either a regulatory standard or a tax reduces the average return to land by ten percent. A program of green subsidy payments for less erosive land management practices cannot attain the same standard with less cost to producers. Overall, the inelastic response of land use change to commodity prices indicates that targeting the use of productive inputs, as opposed to commodity outputs, may be a more efficient means of encouraging agricultural producers to provide environmental benefits.

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CHAPTER 1

INTRODUCTION

While the United States has a tradition of supporting domestic agricultural producers, the magnitude and diversity of support mechanisms have reached unprecedented levels in recent years. The amount of direct government payments disbursed to U.S. farmers more than doubled between 1990 and 2000, peaking at over \$22 billion. This historically high level of support is projected to persist well into the future: the Economic Research Service forecasts that direct payments will exceed \$20 billion annually through 2005, and will remain above \$15 billion per year through 2011. These support payments are currently administered via 75 Farm Service Agency programs, foremost of which are fixed direct and counter-cyclical payments. A host of indirect support mechanisms, such as crop insurance premium subsidies, export credit guarantees, and ad hoc emergency assistance, further increase the level of income support received by domestic producers.

Considering their magnitude and variety, it is not surprising that agricultural subsidies tend to create a number of perverse incentives. The worst offenders are those payment programs that are “coupled;” i.e. the amount of payments received by a producer depends on the production of a specific commodity. Currently, marketing assistance loans and crop-specific payments (for peanuts, dairy, cotton, sugar, and tobacco) are examples of coupled policy mechanisms. Such subsidies alter the relative return to program commodities, skewing agricultural production patterns towards those outputs. In so doing, these mechanisms may generate a number of undesirable outcomes.

For example, by influencing aggregate commodity production, coupled subsidies may subvert their own ability to support producer income by causing an endogenous decline in commodity prices. In addition, subsidies that significantly impact production levels may fall outside of the World Trade Organization's (WTO) "green box" and be subject to international sanction (Adams et al., 2001).

Over the last two decades, in response to the problems generated by coupled support payments, there has been a movement towards "decoupling" subsidy programs. Decoupling removes the linkage between payments received and the production of a specific commodity. Examples include fixed direct and counter-cyclical payments. Theoretically, these subsidies should have no impact on the relative return to program crops. However, they may indirectly affect production decisions by creating wealth and/or insurance effects (Westcott, Young, and Price, 2002; Young and Westcott, 2000; Hennessy, 1998). The former occur when payments augment farmer wealth, encouraging increased investment.¹ The consequence of the wealth effect is an increase in aggregate production. The insurance effect arises when subsidy payments alter the relative risk associated with program commodities. Policies that reduce the revenue variability of specific crops will skew production towards those crops if producers are risk-averse (Hennessy, 1998).² However, these effects are expected to have a relatively minor impact on aggregate production practices, and thus avoid the price endogeneity and trade problems created by their coupled counterparts.

¹ The increase in investment may come about through reduced credit constraints, i.e. if lenders are more willing to finance, or offer lower interest rates to, farmers with a guaranteed higher income. Alternatively, an increase in liquidity may lower the effective cost of capital and increase investment.

² Crop insurance premium subsidies, considered coupled, also impact producers' perception of risk. Because insurance subsidies are generally positively correlated with risk, they tend to encourage the production of riskier crops in relatively risky production regions.

Although decoupling can eliminate some of the negative side effects associated with commodity-based subsidies, it does little to address the environmental impacts of commodity production. Whether coupled or decoupled, agricultural subsidies tend to contribute to environmental degradation by encouraging the extensification and/or intensification of production systems. Extensification refers to the expansion of production onto marginal land. Intensification involves activities designed to increase the yield of a given parcel of land. These generally include the use of high-yield crop varieties, the application of chemical fertilizers and pesticides, and increased irrigation and mechanization. The potential negative impacts of intensification and extensification are many: they may increase soil erosion, reduce soil fertility and biodiversity, contribute to the pollution and eutrophication of ground and surface water supplies, and impact climatic trends.

Since the 1930s, agri-environmental policy instruments have been employed to encourage the use of less environmentally degrading agricultural production practices. Prior to 1990 these programs focused on soil conservation to enhance productivity. However, with the 1985 and 1990 Farm Bills, the scope of agri-environmental policy expanded to include improvements in water quality, air quality, and wildlife habitat (Claassen et al., 2001). These programs have focused almost exclusively on attaining environmental improvements through land retirement (Claassen, 2003). As of January 2003, the largest land retirement initiative, the Conservation Reserve Program (CRP), enrolled nearly 34 million acres of cropland nationwide, with payments of over one and a half billion dollars.

Recently, however, the Farm Security and Rural Investment Act of 2002 (the “2002 Farm Act”) shifted the focus of conservation spending away from land retirement programs and into policies targeted towards working lands. The 2002 Farm Act introduced the Conservation Security Program (CSP), which fully finances the adoption and maintenance of approved management practices. These practices include nutrient management, integrated pest management, crop residue management, and changes in cropping rotations. Although the CSP was enacted, it has yet to be implemented on a large scale because of budgetary concerns.

There are several factors driving the shift in conservation spending. First, by targeting a much greater land area, working land programs may be able to attain greater environmental improvements than land retirement programs. Second, working land provisions may be more cost-effective than land retirement. Specifically, because agricultural commodity production continues, the opportunity cost of providing conservation benefits on working land is lower than that of removing land from production entirely (Feng et al., 2004).³ Finally, depending on how they are administered, working land programs may be able to provide conservation benefits and support producer income without influencing aggregate commodity production. This offers the advantage that producer support may be provided without violating WTO specifications. The possibility that environmental benefits can be provided on working lands provides the motivation behind this analysis.

³ The authors note that the relative cost-effectiveness of working land programs may be an empirical matter: it may depend on the conservation practices adopted, land characteristics, and the details of implementation.

1.1. The Study Area

Nationally, producers specializing in oilseeds and grains receive over half of all direct government payments (Economic Research Service [ERS], “Briefing Room”). Iowa, the dominant producer and exporter of soybeans and feed corn in the U.S., is also one of the foremost recipients of Federal support payments. In 2003, the state of Iowa collected over one billion dollars in Farm Service Agency payments, second only to Texas. Data from the 2002 Census of Agriculture illustrate the dominance of these program crops on the landscape: over 92 percent of harvested cropland statewide is planted to grain corn and soybeans.

The land use pattern in Crawford and Shelby counties is no exception, with over 95 percent of arable land used to cultivate corn and soybeans. However, these two counties are located in western Iowa, a region characterized by heterogeneous terrain and loess-derived soils. The combination of loess soils and highly variable terrain increases the potential for soil erosion and nutrient runoff. Producing row crops, which generally involves tilling, reduced vegetative cover, and increased chemical inputs, further exacerbates rates of environmental damage. The consequences of intensive row crop production on this landscape include productivity losses from topsoil erosion, as well as the degradation of water supplies from increased sedimentation and nutrient contamination.

The juxtaposition of a heavily subsidized homogeneous production pattern on such environmentally sensitive land offers a unique case study opportunity. On the Crawford and Shelby county landscape, slight changes in regional production practices may yield significant environmental benefits. For example, there are a number of

potential environmental benefits to incorporating legume forage crops into a corn-soybean rotation (ERS, 2000). Legumes provide weed control and increased nitrogen fixation, reducing the need for commercial pesticides and fertilizers. In addition, the use of legumes or other small grains establishes vegetative cover and reduces the amount of tilling required over the length of the rotation. The inclusion of legumes can therefore reduce average rates of soil erosion and nutrient runoff/leaching.

Despite the environmental benefits associated with extending crop rotations, doing so is not economically rewarding under current conditions. The basic economic problem arises from the fact that environmental goods and services are non-market commodities. As such, their social value is not explicitly determined on the market and is therefore not reflected in producer land management decisions. This type of market failure is often used to justify public policy intervention. The general objective of current agri-environmental policy instruments, including the CSP, is to provide an incentive for individual producers to internalize the social value of environmental conservation. This thesis assesses the economic and environmental impacts of conservation programs for agricultural working land.

1.2. Study Objectives and Approach

This study empirically analyzes the tradeoff between social welfare, in the form of reduced environmental degradation, and private producer welfare, derived from commodity production. The basic question addressed is whether, and to what extent, public policy can be used to address the dual objectives of providing environmental benefits and supporting producer welfare. There are three specific policy-driven objectives, as follows:

1. To identify the economic factors that influence landscape-level agricultural production patterns in the study area.
2. To evaluate the tradeoff between economic and environmental policy objectives.
3. To determine the relative efficiency with which various public policy instruments attain environmental goals.

Within the context of Crawford and Shelby counties, commodity production and environmental benefits jointly depend upon the spatial location of land management practices. The approach taken to address the above objectives is to build a land use allocation model. While this approach is an established method of addressing these types of questions, the model developed in this analysis differs from those used in previous empirical studies.

While previous land use analyses have focused on modeling either land use or livestock activities, this analysis incorporates both. Crop and livestock outputs, feed and manure nutrients, can be allocated in one of two ways: they can be used as intermediate inputs into livestock and crop production, respectively, or they can be sold on the market (crops) or disposed of with no nutrient redemption (manure). By including both activities, the model is given the flexibility to choose the optimal degree of separability between the two activities. A completely separable, or nonintegrated system, is one in which all crops are sold on the market and all feed and nutrient inputs are purchased.

Nonseparability, or full integration, implies that all feed and nutrients necessary for livestock and crop production are directly exchanged on-farm or between producers.

A second advantage to the model used here is that the production of environmental goods and services is incorporated as an endogenous variable in the producer choice set. Specifically, the spatial allocation of land use activities determines economic and environmental outcomes via a yield loss and soil erosion functions. While the biophysical component of this model is not as sophisticated as many of the ecosystem models available today, this analysis marks a preliminary step towards building an integrated model with a common set of exogenous and endogenous variables for the system's environmental and economic components. The land use allocation model therefore has several methodological advantages that improve its ability to accurately predict the impact of hypothetical policy instruments on land use patterns.

1.3. Thesis Organization

This thesis is divided into six chapters. Chapter two reviews the literature relevant to the development of this analysis. Chapter three outlines the conceptual framework underlying the spatial land allocation model and presents a mathematical description of the model's structure. The fourth chapter describes, in detail, the technical coefficients used to parameterize the model. The fifth and sixth chapters jointly present and discuss the policy analysis results. Chapter 5 describes the baseline model solution and conducts a series of sensitivity analyses used to assess objective (1). Chapter 6 analyzes the policy simulations used to address objectives (2) and (3). The concluding chapter draws general policy implications from the analysis, discusses the model's analytical weaknesses, and suggests directions for future research.

CHAPTER 2

LITERATURE REVIEW

It has long been recognized that agricultural systems produce both commodity outputs and an array of non-commodity goods and services. The term “multifunctionality” captures the intuition that “an activity can have multiple outputs and therefore may contribute to several objectives at once” (Abler, 2004, p. 8). Agriculture’s non-commodity outputs are varied, including, among others, open space amenities, preservation of rural traditions, and the degradation of environmental goods and services. The focus of this analysis is on the latter, with particular attention to the water contamination and soil erosion that occur with the production of agricultural commodities.

Before proceeding, it is useful to define the phrase “ecosystem services.” The Millennium Ecosystem Assessment defines an ecosystem as “a dynamic complex of plant, animal, and microorganism communities and the nonliving environment interacting as a functional unit” (Millennium Ecosystem Assessment [MEA], 2003). Broadly, ecosystem services are the flow of benefits that people derive from various ecosystems. These services can be classified according to the type of benefit they provide, including provisioning, regulating, cultural, and supporting services. Provisioning services refer to the final goods produced by ecosystems and include agriculture’s commodity outputs. Examples of regulating services are flood control, climate regulation, and water purification. Cultural services are the “nonmaterial” benefits obtained from ecosystems, such as recreation and ecotourism, spiritual and religious benefits, and cultural heritage

(*Ibid.*). Ecosystem supporting services include those services that can be thought of as intermediate goods in the production of provisioning, regulating, and cultural services. Examples include soil formation and nutrient cycling.

The majority, if not all, of the supporting ecosystem services associated with agricultural commodity production are non-market commodities. Because the market fails to price these services, their value is not fully reflected in producer land use and management decisions. This type of market failure is frequently invoked as a justification for public policy intervention. Theoretically, to correct the resource allocation distortion, “one need only place explicit values on the non-commodity outputs so that farmers are...penalized for producing those that impose social costs” (Peterson, Boisvert, and de Gorter, 2002, p. 426). Doing so forces producers to internalize the social costs of producing externalities. If all non-market outputs were valued, the end result would be a pattern of production that maximizes social welfare. This theoretical solution assumes that non-commodity services are observable and that their value can be estimated, assumptions that may not hold in practice. However, the above argument provides the theoretical foundation for exploring public policy as a means of altering agricultural production practices to improve social welfare.

2.1. Multifunctionality and Product Jointness

The degree of jointness between the production of agricultural commodities and negative externalities has implications for the design of public policy to correct the aforementioned market failure. Jointness in production can arise from technical interdependencies and/or economic linkages. A technical linkage is one that arises from “inherent features of the production process governed by biological, chemical, and

physical relationships” (Abler, 2004, p. 10). Economic linkages are generated by non-allocable, allocable fixed, or allocable quasi-fixed inputs. Non-allocable inputs are those that produce more than one output but the contribution to each output cannot be discerned. Allocable fixed factors are those for which “outputs are produced in separate processes and inputs can be allocated across the processes, but they compete for inputs that are fixed at the firm level (e.g. producing several crops on a fixed land base)” (Peterson, Boisvert, and de Gorter, 2002, p. 425).⁴ If the production of non-commodity outputs differs by commodity, the allocation of these inputs to different commodities can be varied in such a way as to encourage the provision of specific non-commodity outputs.

According to Abler, the negative externalities associated with agricultural production are best characterized by a technical relationship: “Problems such as soil erosion, nutrient runoff and leaching, and methane from livestock manure are all governed by biophysical processes, although they can be mitigated using alternative production or abatement technologies” (2004, p. 10). However, there may also be economic linkages between the production of commodities and externalities. For example, non-allocable polluting inputs, such as pesticides or fertilizers, contribute simultaneously to commodity production and environmental degradation, although it is difficult to determine their contribution to each. Regardless of the source, “the fact that farmers currently produce these commodity and non-commodity outputs jointly even though they receive an effective price of zero for the public outputs is strong evidence of joint technology” (Peterson, Boisvert, and de Gorter, 2002, p. 426).

⁴ Allocable quasi-fixed inputs are similar to allocable fixed, except that their supply is not perfectly inelastic, i.e. they have an upward-sloping supply curve.

Randall (2002) examines two extreme cases of joint production: one in which multifunctional outputs are strictly separable in production, and one in which they are produced in fixed proportions.⁵ In the former case, there is no justification for targeting the production of multifunctional outputs through commodity policies; the equilibrium prices and quantities of commodity and non-commodity outputs are best set independently. In contrast, when the outputs are produced in fixed proportions, purchasing solely the commodity output(s) at a price that incorporates the value of the corresponding non-commodity products can maximize social welfare. In reality, the relationship between agricultural outputs is likely to lie on the continuum between these two bounds. The primary implication of production jointness is that it creates “economies of scope”, i.e. producing the outputs separately is more costly than producing them together (Peterson, Boisvert, and de Gorter, 2002, p. 425). Therefore, it may be more efficient to use agricultural policies to reduce environmental degradation than to address economic and environmental objectives with separate instruments.

2.2. Modeling Implications of Multifunctionality

Despite the recognition that agriculture’s economic (commodity) and ecological components are related, it is extremely difficult to characterize the linkages between the two. Specifically, agricultural/ecological systems are often context-specific, complex, possess a vast number of interconnected components, and may be subject to nonlinear behavior (Arrow et al., 2000; Antle and Capalbo, 2002).⁶ For these reasons, Antle and

⁵ Both of the cases discussed here also assume a closed economy. For a discussion of the outcome in an open economy, see Randall, 2002, pp. 291-2.

⁶ A system is defined as “a set of interrelated processes, such as crop growth and economic decision making” (Antle and Capalbo, 2002, p. 5). A complex system is one in which behavior is dictated by the interactions of two or more subsystems.

Capalbo argue that it is essential to view agriculture as a managed ecosystem.⁷ Doing so will increase the efficiency with which agricultural outputs, both commodity and non-commodity, are provided by “full[y] accounting for all of the inputs and outputs of the system over the relevant dimensions of time and space” (Antle and Capalbo, 2002, pp. 11-12). Moreover, accurately specifying the relationships between agricultural economic and ecological inputs and outputs improves the ability of a model to accurately predict system behavior, especially outside of the range of observation.

Broadly speaking, there are two methods of modeling an agroecosystem: an integrated or a “coupled” approach.⁸ An integrated model employs a common set of exogenous and endogenous variables for the system’s biophysical and economic components. Antle and Capalbo argue that integrated models are preferable to coupled systems because they are able to represent agriculture “as a complex, dynamic system with spatially varying inputs and outputs which are the result of interrelated physical and biological processes and human decision-making processes” (Antle and Capalbo, 2002, p. 5). Integrated models are advantageous insofar as they incorporate dynamic feedback processes and nonlinearities, as well as considering spatial scale. However, their greater predictive ability is likely to come at a much higher cost in terms of data collection.

Coupled models are those in which the biophysical and economic components of the system are modeled independently. They can be classified according to the degree of integration between interdisciplinary models. A “loosely coupled” model is one in which the endogenous outputs of one disciplinary model are used as an exogenous input into

⁷ A managed ecosystem and a natural system differ in that the latter may be affected by human activity, but the former are purposefully manipulated.

⁸ The use of the term “coupled” with respect to modeling differs from the earlier use of “coupled” pertaining to income support payments.

another. Therefore, each model has its own distinct set of driving factors. This approach is used in the majority of the empirical literature to date. For example, in their analysis of the upper-Mississippi river basin, Wu et al. (2004) simulate producer decisions to adopt a longer-term crop rotation or no-till management practices. The output of the economic decision-making model is then used to simulate the environmental impacts using a separate model, the Erosion Productivity Impact Calculator (EPIC).

In contrast, a “closely coupled” model contains a subset of driving factors that link the system’s economic and environmental components. A coupled framework therefore attempts to more accurately represent the linkages between economic and environmental phenomena. Although closely coupling marks a step towards integrating disciplinary components, it suffers from several key disadvantages relative to an integrated model. By imposing an artificial separation between systems, a coupled model may be driven by the design of the framework rather than the true underlying processes. Specifically, by failing to describe all of the linkages between economic and environmental processes, a coupled model may “impose arbitrary constraints on the dynamic properties of the system” (Antle and Capalbo, 2002, p. 7). Thus, separately modeling interdisciplinary components that are integrated in reality limits the predictive accuracy of coupled frameworks.

The modeling approach used in this analysis is of the closely coupled type. Specifically, economic land use decisions are linked to biophysical aspects, such as soil erosion and nitrogen absorption, through their spatial allocation on heterogeneous terrain. Both economic and environmental outputs of the system are therefore determined by the producer’s endogenous choice of land management practices. This approach does not

reflect the complexity of the interaction between production practices and ecological phenomena that may be represented in an integrated approach. However, it marks an improvement over a loosely coupled modeling framework.

Despite the difficulty associated with precisely describing the relationship between economic and ecological systems, the mere existence of interdependence between the two systems has important policy implications. Jointness in the production of agricultural commodities and ecological services implies that a policy that alters commodity production is not environmentally neutral. The next section discusses the possibility of addressing economic and environmental concerns with a single policy instrument, as well as the issues surrounding the design and implementation of such a policy.

2.3. Green Payments

In practice, green payments are one mechanism proposed to alter agricultural producers' incentives to reflect the value of non-commodity outputs in production decisions. A payment is considered "green" if it is applied based on actions considered to improve environmental outcomes.⁹ Although these payments are based on environmental criteria, they can be used to target multiple policy goals. Specifically, "they have the potential to provide environmental benefits as well as an alternative source of producer income relative to traditional commodity programs" (Horan, Shortle, and Abler, 1999, p. 2). A green payment program designed to address both objectives will therefore combine the goals of traditional commodity-based income supports and a pure

⁹ Lynch and Smith (1994) make a distinction between "green support programs" and "green payment programs." A green support program is defined as one that provides environmental benefits while supporting producer income. A green payment program makes no explicit provisions for financial support. Here, the term "green payments" is used synonymously with "green support programs."

environmental improvement policy. Because there exists jointness in the production of agricultural commodities and negative externalities, it is plausible that a single green payment instrument may more efficiently achieve both farm income and environmental quality targets.

There are several issues that complicate the design of a program of green payments. Among these are the problems associated with addressing nonpoint source pollution. Because there are multiple, heterogeneous contributors to the pollution problem, and because there is a stochastic element to natural systems, it is difficult to observe and measure the environmental impacts associated with an individual's specific actions. As a result, "relationships among management practices on specific farms, effects on environmental services, and benefits derived from these services are often complex and not completely understood" (Claassen and Horan, 2000, p. 15). This complicates the monitoring of environmental performance and the targeting of payments to reflect each producer's marginal contribution to damages.

Equity concerns also complicate the design of green payment mechanism. For example, a potential complication arises if the distribution of current income support payments does not coincide geographically with the distribution of the most environmentally sensitive land. In this situation, a policy that places a relatively heavier weight on income support objectives will tend to reinforce the current income distribution, whereas policy weighted towards environmental objectives may alter the current distribution of payments.¹⁰ Therefore, "such dually targeted programs...beg the

¹⁰ In addition to the geographical issues discussed here, Claassen et al. (2001) point out that less than half of total rainfall erosion, wind erosion, and nitrogen runoff occur on small or moderately unprofitable farms, which suggests that targeting payments based on financial criteria may not be the most efficient means of ensuring environmental improvements.

question of how farm income support would be achieved on farms or in areas that do not present high potential for environmental improvement” (Lynch and Smith, 1994, p. 9). Moreover, the payment distribution may also depend on the environmental objective emphasized: payments to improve water quality would be concentrated in the eastern U.S., while payments to reduce wind erosion would be distributed across the Plains states (Batie, 1999).

Based on an analysis of current agri-environmental policy instruments, Claassen et al. identify a number of factors that are expected to increase the efficiency and effectiveness of green payments in practice. Coordination across farm programs is necessary to minimize incidences of duplication and/or contradiction in incentives. They recommend that attention be paid to the tendency for subsidy programs to create a perverse incentive to expand crop production, negating the environmental benefits of agri-environmental payments. In addition, spatial targeting to ensure that payments reflect contextual heterogeneity is crucial in ensuring that payments are cost-effective in attaining environmental improvements. The following section discusses a number of empirical studies that examine the implementation of green payments and their ability to provide environmental benefits while sustaining producer welfare.

2.4. Empirical Analyses of Green Payments

To begin, two studies that assess the tradeoffs between economic and environmental objectives are discussed. The section proceeds from there with an outline of the empirical literature that analyzes the effect of green payments on that tradeoff. These studies can be divided into three sub-groups based on their focus. The first group includes analyses of subsidy payments that target land use change directly. The second

sub-group simulates the environmental and economic impacts of green payments based on management practices, such as the adoption of no-till technology or long-term crop rotations. The final class of analyses confronts issues surrounding the current system of commodity-based income support payments in the United States. More specifically, these studies analyze the impact of government payments on the return to cropland, the effect of eliminating current subsidy payments on aggregate land use patterns, and the transfer of current support payments into a program of green subsidies.

2.4.1. Economic and Environmental Tradeoffs

Both Segarra et al. (2003) and Coiner, Wu, and Polasky (2001) examine the extent to which improving environmental quality involves a tradeoff with social welfare. The former formulates a non-linear programming model of Ecuadorian agriculture to maximize social welfare subject to a reduction in pesticide applications.¹¹ The authors conclude that the extent to which welfare and environmental objectives are complementary depends on whether a change in production generates endogenous price effects. Specifically, they find that reducing pesticide loads has no effect on the surplus generated by those crops for which Ecuador is a small producer in the international market. In contrast, in the case of bananas, for which Ecuador is a large producer, a 30 percent reduction in the degradation caused by pesticides causes producer surplus and the consumer surplus from all crops to fall by 7.9 and 19.5 percent, respectively, due to an increase in the price of bananas (Segarra et al., 2003). Therefore, the extent to which

¹¹ The authors construct a degradation of the environment index (DEI) associated with current production, from which six scenarios of decreased degradation are derived. The DEI is constructed from an estimation of the Environmental Impact Quotient, which takes into account the short and long-term impacts of pesticide use on humans, aquatic, avian, and insect life, ground water, and soil.

environmental and economic objectives are complements or substitutes may depend on assumptions regarding price endogeneity.

Coiner, Wu, and Polasky (2001) likewise focus on the tradeoffs between economic and environmental objectives, but limit the scope of their analysis to a single watershed. Commodity prices are therefore assumed exogenous. The study compares total returns to agricultural land and four environmental indicators (nitrate runoff/leaching, and wind/water erosion) across several land use scenarios. The scenarios emphasize distinct economic and environmental objectives, namely increased producer profitability, water quality improvements, and the maintenance and restoration of biodiversity. Holding commodity prices constant, the two environmentally focused land use scenarios generated a decline in the total return to land of 24 and 5.5 percent, respectively.¹² This result illustrates that some environmental objectives may be obtained at less cost to producers than others. Moreover, they find that no one scenario results in an improvement in all four environmental indicators, indicating that there may be tradeoffs between addressing differing environmental objectives. These two analyses highlight the importance of considering price endogeneity and multiple environmental impacts in an analysis of the tradeoff between economic and environmental objectives.

2.4.2. Green Payment Simulations

This section is divided into three subsections based on the analytical focus. The first section examines the use of green policy for agricultural land retirement. The second looks at analyses of policy instruments that target environmental improvements on working lands. The final sub-section includes studies that analyze the impact of

¹² The latter estimate is sensitive to the assumptions made about the price of seed inputs into one of the crop rotations considered, and may be as low as 1.7 percent.

current commodity payments on agricultural production, and their interaction with green payment mechanisms.

2.4.2.1. Green Payments for Land Use Change

Each of the analyses in this sub-section analyzes the effect of green payments on agricultural land use decisions, while setting aside concerns about social welfare.

Plantinga and Wu (2003) consider a uniform subsidy to convert agricultural land in southeastern Wisconsin to forest, in order to develop carbon sinks. They calculate the subsidy value necessary to achieve various levels of land use change, i.e. 5 to 25 percent of baseline agricultural land. By combining an econometric model of producer land use choices with environmental survey data, the authors are able to predict the location of converted parcels, and estimate the corresponding changes in several environmental indicators.¹³ They then apply benefits estimates from previous studies to assign a monetary value to each of the ecosystem goods provided. Assuming exogenous commodity prices, and accounting for a number of the environmental benefits obtained from an increase in forestland, the benefits of a carbon sequestration program are expected to exceed the costs.¹⁴ This analysis highlights the importance of considering all impacts when evaluating a program of green payments.

Claassen and Tegene (1999) emphasize the role of adjustment costs and rigidities in agricultural land use change in response to green payments. Specifically, “agricultural assets, such as land, [may] become ‘fixed’ to a specific sector, resulting in chronic overproduction” (Claassen and Tegene, 1999, p. 26). To test this hypothesis, they

¹³ Including carbon sequestered, soil erosion, and nitrogen and atrazine pollution.

¹⁴ Endogenous price changes will increase the opportunity cost associated with taking agricultural land out of production, necessitating an increase in the subsidy rate to convert the same amount of land to forest.

examine the probability of conversion from cropland to pasture and from cropland to CRP in Iowa between 1980 and 1987. They find that land conversion probabilities depend on the relative returns to each land use and on land quality. Specifically, landowners are less likely to convert land from cropland to pasture than *vice versa*, as land quality increases. The authors find evidence that the CRP successfully encouraged the conversion of eligible cropland beyond that which would have been converted to pasture in the absence of the program. These results once again emphasize the inelasticity of agricultural land, and the corresponding difficulty of achieving environmental benefits through land use change.

2.4.2.2. Green Payments for Management Practices

Zhang, Horan, and Claassen (2003) assess the effect of implementing policy instruments designed to reduce nitrogen loading across the “Heartland” production region.¹⁵ The two subsidy instruments examined are a payment based on reductions in estimated runoff and a nutrient management subsidy based on reduced nutrient use. In each case, a targeted and non-targeted approach to administering the payment is simulated. Non-targeted subsidies are those that are applied uniformly, while targeted subsidies are administered to reflect heterogeneity in marginal environmental damages across producers. The authors find that, targeting aside, payments based on reductions in estimated runoff are more efficient in attaining a given standard than those based on land management practices. Specifically, “altering nitrogen use is by far the most efficient approach for reducing nutrient loads, whereas altering land use to confront the problem would be a comparatively costly measure” (Zhang, Horan, and Claassen, 2003, p. 9).

¹⁵ The “Heartland” consists of Iowa, Illinois, Indiana, large portions of Missouri, Minnesota, and Ohio, and small portions of Kentucky, Nebraska, and South Dakota (Zhang, Horan, and Claassen, 2003).

However, in either case, the targeted instrument is more efficient than the non-targeted version.

Because the subsidies are administered regionally, the authors also analyze the impact of price endogeneity on producer welfare. Without accounting for the social welfare gain from environmental improvements, they conclude that producers, as a whole, gain at the expense of consumers when commodity prices are variable. This transfer occurs because producers who undertake abatement measures reduce their commodity output, generating an increase in price. That price increase benefits those producers who have not undertaken the same degree of abatement. The authors explain that the endogenous price increase necessitates an increase in the subsidy rate to overcome the initial output and price effects. While the subsidy benefits producers as a whole, some clearly gain at the expense of others. This result indicates that equity could be an important concern when choosing from various policy instruments to attain the same environmental end.

Green payments in the form of cost-share subsidies are often employed to encourage the use of “complementary technologies,” defined as those that improve the effectiveness of input use, thereby providing both economic and environmental benefits. Khanna, Isik, and Zilberman (2002) examine the social welfare effect of cost-share and/or input reduction subsidies applied to the control of irrigation drainage from cotton production in the San Joaquin Valley. A nonlinear programming model is used to solve for the levels of policy variables, optimal input use, and adoption decisions for individual producers that maximize gross social welfare while constraining aggregate pollution. The results suggest that the efficiency with which green payments achieve a given level

of abatement depends on whether they are restricted to current producers. When a subsidy payment is not restricted to current producers, it may augment producer profitability, which, in a competitive industry, induces firm entry. As a result, when an unrestricted cost-share subsidy is administered, all available marginal land is optimally pulled into production. An unrestricted subsidy is the most costly in terms of social welfare, but generates a significant transfer to private producers. They conclude that, “programs that have small entry effects and achieve abatement primarily by subsidizing a reduction in input use have much smaller effects on aggregate farm income levels” (Khanna, Isik, and Zilberman, 2002, p. 170). In addition to emphasizing the importance of restricting the subsidy base, this study lends further support to the finding that policies that target the use of productive inputs are more efficient than those that target land use activities directly.

Within the context of the upper-Mississippi River basin, Wu et al. (2004) examine green payments to reduce agricultural runoff into the Gulf of Mexico. Micro-level data is employed to determine each farmer’s choice of crop and tillage practices in response to payments that decrease the costs of adopting conservation tillage or increase the expected profit from a more diversified crop rotation. The estimated acreage response under varying levels of payments for these two practices is highly inelastic. Also, while the two payment mechanisms differentially impact environmental indicators, neither generates a significant decrease in overall runoff and leaching.¹⁶ This result may be attributed to the limited number of crop choices in the region and to the relatively small improvement in nitrogen leaching and runoff resulting from the adoption of the management practices considered. The authors conclude that the marginal cost curves associated with reducing

¹⁶ The environmental indicators considered are nitrogen leaching and runoff and wind and water erosion.

nitrogen runoff and leaching through changes in management practices are nearly vertical. In the upper Mississippi river basin, this implies that improving water quality using incentives for management practices may be ineffective.

The results across these three studies indicate that changes in land use practices may not be the most effective means of encouraging an improvement in environmental outcomes. The technical and economic interdependencies in the production of non-commodity and commodity outputs, as discussed in the first section of this chapter, do not necessarily imply that the commodities and non-commodity outputs are joint with each other.

Econometric evidence indicates that the elasticity of supply of land to agriculture as a whole is very low, and elasticities of supply to individual crops and livestock products are also very low. At the same time, elasticities of substitution between land and purchased inputs, particularly fertilizer, are relatively high. The result is that changes in agricultural output are accomplished primarily through changes in purchased inputs rather than changes in land. (Abler, 2004, p. 11)

However, even among those policies that target inputs, rather than land management practices (e.g. a runoff reduction policy [Zhang, Horan, and Claassen, 2003] or an input reduction subsidy [Khanna, Isik, and Zilberman, 2002]), the form of the policy instrument matters. The studies in this section indicate that targeting to reflect producers' heterogeneous contributions to environmental degradation and restricting the subsidy base are likely to improve the efficiency of a green payment instrument.

2.4.2.3. Current Income Support and Green Payments

All of the studies discussed hence hold current government payments constant while simulating the impact of green payments on agricultural production patterns. If current income support mechanisms reward relatively more environmentally degrading

production practices, it may be possible to shift production out of those activities simply by eliminating current subsidy payments. Gray et al. (2004) test whether current government payment instruments impact the returns to farmland by increasing the expected return to, or by altering the risk associated with, agricultural production. Using a stochastic budgeting model, they simulate the impact of subsidy payments with and without crop revenue insurance. While the impacts differ across types of subsidies, they find that, in total, agricultural subsidies increase the mean return to land from \$80.50 per acre to \$135.58 with crop insurance, or \$136.69 without insurance. In addition, they show that agricultural subsidies substantially reduce the variance and skewness of the distribution of returns to land, reducing the overall risk associated with the production of program commodities.

Plantinga (1996) examines the effect of reducing current price support levels on agricultural land use and environmental quality. Because higher commodity output prices generate an incentive to utilize marginal land for agricultural production, price supports may encourage an increased rate of environmental damage. Therefore, “agricultural policy reforms may yield a significant environmental dividend, particularly in the case of policies which encourage the expansion of agricultural acreage” (Plantinga, 1996, p. 1082). Using a dynamic programming model of 14 counties in southwestern Wisconsin, the author simulates the impact of policy changes on the land use choice between crop production and forestry. The results indicate that an increase in the timber to milk price ratio yields a nearly identical percentage increase in forest area. That increased acreage consists primarily of land with lower soil quality. The land use change therefore yields substantial environmental benefits. The analysis suggests that a

reduction in current subsidies could more efficiently attain the environmental objectives of land retirement programs.

Both Gray et al. (1994) and Plantinga (1996) find that removing current subsidy payments reduces the return to cropland, which may induce land conversion and environmental benefits. It follows that these subsidy payments may be retargeted to provide even greater environmental benefits while supporting producer income. Callaway and McCarl (1996) assess the environmental and welfare impacts associated with shifting current government payments into a subsidy for carbon sequestration. To do so, they use the Agricultural Sector Model (ASM), a national non-linear mathematical programming model that accounts for price endogeneity. Holding constant current government payment programs and without accounting for the social benefits of carbon sequestration, they find that any level of carbon sequestration is associated with a loss in net social benefits. However, this result is not disaggregated to determine the impact on consumers and producers.

The authors approach the subsidy transfer analysis from both a Marshallian and a Hicksian perspective. In the former, government payments are held constant while net welfare is allowed to fluctuate. The latter analysis permits government payments to adjust while holding total welfare constant. Under the Marshallian approach, they find that shifting about 30 percent of government expenditures into carbon payments results in carbon sequestration of 133 million tons per year, at a cost of \$1.6 billion in social welfare. In the Hicksian analysis, if all farm program payments are shifted into payments for carbon sequestration, welfare could be maintained for \$6.2 billion less than current federal expenditures, with total carbon sequestration of 115 million tons per year.

Because it is difficult to assign a value to carbon sequestration it is not possible to compare the costs and benefits under these two payment transfer scenarios. While the authors do not proffer any conclusions about the efficiency of subsidy shifting, the study establishes an empirical precedent for examining the welfare and environmental impacts of transforming current subsidies into a program of green payments.

2.5. Implications for the Current Study

The theoretical discussion in the first section of this chapter provides the conceptual framework for exploring the use of public policy to encourage the production of agriculture's multifunctional outputs. Abler notes that,

In any analysis of agricultural/environmental policy and multifunctionality, it is essential to consider not only public goods and beneficial externalities associated with agriculture but also negative externalities. Failure to consider both positive and negative external effects can lead to erroneous policy conclusions. (2004, p. 10)

To correct the resource distortion generated by the production of public goods and negative externalities, it is necessary to identify and assign a value to all of the non-commodity outputs of agricultural production. However, fully assessing the social cost of agricultural production is a formidable task and is outside of the scope of this analysis. This study focuses on evaluating policy mechanisms to address two specific negative externalities, excess fertilizer applications and the production of soil erosion. Both of these practices contribute to significant water quality problems and have attracted increasing attention from Iowa policymakers.¹⁷ This thesis analysis is not an assessment

¹⁷ Currently, excess nitrogen applications are regulated by the Iowa Department of Natural Resources. A new regulatory instrument, based on the Phosphorous Index (P-Index), is also being considered by the state. The P-Index is designed to limit phosphorous applications in excess of crop needs, and to limit soil erosion production, on lands that are ranked as contributing significantly to water contamination.

of public policy to encourage multifunctionality. Rather, it addresses one component of the larger issue.

The empirical analyses discussed in this chapter highlight a number of important issues relevant in the development of this thesis analysis. First, they point out the inelasticity of the supply of agricultural land, crops, and livestock products. In terms of public policy, this result implies that instruments that target productive inputs are likely to be more efficient in encouraging reduced environmental degradation than those that attempt to influence commodity production directly. Further, there are a number of important issues to consider in the design of a program of green payments. These include targeting, restricting the subsidy base, addressing capital rigidities, and prioritizing environmental objectives. In addition, it is essential to consider the endogeneity of commodity prices. For a policy administered on a large scale, price exogeneity may have implications for the magnitude of the tradeoff between environmental and economic objectives.

This thesis analysis expands upon the existing literature in several formidable ways. The majority of prior analyses focus on either a micro-level assessment of farmer decisions or on a large-scale analysis (e.g. watershed, regional, or national). The study area considered in this empirical analysis consists of two counties, and therefore constitutes an intermediate-level approach, relative to previous analyses. As such, it adds a new perspective to a growing body of literature. In addition, former studies of green payments and production practices have considered only crop production. Implicitly, these studies assume that crop and livestock production are separable activities. However, the potential exists for the exchange of outputs between crop and livestock

production (i.e. crops for feed and manure for fertilizer), which implies that the two activities may be to some degree nonseparable. Therefore, livestock production may have an impact on the allocation of land use activities that has not yet been explicitly modeled. Finally, the model developed here is a “closely coupled” model of both economic and biophysical processes. Crop yield, soil erosion, and nutrient requirements are all biophysical aspects that are incorporated into the economic model. They are linked to the economic component through the spatial allocation of land use activities across heterogeneous terrain. The incorporation of livestock production activities and environmental processes are expected to improve the model’s ability to accurately predict the land use outcome under various policy scenarios.

CHAPTER 3

THE LAND USE MODEL

The approach chosen to evaluate the impact of public policy on the tradeoff between economic and environmental objectives is to build a model of land use allocation. This approach is often employed in empirical studies of spatial price and allocation problems, such as the distribution of livestock manure to cropland (Feinerman, Bosch, and Pease, 2004; Ribaud et al., 2003) and the regional allocation of commodity production and conservation activities (Segarra et al., 2003; Callaway and McCarl, 1996). The conceptual framework underlying this methodology is established by Takayama and Judge (1971). Generally, the problem is one of allocating productive activities over space and solving for a set of internal prices given an exogenous resource endowment and a set of commodity prices. In this analysis, the specific problem is to allocate the production of commodities and environmental externalities over space in order to maximize the rental rate of arable land.

This chapter begins with a general overview of the model, which includes a discussion of its scale and the relationship between the spatial allocation of commodity production and the creation of environmental externalities. The second section details the algebraic formulation of the model's constraints and objective function. Chapter 4 follows with a detailed presentation of the technical information used to parameterize the programming model. A copy of the detailed mathematical programming code is included in the appendix.

3.1. Model Overview

The model study area is Crawford and Shelby counties, Iowa. A two-county area of observation is an intermediate scale relative to previous studies, which have analyzed land-use decisions at either the individual farm level or on a larger scale (e.g. watershed, regional, or national). Beyond contributing a novel perspective to the body of empirical literature, there are several advantages to using a sub-regional scale. Aggregating up from the individual producer facilitates the comparison of private producer welfare with environmental outcomes that operate on a broader scale. Focusing on a sub-regional scale also simplifies the model because it is reasonable to assume price exogeneity. Another key advantage is that a majority of the secondary data on agricultural production practices is available at the county level.

There are also a number of disadvantages to using a county-level scale of analysis. One disadvantage to aggregating is that it tends to obscure individual equity issues, particularly those related to the spatial distribution of income support payments. There are also disadvantages to assuming exogenous commodity and input prices. As discussed in the previous chapter, using this assumption may tend to overstate the complementarity between environmental and economic objectives. Moreover, the model cannot accurately predict the impacts of a policy applied on a broader scale. Finally, using a study area defined by political boundaries may be objectionable because it does not correspond to the scale at which environmental systems operate. The appropriate scale at which to jointly examine economic and environmental phenomena is complex, and no one recommendation emerges from the literature.

The model is designed to assign production activities across a heterogeneous landscape to maximize the average return to land. Therefore, the land use activities considered must be related to economic and environmental outcomes through both their production processes and their placement in space. The former is accomplished by representing land use activities as land management strategies, e.g. a two-year corn-soybean rotation or continuous pasture, rather than as individual crops. Soil erosion and the amount of nitrogen fertilizer input are both dependent on long-term crop rotations. The land use allocation is related spatially to environmental and economic outcomes through slope, a physical land attribute. In the model, per-acre crop yields, nutrient requirements, and rates of soil erosion are expressed as functions of the management practice and slope. These functions relate land use activities directly to environmental phenomena and allow the economic return to cropping activities to decline on marginal agricultural land.

The number of acres in each land use activity by slope is an endogenous variable, defined as one for which the model solves. There are a number of other endogenous variables, including the number of livestock marketed per year, the total amount of crops sold, the amount of crops used as livestock feed, and the amount of livestock manure used as crop fertilizer. Total revenue and government payments received by producers in the two counties depend on crop and livestock production, and are therefore endogenous. Similarly, the two environmental indicators examined – excess nitrogen and total soil erosion – depend on the endogenous assignment of land use and livestock activities. The model is annual, such that all of the endogenous variables represent the allocation for one

year of production. The next section describes the model constraints and objective as functions of these endogenous variables and a number of exogenous parameters.

3.2. The Mathematical Programming Model

This section describes the structure of the MP model and the algebraic formulation of the technical constraints and objective function. To begin, the first sub-section outlines the constraints that pertain to the production of land use activities. The second describes the linkages between crop and livestock production created by the exchange of feed and nutrients. The final sub-section defines the accounting identities used to build the model's objective function. Throughout the chapter, a number of sets are used to index the model variables and equations. These indices are summarized in Table 3.1, below.

Table 3.1. Indices Used in Mathematical Programming Equations

Index	Description	Range
<i>Land Use Indices</i>		
y	land use activities	1,...,6
c	cropping activities	1,...,7
f(c)*	feed crops	1,...,5
n	slope (% grade)	1,...,49
<i>Livestock Indices</i>		
l	livestock type	1,2
m	livestock production cycle	1,2
k	livestock production method	1,2
r	feed ration	1,...,3
<i>Land-Livestock Indices</i>		
v	crop/livestock production inputs/outputs	1,...,10
j(v)*	nutrient inputs/outputs	1,...,3
s(v)*	other inputs/outputs	1,...,6

*Indices are a subset of index in parentheses.

3.2.1. Land Use Constraints

The acreage devoted to each land use activity by slope class (YACRES) is an endogenous variable in the optimization problem. As previously discussed, indexing the acreage variable across slope is essential to linking the land use allocation with variables that are slope-dependent, such as crop yields, nutrient requirements, and soil erosion.

The following identity is used to summarize the total amount of acres assigned to each land use activity across the landscape:

$$3.1 \quad \sum_n YACRES_{yn} = LANDUSE_y$$

where LANDUSE is the total acreage in each land use activity.

The first land use allocation constraint limits the total acreage assigned by the model to be less than exogenous endowment of arable land in the two counties. The constraint is indexed across slope, such that there are 49 total equations limiting acreage utilized in each slope class by land available in that slope class:

$$3.2 \quad \sum_y YACRES_{yn} \leq TLAND_n$$

where TLAND is the total acreage available for production by slope class.

There are two land use constraints related to livestock production. They are both stocking density equations, which ensure that adequate housing and pasture acres are assigned to satisfy the needs of livestock produced. The constraints are as follows:

$$3.3 \quad \sum_l \sum_m \sum_k (HEAD_{lmk} * HREQ_{lmk}) \leq LANDUSE_{LH}$$

$$3.4 \quad \sum_l \sum_m \sum_k (HEAD_{lmk} * PREQ_{lmk}) \leq LANDUSE_{PT} + CACRES_{GL}$$

where HEAD is the number of livestock produced for marketing, indexed by type of livestock, production cycle, and production method (confinement or pasture-based).

HREQ and PREQ are the housing and pasture requirement for each type of animal in acres. The subscripts in capital letters denote specific land use and cropping activities: LH denotes livestock housing, PT is continuous grass-legume pasture, and GL is grass-legume pasture in rotation. Notice that livestock housing and continuous grass-legume pasture are land use activities, while grass legume in rotation is a cropping activity. One of the land use activities considered in the model is a six-year rotation that involves two years of grass-legume production for grazing. Therefore, the proportion of acreage within that land use activity available for grazing must be included in the total pasture constraint. The variable CACRES distinguishes cropping acres from land use acres, for the purpose of including that portion of the rotation in the constraint.

The final land use constraint limits the amount of Conservation Reserve Program (CRP) acres assigned by the model to current enrolled acres. Because of the relative difficulty of enrolling land in the CRP, and because of limited program funding, it is unreasonable to allow the model to assign an unlimited number of acres to this land use activity. Therefore,

$$3.5 \quad LANDUSE_{ER} \leq ENROLL$$

where the subscript ER indicates the land use activity “ecoreserve.”¹⁸ The scalar ENROLL is equal to 22,526 acres, which was the CRP enrollment in Crawford and Shelby counties as of July, 2003 (Iowa Farm Service Agency [FSA]).

3.2.2. Land Use – Livestock Balances

The second series of constraints involves the use of inputs in crop and livestock production activities. These constraints allow for the purchase of feed and nutrient inputs

¹⁸ The term “ecoreserve” is used synonymously with Conservation Reserve Program.

or for their exchange between crop and livestock production activities. Specifically, land use activities involve the production of crops that can be used as feed in livestock production (i.e. grain corn). Livestock production generates waste that contains nutrients that can be spread on land for crop fertilization. These linkages permit the model to select the optimal degree of integration between crop and livestock production activities.

The first equation is a crop production demand-supply balance. It prevents the amount of crops demanded, consisting of those sold on the market and those used for livestock feed, from exceeding the total amount of crop production. The balance is indexed across cropping activities, such that there are seven total constraints.

$$3.6 \quad CSALES_c + CFEEDS_c \leq \sum_y \sum_n (YACRES_{yn} * YIELD_{ycn})$$

where CSALES is the total amount of a crop sold and CFEEDS is the total amount of a crop used as livestock feed. The units of production vary across crops produced: corn, oat, and soybean production are measured in bushels, while alfalfa hay/forage and grass-legume hay production are measured in tons. As written, the model is permitted to split non-feed crops into sales and feed supply. To prevent this from occurring, the variable CFEEDS is fixed at zero for soybean and oats, the two non-feed crops. The variable YIELD, in either bushels or tons per acre, is indexed by land use activity, crop, and grade. It is indexed by both land use activity and by crop because, within each rotation (or land use activity), each crop constitutes a different percentage of the whole.¹⁹

¹⁹ For example, for one acre in a corn-soybean rotation, in any one year, corn occupies half of the acre (and soybeans the other half). Therefore, corn yield is half of a full acre yield. For one acre in a six-year crop rotation, corn occupies one third of the acre in any one year (corn is grown in two out of six years), so that corn yield for that land use activity is one third of a full acre's corn yield.

The feed balance is formulated so that feed may be supplied by crop production or purchased in order to supply the feed requirement for livestock production. The feed balance is indexed across the ration set (r). There are three feed balances of the form:

$$3.7 \quad \sum_f (CFEEDS_f + PRFEED_f) \geq \sum_l \sum_m \sum_k (HEAD_{lmk} * RATIONREQ_{lmkr})$$

where CFEEDS is the endogenous supply of feed from crop production, PRFEED is purchased feed, and RATIONREQ is the feed ration requirement for each head of livestock produced. CFEEDS is the same variable as in equation (3.5), but is indexed across only those crops that are used for livestock feed. The left-hand side of equation 3.6 is indexed across the feed set, which is a subset of cropping activities. However, feed required is indexed across the ration set. This is necessary so that more than one crop may satisfy a given ration requirement. For example, the forage requirement may be satisfied with either alfalfa hay or grass-legume hay.²⁰ To write the equation as above, it is necessary to map the feed set onto the ration set. This mapping is described in Table 3.2.

Table 3.2. Mapping of the Ration Set to the Feed Set

<i>Set Name</i>	<i>Ration (r)</i>		<i>Feed (f)</i>
	Grain	maps to	Corn
<i>Set Members</i>	Forage	maps to	Alfalfa Hay Grass-Legume Hay
	Graze	maps to	Pasture in Rotation Continuous Pasture

²⁰ For simplicity, it is assumed that any crops used to satisfy the same ration requirement are perfect substitutes in feed. This is an oversimplification, as feeds differ in nutritional value.

The production of pasture acres for feed presents an additional complexity in the model. Because the unit of production for pasture is one acre, the sale of pasture would indicate that an acre of pasture is being rented for livestock production, perhaps by a producer located outside of the two counties. That producer bears the cost of establishing and maintaining improved pasture on those rented acres, and collects the revenue earned from the sale of livestock. Similarly, if a producer located within Crawford and Shelby counties were to rent an acre of pasture, they would bear the cost of producing pasture for livestock production. For simplicity, this type of acreage exchange is not considered.²¹ Therefore, it is necessary to fix the values for pasture sales and purchases, CSALES and PRFEED, equal to zero. The model implicitly avoids this pitfall for all other crops because production is specified as the crop yield per acre.

Like the feed balance, the nutrient balance ensures that the amount of nitrogen (N), phosphate (P₂O₅), and potash (K₂O) supplied by livestock and purchased as fertilizer inputs satisfy crop nutrient requirements. Equation 3.8 requires that total demand for each of the three nutrients not exceed the total supplied. The constraint is indexed across the fertilizer set, which is a subset of all crop and livestock production inputs and outputs. The three nutrient balances are as follows:

$$3.8 \quad \sum_y \sum_n (ACRES_{yn} * NUTRREQ_{yn}) \leq PRNUTR_j + \sum_l \sum_m \sum_k [HEAD_{lmk} * MNUTR_{lmkj} * (1 - MLOSS_{lmkj})]$$

where NUTRREQ is the nutrient requirement by land use activity and grade, PRNUTR is the amount of nutrient input purchased, MNUTR is the amount of each nutrient in livestock manure, and MLOSS is the nutrient loss from manure storage and application.

²¹ Producer surplus calculated by the model is therefore similar to a measure of net domestic product (NDP).

3.2.3. Accounting Identities

The objective of the mathematical programming model is to maximize the return to land across Crawford and Shelby counties, subject to the series of technical constraints described by equations (3.1) through (3.7). The following accounting identities are used to relate the return to land to the set of endogenous variables. There are three primary components used to formulate the objective function. They are total revenue, government payments, and total production costs.

3.2.3.1. Total Revenue

The revenue earned by producers in the two counties is composed of the annual sale of crops and livestock. Total revenue can be expressed as follows:

$$3.9 \quad \sum_c (CSALES_c * CPRICE_c) + \sum_l \sum_m \sum_k (HEAD_{lmk} * WEIGHT_l * LPRICE_{lk}) = TREV$$

where CPRICE is the producer price of each crop per unit of production and LPRICE is the price per pound of each type of livestock marketed. Note that the model solves for the number of head marketed from each livestock enterprise in a year. The number of inventory animals, and their sale and purchase, are not explicitly considered. The model focus is on the flow of livestock through the system, rather than on the stock.

3.2.3.2. Government Payments

There are several types of support payments available to crop producers in the two-county area. The payments considered in the model are fixed direct payments, counter-cyclical payments, loan deficiency payments (LDPs), and Conservation Reserve Program (CRP) payments. Each of the following payment accounting identities is

formulated based on a description of their calculation and published payment rates (United States Department of Agriculture [USDA], 2003).

The amount of fixed direct payments disbursed is based on the number of acres of each program crop cultivated in the two counties, and the direct payment rate for eligible commodities.²² Published direct payment rates are indexed by commodity. To index the direct payment rate by land use activity, a weighted average of the per-acre payment rate by commodity is constructed using the proportion of each program commodity in each land use activity:

$$3.10 \quad \sum_c (RWT_{yc} * BYIELD_c * DPR_c) = DPR_y$$

where RWT is the proportion of each program crop on one acre of a land use activity, BYIELD is the base yield for each crop, calculated as a historical average of mean annual yield by county, and DPR is the published direct payment rate per unit of production.²³

The total amount of direct payments received by producers in the two counties is therefore:

$$3.11 \quad \sum_n (BASE * YACRES_{yn} * DPR_y) = DP_y$$

where BASE is the proportion of base acres eligible to receive payments.

Counter-cyclical payments are determined similarly to direct payments, but are disbursed only when the market price of a program commodity falls below the target price. It is necessary to specify the counter-cyclical payment rate in order to calculate the total amount of counter-cyclical payments received. The payment rate is based on the

²² In reality, direct and counter-cyclical payments are calculated using the base acres registered by producers. However, here they are calculated based on the amount of land allocated to each crop for modeling simplicity (see Chapter 4 for further discussion).

²³ Average yield differs from yield used to determine production in the model: it does not vary by slope.

difference between the published target rate and the effective price of each commodity.

The effective price (EFP) is conditional on the commodity's market price:

$$3.12 \quad \begin{cases} CPRICE_c + DPR_c = EFP_c & \text{if } CPRICE_c > LNR_c \\ LNR_c + DPR_c = EFP_c & \text{otherwise} \end{cases}$$

where LNR is the national loan rate for each commodity. All payment rates are expressed in dollars per unit of production. To calculate the per-acre counter-cyclical payment rate by land use activity, a weighted average is constructed, where the weights are identical to those used to calculate the direct payment rate above:

$$3.13 \quad \begin{cases} \sum_c [RWT_{yc} * BYIELD_c * (TGR_c - EFP_c)] = CCPR_y & \text{if } TGR_c > EFP_c \\ 0 = CCPR_y & \text{otherwise} \end{cases}$$

where TGR is the pre-set target rate for each program commodity.

The total amount of counter-cyclical payments received by producers in the two counties is calculated using the formula:

$$3.14 \quad \sum_n (BASE * YACRES_{yn} * CCPR_y) = CCP_y$$

where CCPR is the per-acre counter-cyclical payment by land use activity, and all other variables are as previously defined.

Loan deficiency payments (LDPs) are similar to counter-cyclical payments in that they are distributed only when the market price of a commodity falls below a pre-specified level. The payment rate is determined as follows:

$$3.15 \quad \begin{cases} LNR_c - CPRICE_c = LDPR_c & \text{if } LNR_c > CPRICE_c \\ 0 = LDPR_c & \text{otherwise} \end{cases}$$

where LNR is the national loan rate, CPRICE is the average annual producer price received for each commodity, and LDPR is the loan deficiency payment rate by commodity.²⁴

LDPs differ from counter-cyclical payments in that they are not distributed based on acreage of program commodities. Rather, they are based on the amount of a program crop produced that a farmer uses as collateral for a loan payment. For simplicity, it is assumed that producers in the two counties use all acres of production as collateral when the market price falls sufficiently for LDPs to apply. The payment rate per acre, by land use activity, is based on actual yield, as opposed to the historical average used to calculate fixed direct and counter-cyclical payments. The per-acre LDP rate is calculated as:

$$3.16 \quad YIELD_{ycn} * LDPR_c = LDPR_{ycn}$$

The total amount of LDPs received by land use activity is:

$$3.17 \quad \sum_c \sum_n (YACRES_{yn} * LDPR_{ycn}) = LDP_y$$

This formulation represents the maximum amount of LDPs that producers in the two-county area can collect if a program commodity's market price falls below the national marketing loan rate.

Conservation Reserve Program (CRP) payments are calculated as a simple product of the number of acres enrolled in the CRP and the per-acre CRP payment rate:

$$3.18 \quad \sum_n (YACRES_{ERn} * CRPR) = CRP$$

²⁴ In reality, the market price used to determine the loan deficiency payment rate is the posted county price, which varies daily.

where CRPR is the average per-acre Conservation Reserve Program payment rate, and the subscript ER denotes the land use activity “ecoreserve.”²⁵

Total government payments received by producers in Crawford and Shelby counties is the sum across payment programs for all land use activities:

$$3.19 \quad \sum_y (DP_y + CCP_y + LDP_y) + CRP = GPAY$$

3.2.3.3. Total Costs of Production

The total costs of production consist of variable production costs and ownership (fixed) costs. The variable costs associated with crop and livestock production are disaggregated into three categories: feed costs, nutrient costs, and all other variable costs (e.g. seed, fuel, and veterinary costs). The feed and nutrient cost identities are structured to differentiate the price of purchased inputs and those inputs that are exchanged between crop and livestock production activities. Because this analysis is concerned with landscape-level production patterns, no assumptions are made regarding the form of integration, i.e. whether feed and nutrients are exchanged on an inter- or intra-farm basis. Rather, it is assumed that the prices of any feed or nutrients produced within the two-county area and used as an input into livestock or crop production are valued at their cost of production, rather than their consumer prices. For those variable inputs that are purchased, it is assumed that they are available in perfectly elastic supply. The feed and nutrient cost identities are:

$$3.20 \quad \sum_f [(CFEEDS_f * PLFEED_f) + (PRFEED_f * PPFEED_f)] = TCFEED$$

²⁵In practice, CRP contracts are awarded based on a bidding process, so the per-acre payment rate can vary substantially across producers.

$$3.21 \quad \sum_j [(LNUTRS_j * PMNUTR_j) + (PRNUTR_j * PPNUTR_j)] = TCNUTR$$

where PLFEED is the price of feed produced locally, PPFEED is the price of purchased feed, LNUTRS is the supply of crop nutrients from livestock manure, PMNUTR is the price of nutrients in livestock manure, and PPNUTR is the price of purchased nutrients. TCFEED and TCNUTR are the total cost of feed and nutrient inputs in the two-county area.

The fixed costs of crop and livestock production include the cost of land in livestock housing and all other ownership costs of production. To calculate the former, it is assumed that land in livestock housing is converted from prime cropland. Therefore, the cost of land conversion represents an upper bound on the opportunity cost of converting land from cropland to livestock housing:

$$3.22 \quad LANDUSE_{LH} * PLAND_{LH} = LCOST_{LH}$$

where PLAND is the per-acre rental rate of land in livestock housing, which is assumed equal to the rental rate of land in a corn-soybean rotation, the highest value land use in Crawford and Shelby counties.

The ownership costs of production are those costs that are fixed in the short-run, including depreciation, interest, taxes, and insurance on factors of production. One accounting identity is used to calculate the costs of other variable inputs and ownership costs in crop and livestock production. The equation is summed over the set s , which consists of all variable and ownership costs of production aside from feed, nutrient, and land costs:

$$3.23 \quad \sum_y \sum_n \sum_s (ACRES_{yn} * YINPUTS_{ys} * PINPUTS_s) + \sum_l \sum_m \sum_k \sum_s (HEAD_{lmk} * LINPUTS_{lmks} * PINPUTS_s) = TCOTHER$$

where YINPUTS and LINPUTS are the variable and fixed inputs, other than feed and nutrients, into crop and livestock production, PINPUTS is a vector of the prices of inputs into crop and livestock production, and TCOTHER is the total cost of other variable inputs and ownership costs.

The total cost of production is expressed as the sum of the cost identities:

$$3.24 \quad TCFEED + TCNUTR + PLAND_{LH} + TCOTHER = TCOST$$

The equations for total revenue (equation 3.9), total government payments (3.19), and total cost (3.24) are used to formulate the model's objective function, described in the following section.

3.2.4. Objective Function

The net return to land and management (NRLM) is the sum of total revenue and government payments received by producers in the two counties, less the total costs of production described in the preceding section:

$$3.25 \quad TREV + GPAY - TCOST = NRLM$$

The distinction between aggregate profit and the NRLM lies in the land cost accounting. By excluding the per-acre rental rate by land use activity from the total costs of production, with the exception of land in livestock housing, the above identity measures the NRLM. Dividing the NRLM by total available acreage yields the average per-acre return to land (ARL):

$$3.26 \quad \frac{NRLM}{\sum_n TLAND_n} = ARL$$

The model's objective is to maximize the average per-acre return to land subject to the constraints described in sections 3.2.1 and 3.2.2. Because the objective is a linear function of endogenous variables, the model is specified as a linear programming problem.

3.3. Comments on the Model

The objective function and constraints outlined in this chapter form the structural framework of the linear programming model used in this analysis. The next chapter presents the technical details that are the foundation for these equations. However, before proceeding, there are several important points to mention concerning the model formulation. Given a set of technical parameters, the model solution represents the long-run equilibrium land use allocation that maximizes the average return to land.²⁶ The model developed in this study is static and therefore does not describe the path of transition to that end result. Moreover, the specified set of parameters is assumed invariant during that transition.

There are also several issues that center around the use of a single objective function. Modeling agricultural producers as simple profit-maximizers offers the advantage of modeling simplicity. The corresponding disadvantage is that the model implicitly maintains several assumptions concerning producer behavior that may be unrealistic. For instance, producers are assumed to be risk-neutral. When producers are risk-averse, an objective function that seeks to maximize the *expected* return to land may

²⁶ The solution is the long-run allocation because the objective function includes both the variable and fixed costs of production.

be more appropriate (Tomek and Robinson, 1990). Moreover, there are a number of other unidentified factors omitted from the model that may influence producer decisions. Examples include capital adjustment rigidities and socio-cultural issues, such as the accumulation of social capital.²⁷ These factors may influence the transition to, and the form of, the long-run land allocation. However, incorporating these complexities is outside of the scope of this analysis.

²⁷ The definition of social capital, as adopted by the Organisation for Economic Co-operation and Development (OECD) is as follows: “networks together with shared norms, values and understandings that facilitate cooperation within or among groups” (OECD, 2002).

CHAPTER 4

TECHNICAL FOUNDATIONS OF THE MODEL

This chapter complements Chapter 3 by providing a detailed description of the technical information used to parameterize the mathematical programming model's constraints and objective function. The chapter is organized into two sections. The first outlines the representative land use activities chosen and explains the technical coefficients of crop production. This section also includes a brief description of the subsidy payment rates for those Federal income support programs considered in the analysis. The second section covers information related to the production and sale of livestock, as well as the nutrient content of manure. The technical information presented is meant to be representative of current production activities, and therefore does not represent the heterogeneity in production practices observed in reality. However, the purpose of the model is not to account for all aspects of reality, but to present a stylized representation that can be used as a tool for analyzing changes in aggregate land use patterns.

4.1. Land Use Activities and Data

As described in Chapter 3, the representative land use activities used to formulate the model are long-term management strategies, not annual cropping activities. The advantage to specifying land use activities as such is that the level of environmental inputs into crop production, specifically nutrients and soil erosion, depend on the long-term rotation. There are six land use activities included in the MP model. These were

chosen to represent the predominant production pattern in the study area, and to represent land use alternatives that yield greater environmental benefits than current practices.

Included among the representative land use activities is a two-year corn-soybean rotation, which is the predominant land use activity in Crawford and Shelby counties. According to the 2002 Census of Agriculture, corn and soybeans occupy 95.7 percent of total harvested cropland, accounting for 50.4 and 45.3 percent, respectively. The ration of corn to soybean acres indicates that corn and soybeans are predominantly grown in rotation with one another.²⁸ This supposition is supported by regional data from the Agricultural Resource Management Survey (ARMS): in 2001, soybeans preceded 80.5 percent of corn acreage across the Corn Belt states (Economic Research Service [ERS]).

In addition to the two-year corn-soybean rotation, two hypothetical six-year crop rotations are considered in the model. They were chosen by a team of interdisciplinary researchers at Iowa State University on the basis of the environmental benefits they provide. Both six-year rotations incorporate legume crops, which reduce erosion and increase nitrogen uptake, which reduces runoff and leaching, over the course of the rotation. The first rotation, denoted “six-year alfalfa,” is a corn-soybean-corn rotation followed by three years of alfalfa. In its establishment year, alfalfa is planted with an oat leader crop. Using an oat leader eliminates the need for an herbicide application to establish the alfalfa crop. In all three years, alfalfa is harvested for use as livestock forage. The second six-year rotation, denoted “six-year grass-legume,” is a corn-soybean-corn rotation followed by three years of a 75-25 grass-legume mixture. In its

²⁸ A corn-soybean acreage ratio of one implies that all corn and soybeans are produced in a two-year rotation. The slight discrepancy between the proportions indicates that some corn producers use alternate rotation patterns, i.e. continuous corn or corn following wheat.

establishment year, grass-legume is harvested for hay.²⁹ In the subsequent two years, the grass-legume crop is used as pasture for livestock grazing.

In addition to the rotations described above, there are three land uses considered that do not involve crop production. They are continuous pasture, ecoreserve, and land in livestock housing. Continuous pasture is assumed to consist of a 75-25 grass-legume mixture, and is physically identical to the grass-legume used for pasture in the six-year grass-legume rotation. However, continuous pasture is grown in back-to-back five-year cycles with renovation every fifth year. Because cultivating pasture acreage requires productive inputs, including labor, seed, and chemicals, it is considered “improved” pasture.³⁰ Land in ecoreserve is retired from production and is therefore not used for either grazing or crop production. Acreage in ecoreserve earns revenue only through Conservation Reserve Program payments.³¹ Land in livestock housing includes the area occupied by all structures used to house and contain livestock, excluding pasture. As previously discussed, including housing as a land use activity reflects the opportunity cost associated with converting cropland to a permanent structure.

There are several assumptions regarding the production of these land use activities that are maintained throughout the analysis. While corn and soybeans in the six-year rotations are produced using no-till practices, it is assumed that land planted to the corn-soybean rotation is produced using conventional tillage practices. According to the ARMS, the adoption of no-till practices has increased significantly since 1990 (ERS). Across the Corn Belt, 39.2 and 14.3 percent of all soybean and corn acres were cultivated

²⁹ Hay is produced when the grass is harvested when dry; forage is produced when grass/alfalfa is harvested when wet.

³⁰ As opposed to “native” pasture, which does not involve the use of productive inputs.

³¹ This assumption may be erroneous when landowners are able to charge for hunting or other recreational uses on reserve land.

using no-till. Of those acres that are considered “highly erodible,” no-till is used on 55.2 percent of soybean acres, and 29.6 percent of corn acreage.³² The effect of excluding a no-till corn-soybean option from the model is that it biases upward the cost of producing corn and soybeans by \$8.63 per acre (2.5 percent of the total per-acre cost of production).

All cropland in the model is assumed non-irrigated. This is a reasonable assumption, as the use of irrigation in the two counties is negligible: only 5 farms out of a total of 1795 in Crawford and Shelby counties reported using irrigation technology (National Agricultural Statistics Service [NASS], “2002 Census”).

While the MP model is constructed to assign land use activities across the landscape, the majority of the technical information used to parameterize the programming model applies to the production of individual crops. In order to phrase these technical coefficients in terms of land use activities, it is necessary to define each land use activity as a vector of crop production activities. Table 4.1 presents the composition of each land use acre as a relative proportion of that acre in each crop.

Notice that sum of the relative proportions in the six-year alfalfa land use is greater than one. Because alfalfa is established with an oat leader crop, an acre of establishment year alfalfa yields two crops annually. The proportions in Table 4.1 are used to calculate crop production (yield), revenue, and government payment parameters for the six-year alfalfa land use. However, the costs of producing establishment year alfalfa, obtained from Iowa State University Extension budgets, include the costs of producing the oat leader crop. Therefore, the proportions in the above table must be

³² Highly erodible land (HEL) is defined as that with an erodibility index (EI) of greater than eight, which indicates that, if cover or conservation measures are not used, the soil will erode at a rate of eight times the tolerance level. Fields with at least 1/3 of their acreage (or 50 acres, whichever is less) designated as HEL, are subject to HEL Conservation Provisions (ERS, “Glossary”).

Table 4.1. Proportion of Each Land Use Acre in Each Crop

Crop	Land Use Activity			
	Corn-Soybean	Six-Year Alfalfa	Six-Year Grass-Legume	Continuous Pasture
Corn	1/2	1/3	1/3	
Soybeans	1/2	1/6	1/6	
Oats		1/6		
Alfalfa		1/2		
Grass-Legume in Rotation				
Harvested for Hay			1/6	
Pasture			1/3	
Continuous Grass-Legume				1

adjusted to calculate the costs of producing the six-year alfalfa rotation. The vector used to calculate the cost of production is: one-third of an acre in corn, one-sixth in soybeans, one-sixth in establishment alfalfa with an oat leader, and one-third in established alfalfa. All other proportions are as described in Table 4.1 throughout the analysis.

The crop grass-legume is listed separately for land in rotation and land in continuous pasture. While the physical crop is identical (75-25 grass-legume mixture), the costs of production are different due to both the length of the production cycle and because grass-legume in rotation is harvested for hay in its establishment year, while continuous grass-legume is used only as pasture.

4.1.1. Land Supply

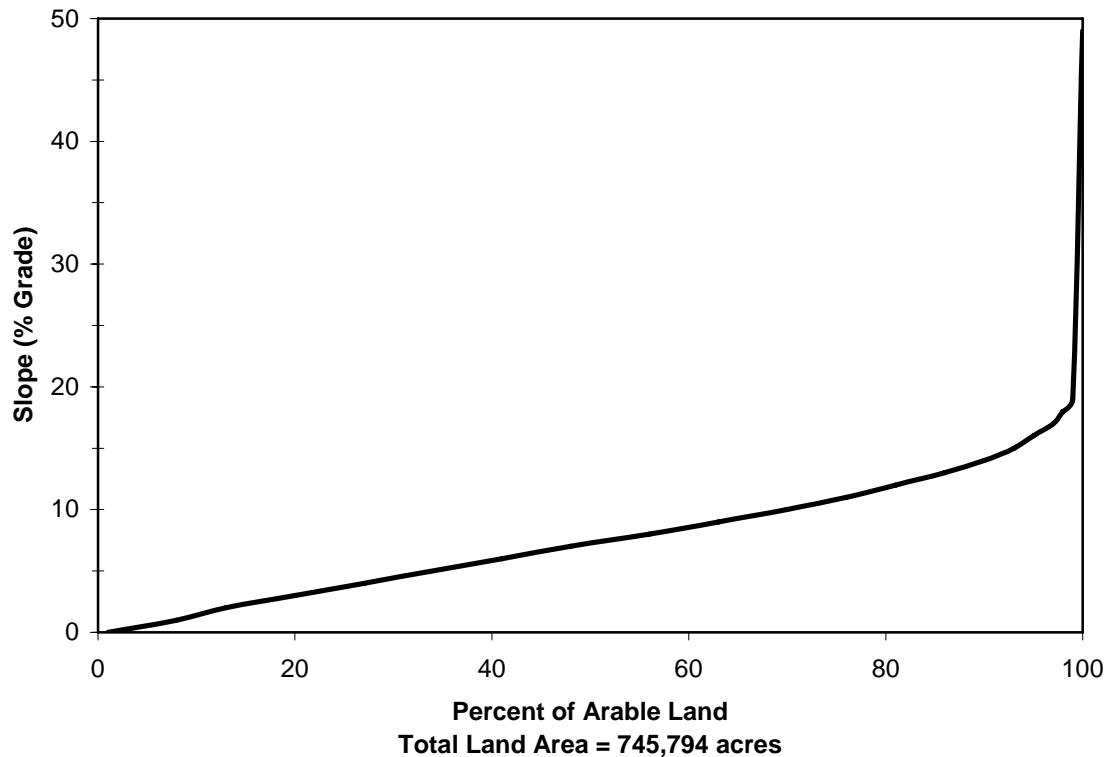
To determine the total land area available for agricultural production, two data layers created by Mike Burkhart and David James of the National Soil Tilth Laboratory at Iowa State University are manipulated using ArcMAP software. The first is a layer of the crop cover in Iowa in 2001 from the National Agricultural Statistics Service annual

cropland database. The second layer describes the topography of Crawford and Shelby counties. Both are raster datasets, with a resolution of 30m². There are a total of 3,759,910 cells in each raster data layer. To derive the number of arable acres by slope class, the crop cover data layer is reclassified into two categories: cropland and all non-arable land, i.e. land in artificial cover or waterways. This layer is then combined with the topography layer using the “Raster Calculator” function. Doing so creates a unique identifier for arable land by slope degree.³³ Using the ratio of 30m² pixels to one acre (4.49 pixels per acre), the number of arable acres in each slope category is derived using the count of pixels in each land-slope class.

The total number of acres calculated using these data layers is slightly greater than the total amount of land in cropland and pasture in the two-county area, as reported in the 2002 Census of Agriculture. According to the Census, a significant amount of arable acreage is in failed/abandoned crops, house lots, ponds, roads, and wasteland. The discrepancy between the two acreages may exist because the GIS cropland data layer does not differentiate these types of non-productive land from land in production. Assuming that non-productive land is evenly distributed across the landscape, the total amount of land in each grade can be scaled down by a factor of 7.53 percent so that the total supply of arable acreage in the model corresponds to the amount reported in the Census. After the adjustment, the total land area available for production is 745,794 acres. Figure 4.1 shows the cumulative distribution of arable land by degree slope. The bulk of the land available for production is concentrated on slopes less than 20 degrees, with land between 20 and 49 degrees accounting for only one percent of the total.

³³ For example, an ID of 1035 would indicate cropland (with an ID of 1000) on a 35 degree slope.

Figure 4.1. Cumulative Distribution of Arable Land by Degree Slope



4.1.2. Prices and Yields

The per-acre revenue associated with each land use activity is calculated as the per-acre crop yield multiplied by the per-unit price of each crop. Average annual producer price data are obtained from the NASS Agricultural Statistics Database for the years 1994-2003. The price assigned to grass-legume hay is that for “all hay.”³⁴ As a starting point, the ten-year median price for each commodity is used to parameterize the MP model. Producer prices by crop are reported in Table 4.2. The median, rather than the mean, is used because commodity prices were unusually high in 1996. Using the

³⁴ Hay prices in the NASS Agricultural Statistics Database are disaggregated into three categories: alfalfa hay, other hay, and all hay. Because grass-legume is a mixture of grass hay and alfalfa hay, the price for “all hay” is used.

average would tend to bias crop prices upwards from their most likely level because of these outliers.

Two sets of crop yield data are used in the model: county average yields, and a slope-dependent yield function. The former are obtained from the Iowa NASS for the years 1994-2003. These estimates are used in the government payment formulas described in Chapter 3. Slope-dependent yield data were constructed by Mike Burkhart and David James of the National Soil Tilth Laboratory at Iowa State University from the Iowa Soil Properties and Interpretation Database (ISPAID). This data is used to estimate average yield by slope class as a function of slope. A simple linear relationship between slope and yield is assumed:

$$4.1 \quad YIELD_c = \alpha_c + \beta_c(SLOPE)$$

where SLOPE is an integer ranging from zero to 49 representing slope degree.

The regression intercept is the crop's base yield, and the slope coefficient represents the yield loss with an incremental increase in the slope degree (the "yield loss" a

Table 4.2. Median Producer Price and Estimated Per-Acre Yield Regression Coefficients, by Crop

Cropping Activity	Unit	Median Price (\$ per unit)	Yield Regression Parameters	
			$\hat{\alpha}_c$	$\hat{\beta}_c$
Corn	bushels	2.16	134.58	-1.3861
Soybeans	bushels	5.79	45.17	-0.4645
Oats	bushels	1.58	74.03	-0.7626
Alfalfa Hay	tons	87.63	4.19	-0.0458
Grass-Legume Hay	tons	84.75	3.92	-0.0370

coefficient). While data is available for the mean yield for each slope class (ranging from zero to 49), yield observations for slope classes greater than 30 are excluded from the regression. There are a limited number of observations in these slope classes, and, as result, the yield estimates are highly variable. Because each regression is run on only 31 observations, the estimation is subject to the problems associated with small sample bias. A regression based on all yield observations by slope class, rather than the mean of the observations within a class would likely yield more accurate results. However, due to time and data limitations, the small-sample regression estimates are used to parameterize the MP model. The coefficient estimates by crop are reported in Table 4.2.

The following formula is used to calculate yield by land use activity:

$$4.2 \quad YIELD_{ycn} = RWT_{yc} * [\hat{\alpha}_c + \hat{\beta}_c (SLOPE_n)]$$

where RWT is the proportion of each crop in each land use activity (from Table 4.1), and the right-hand bracketed term is the estimated crop yield by slope based on the regression results reported in Table 4.2.

4.1.3. Nutrient Requirements and Soil Erosion

The nutrient requirements by crop depend directly on the crop rotation and indirectly on slope, via the yield functions estimated in equation 4.1. The three nutrient inputs into crop production are nitrogen (N), phosphate (P₂O₅), and potash (K₂O). The base nutrient requirements by crop, in pounds per unit produced, are taken from the Iowa Department of Natural Resources (DNR) Manure Management Plan Form for 2004. Non-legume crops, such as corn and oats, require a nitrogen fertilizer input, while legume crops utilize nitrogen in the soil and therefore require no additional nitrogen input. The

nutrient requirements for the grass-legume crop are calculated as a weighted average of the requirements for orchardgrass (75 percent) and alfalfa (25 percent).

When a non-legume crop follows a legume crop in rotation, the non-legume crop requires less nitrogen fertilizer. The amount of this nitrogen “credit” differs across legume crops. The Iowa DNR allows a producer to take a credit equivalent to one pound per bushel of soybeans produced in the previous year, not to exceed a total of 50 pounds. For each acre of a non-legume crop following an alfalfa crop, the legume credit is 140 lbs per acre. If alfalfa is grown two years prior to a non-legume crop, an additional credit of 30 pounds per acre is earned. A credit of 55 pounds of nitrogen per acre is earned for a 75-25 grass-alfalfa mixture grown in the year prior to a non-legume crop.

The total nitrogen requirement for each land use activity is a function of per-acre crop yield, nutrient requirement by crop per unit of yield (bushel or ton), and the total nitrogen credit earned from incorporating legume crops into the rotation:

$$4.3 \quad TNREQ_{yn} = \sum_c (YIELD_{ycn} * NREQ_c) - (SNCREDIT_{yn} + LNCREDIT_y)$$

where TNREQ is the total nitrogen requirement, NREQ is the requirement by crop, SNCREDIT is the soybean nitrogen credit earned in the rotation, and LNCREDIT is the legume nitrogen credit earned in the rotation. Notice that SNCREDIT is indexed by land use and grade, while LNCREDIT is indexed by land use only. This reflects that the nitrogen credit earned from soybeans is yield-dependent, while that earned from legumes is not. For phosphate and potash, the input requirement by land use activity is:

$$4.4 \quad TNURREQ_{ynj} = \sum_c (YIELD_{ycn} * NUTRREQ_{cj})$$

where TNURREQ is the total nutrient requirement and NUTRREQ is the nutrient requirement by crop. Because nutrient requirements vary by slope and land use activity,

Table 4.3. Estimated Per-Acre Soil Erosion Regression Coefficients*

	$\hat{\alpha}_y$	$\hat{\beta}_{1y}$	$\hat{\beta}_{2y}$
Corn-Soybean	0.9289	-0.0115	0.1304
Six-Year Alfalfa, Grass-Legume	0.2713	0.0507	0.0194
Continuous Pasture	0.0507	0.0042	0.001

*Soil erosion is in tons per year.

the parameters are not reported in table format here. The mathematical programming code in the Appendix reports the base nutrient requirements by crop, the nitrogen credit parameters, and the above equations.

Soil erosion production is also estimated as function of land use activity and slope. Mike Burkhart and David James developed estimates of soil erosion for each of the land use activities using NRI data for all watersheds affected by production activities in Crawford and Shelby counties. The resulting dataset contains 2,485 observations across slopes ranging from zero to 23 degrees. The estimated relationship is assumed to hold for slopes greater than 23 degrees. A quadratic relationship between erosion and slope is assumed:

$$4.5 \quad EROSION_y = \alpha_y + \beta_{1y}(SLOPE) + \beta_{2y}(SLOPE^2)$$

The estimated parameters are reported in Table 4.3.

4.1.4. Costs of Production

Cost of production data for corn, soybeans, and alfalfa are obtained from the Iowa State University Extension publication, *Estimated Costs of Crop Production in Iowa – 2004* (Duffy and Smith, 2004). Costs of production for grass-legume hay and pasture are

taken from the Iowa State University Extension publication, *Estimated Costs of Pasture and Hay Production* (Barnhart, Duffy, and Smith, 2004).

The variable production costs associated with each land use activity consist of labor, nutrient, and other variable costs. Farm labor in Crawford and Shelby counties is primarily composed of operator, family, and permanent hired labor. This implies that labor is a fixed cost of production at the farm level. However, labor costs are considered variable for the purpose of choosing among alternative land use activities (Duffy and Smith, 2004). “Other” variable input requirements include annual seed, lime, herbicide, insecticide, crop insurance, pre-harvest and harvest machinery, interest on pre-harvest variable costs, and other miscellaneous costs.

Each of these inputs is assumed to be available in perfectly elastic supply. Therefore, the cost of each is calculated by multiplying the amount of input used by a fixed price per unit. A constant wage rate of \$9.50 per hour is assumed. The input prices for purchased nutrients are \$0.25, \$0.28, and \$0.15 per pound for nitrogen, phosphate, and potash, respectively. The “other” variable costs of production are aggregated into one category and reported in Table 4.4 in dollars per acre.

The ownership or fixed costs are the costs of depreciation, interest, and maintenance that do not vary with the level of crop production. These costs are aggregated into one category and are reported as a fixed expenditure in dollars per acre. The rental rate of an acre of cropland is also considered a fixed cost of production. However, cropland rental rates are excluded from the total cost accounting, such that the model’s objective function reflects the average return to land. The rental rate of

prime cropland (that in corn and soybeans) is included as a fixed cost of allocating land to livestock housing.

The costs of production for several crops require calculation beyond the technical production parameters in the published enterprise budgets. Alfalfa and grass-legume pasture are both produced over multiple year cycles. There is a cost of production associated with establishing each of these crops, as well as harvesting them, in the first year of production. After the establishment year, the costs of production are simply maintenance and harvesting costs. To reflect the opportunity cost of investing in the production of these crops, the establishment costs are amortized over the length of the production cycle. The production cycle is three years for both alfalfa and grass-legume pasture in rotation, and five years for continuous grass-legume pasture. Throughout, a real interest rate of 4.7 percent is assumed. In each of the years following the

Table 4.4. Per-Acre Labor Requirement and Costs of Production, by Crop

Cropping Activity	Labor (hours)	Other Variable Costs (\$)	Ownership Costs (\$)
Corn	2.6	129.49	39.78
Soybeans	2.45	84.92	27.04
Alfalfa*			
Year 1	4	51.70	40.86
Years 2,3	1.33	27.65	72.79
Grass-Legume*			
Year 1	4.85	46.08	35.15
Years 2,3	1.5	2.55	39.30
Continuous Grass-Legume	1.57	5.38	22.04

*Alfalfa and grass-legume costs of production reflect amortized establishment costs.
Source: Duffy and Smith (2004), Barnhart, Duffy, and Smith (2004).

establishment year, the amortized costs of establishment are included as a fixed cost of production. The establishment labor costs are not amortized over the production cycle: the labor requirement in hours is added to the labor requirement for the establishment year.³⁵ The labor, variable, and fixed costs of producing each crop are reported in Table 4.4.

The cost of each input used in the production of each land use activity can be derived using the per-acre crop input requirement, the market price of inputs, and the composition of each land use activity (from Table 4.1).³⁶ The formula is:

$$4.6 \quad CINPUT_{yv} = \sum_c (RWT_{yc} * INPUT_{cv} * PINPUT_v)$$

where v is the set of all crop production inputs, RWT is the vector of crops in each land use activity, CINPUT is the cost of each input for each land use activity, INPUT is the level of each input required for production, and PINPUT is the market price. Because the level of “other” variable and “ownership” costs is reported as a dollar amount, PINPUT for those inputs is set equal to one.

4.1.5. Government Payments

The three primary commodity-based payment vehicles for farm income support are fixed direct payments, counter-cyclical payments, and loan deficiency payments (LDPs).³⁷ Fixed direct payments are calculated using a base acreage, a historical average yield, and a pre-defined direct payment rate per program commodity. A producer’s base

³⁵ Because the ratio of years in establishment and maintenance are fixed within a given land use activity, including the total establishment labor requirement in the first year of production does not affect the land use allocation.

³⁶ The exception is the six-year alfalfa rotation. The vector of crop proportions used to calculate the cost of producing the six-year alfalfa rotation is described in section 4.1.

³⁷ LDPs are administered under the broader heading of marketing assistance loans. The other three types of benefits available that are not considered in the model are marketing loan gains, certificate exchange gains, and forfeiture gains.

acreage is the total amount of acres in commodity production that the producer registers for direct payments. Payment acres are equal to eighty-five percent of the registered base acres. Direct payment base acreage is not linked to a specific commodity, i.e. a producer may claim all farm acres as corn base acreage, even if those acres are planted to soybeans. However, for simplicity, it is assumed that direct payments received correspond to the crop cultivated. For example, for an acre allocated to the corn-soybean rotation, it is assumed that half of the acre is registered as corn base acreage and half is registered as soybean base acreage. The direct payment yield per-acre is a historic farm average, which is approximated using the average yield, by commodity, across Crawford and Shelby counties from 1994-2003 (Iowa NASS).

The amount of counter-cyclical payments received depends on the same base and payment acres used to determine direct payments. The total payment is based on the counter-cyclical payment yield, the effective price, and the target price. The counter-cyclical payment yield assumed is the two-county historical average, as described in the previous sub-section.³⁸ The effective price is the greater of the sum of the commodity's

Table 4.5. Support Payment and Marketing Assistance Loan Rates for Select Crops, in Dollars per Bushel

Crop	Direct	Counter-Cyclical Target		National Marketing	
	Payment Rate	Prices		Assistance Loan Rates	
	2002-07	2002-03	2004-07	2002-03	2004-07
Corn	0.280	2.60	2.63	1.98	1.95
Oats	0.024	1.40	1.44	1.35	1.33
Soybeans	0.440	5.80	5.80	5.00	5.00

Source: United States Department of Agriculture (2003).

³⁸ In reality, the counter-cyclical yield may differ slightly from the direct payment yield because producers were allowed the opportunity to update the yield estimate in 2002, based on yields from 1998-2001.

direct payment rate and its producer price, or the sum of the direct payment rate and the national loan rate.

In order to receive a loan deficiency payment, a producer must specify the amount of the current year's production to be used as collateral. In practice, the LDP rate is determined daily as the difference between the national loan rate and the daily posted county price for a program commodity. Therefore, the day on which a producer chooses to apply for the loan determines the total amount of the loan. However, the model, as constructed, cannot account for daily commodity price fluctuations. Therefore, total LDPs are estimated based on the difference in the annual commodity price and the national loan rate. The direct payment rate, target prices, and the national loan rate defined by the 2002 Farm Act are reported in Table 4.5.

Conservation payments received in Crawford and Shelby counties were administered primarily through the Conservation Reserve Program (CRP) and the Environmental Quality Incentives Program (EQIP). In 2003, total EQIP payments to Crawford and Shelby county producers amounted to \$124 and \$60 thousand, respectively, less than a tenth of the payments received through the CRP. Because total EQIP payments are so small in magnitude and because it is a cost-share program that cannot be linked directly to specific land use activities, this conservation program is not considered in the model.

The CRP is a voluntary program administered by the United States Department of Agriculture's Farm Service Agency (FSA). When a producer chooses to enroll cropland in the program, that land is taken out of production and planted in long-term ground cover. To be eligible, the cropland must have been devoted to the production of an

agricultural commodity for at least four years between 1996 and 2001, or it must be marginal pastureland suitable for use as a riparian buffer.³⁹ The land must also be classified as highly erodible, be expiring CRP acreage, or be located in a national or state CRP conservation priority area. CRP bids for contracts are accepted based on their ranking on the Environmental Benefits Index (EBI). The EBI is based on the land’s potential for wildlife habitat benefits, water quality benefits from reduced erosion, nutrient runoff, nutrient leaching, on-farm benefits from reduced erosion, air quality benefits from reduced wind erosion, the likelihood that benefits will persist after the contract expires, and cost.

The FSA offers four types of payments for land enrolled in the CRP. For enrolled acres, the FSA distributes a payment equal to the land rental rate, which is based on the relative productivity of the soil within the county and the average dryland cash rent or cash-rent equivalent.⁴⁰ Producers may offer to retire land for a lower rental rate to increase the likelihood that their enrollment bid will be accepted.

Table 4.6. Average Rental Payment for Conservation Reserve Program Land in 2002, by County

County	Acres Enrolled	Total Rental Payment (\$1000)	Avg. Rental Payment per Acre (\$)
Crawford	11432	1357	118.70
Shelby	7961	951	119.46
Total	19393	2308	119.01

Source: Acres enrolled, USDA FSA; Total payments, NASS, 2002 Census of Agriculture

³⁹ The land must also be “physically and legally capable of being planted in a normal manner to an agricultural commodity” (USDA, 2003).

⁴⁰ In addition, the FSA administers maintenance incentive payments of up to \$5 per acre per year, cost-share assistance of no more than 50 percent of the cost of establishing an approved cover practice, and additional incentives of no more than 20 percent of the annual rental payment for additional conservation practices.

There are several simplifying assumptions used to calculate CRP payments in the model. It is assumed that a uniform payment is received for each acre of land retired from production. The average per-acre payment rate is derived from the total amount of payments received according to the 2002 Census of Agriculture and the total number of enrolled acres as of July of 2002 (Iowa Farm Service Agency [FSA]). The payment rate is reported in Table 4.6. In this analysis, the costs of establishing CRP approved practices on enrolled land are not included due to the variety of potential CRP practices producers may undertake.⁴¹ The relative profitability of enrolling land in the CRP may therefore be overstated. In addition, because slope is the only form of land heterogeneity allowed in the model, ecoreserve (CRP) acres are assigned based solely on topography. Therefore, the spatial allocation of ecoreserve acres may not coincide with their actual location. For example, CRP acres in the model may be placed on marginal land, which is that on higher slopes. However, land on the lowest slopes is adjacent to waterways, and may be retired for use as a riparian buffer. This section concludes the discussion of the technical coefficients of land use production.

4.2. Livestock Enterprises

This section begins with a brief description of the representative livestock production activities chosen for inclusion in the mathematical programming model. In the first subsection, the technical details of livestock production are outlined, including a representative production timeline for each type of marketed animal. The final subsection presents the technical assumptions and coefficients used to parameterize the

⁴¹ These include, among others, the planting of grasses or trees, establishment of wildlife habitat, the construction of field windbreaks, diversions, erosion control structures, grass waterways, vegetative filter strips, contour grass strips, shelter-belts, living snow fences, alley cropping, riparian/wetland buffers, cross wind trap strips, or the restoration of wetland or introduction of salinity reducing vegetation.

model, including revenue and cost of production data, livestock housing requirements, and manure nutrient production.

Livestock production in Crawford and Shelby counties is predominantly focused on finished swine and beef cattle. There are several points during the maturation of these animals at which they can be sold: immediately after weaning, after an intermediate stage of growth, or upon reaching finished market weight. Using data from the 2002 Census of Agriculture on the number of breeding swine and cattle and the total number of swine and cattle marketed in 2002 in the two counties, it is estimated that over half of all swine (51 percent), and nearly two-thirds (66 percent) of all beef cattle marketed from the two counties were earlier imported as feeder animals (I-FARM). These estimates indicate that, on the whole, livestock production in Crawford and Shelby is focused on finishing animals, rather than on producing feeder animals to be sold for finishing elsewhere.

The livestock activities that best characterize current livestock production patterns are therefore those that carry animals through to their final market weight. There may be an exchange of immature animals between producers within Crawford and Shelby counties. However, it is assumed that there is no sale before maturity outside of the two counties. Four representative livestock activities, two each for swine and beef cattle production, are included in the model. For swine, a farrow-to-finish and a finishing enterprise are included. Similarly, the beef cattle enterprises considered are cow-calf production and finishing. The farrow-to-finish swine and the cow-calf beef cattle production enterprises require investment in and maintenance of a breeding herd. There is therefore both a stock and a flow element to livestock production. The model is

constructed to assign the number of head marketed from each enterprise, and therefore explicitly focuses on the flow of livestock through Crawford and Shelby counties.

For each of these enterprises, there are two methods of production considered: an intensive method, which corresponds to a confinement or grain-fed production system, and an extensive or pasture-based system. The exception is the finishing stage of hog production for which only a confinement enterprise is considered. There are alternatives to confinement finishing hog production, namely finishing in hoop structures. However, this option is not included in the model because reliable data on the costs of production for such systems are not sufficiently developed at this time.

While pasture-based systems are the exception, rather than the rule, the inclusion of this option has important implications with respect to land use scenarios that require or encourage the expansion of pasture acreage. Specifically, if the production of pasture-based livestock becomes more profitable, it may encourage the production of pasture, which would generate ecological benefits, in terms of reduced soil erosion and fertilizer applications. Rewarding the production of extensively produced livestock may provide a means, aside from land-use based payments, of encouraging the provision of environmental goods and services. This potential will be explored in Chapter 5 by examining the impact of a price premium on the production of pasture-based livestock.

4.2.1. Swine and Cattle Production

For each swine and beef cattle enterprise, there are several stages of production. The following text, along with Figures 4.1 and 4.2, describes the length of each stage of production and the assumed growth rate of livestock during each stage. The technical parameters described rely heavily on the information provided in the livestock enterprise

budgets published by the Iowa State University Extension, and on the parameters used in the I-FARM Integrated Crop and Livestock Production and Biomass Planning Tool formulated by researchers at Iowa State University.

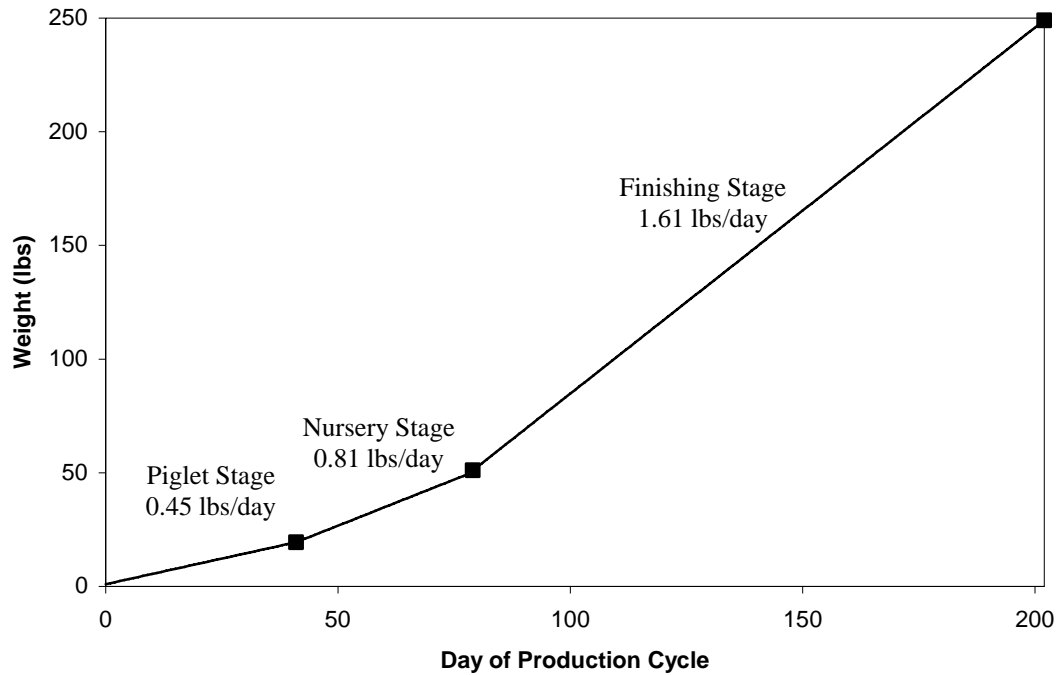
4.2.1.1. Swine Production Cycles

After insemination, sows are in gestation for 111 days. At the end of the gestation period, the sow farrows (gives birth to a litter of piglets). Piglets are weaned from the lactating sow at a weight of 20 pounds each. The average growth rate of a piglet during this production period is 0.45 pounds per day. The assumed litter size for sows farrowing in confinement and on pasture are 9 and 8 piglets per sow, respectively. After weaning, piglets are raised from 20 to 50 pounds, at an average growth rate of 0.81 pounds per day. During this period piglets are referred to as “nursery” pigs. Upon reaching 50 pounds, a pig enters its “finishing” stage, and is raised to a market weight of 250 pounds, with an average daily gain of 1.61 pounds. At this point, the animal is sold. The total length of a farrow-to-finish cycle is 202 days.⁴² For simplicity, it is assumed that all piglets produced per litter, as above, are marketed. By making this assumption, the piglet mortality rate and the number of animals recycled into the breeding inventory are set equal to zero. In reality, about one piglet per litter is not marketed. The assumption of zero loss is one that is made for all livestock considered in the model, and is meant to simplify the calculation of parameter estimates. The effect of maintaining this assumption is that it tends to overstate the total revenue earned per livestock enterprise.

The finishing hog enterprise involves purchasing a 50-pound feeder pig and raising it to its full market weight. The production cycle of a finishing hog enterprise is

⁴² Length of cycle is calculated as the sum of days to raise lactating sows and piglets (41), nursery/feeder pigs (37), and finishing feeder pigs (124).

Figure 4.2. Stages of Swine Growth, Including Mean Growth Rate by Stage



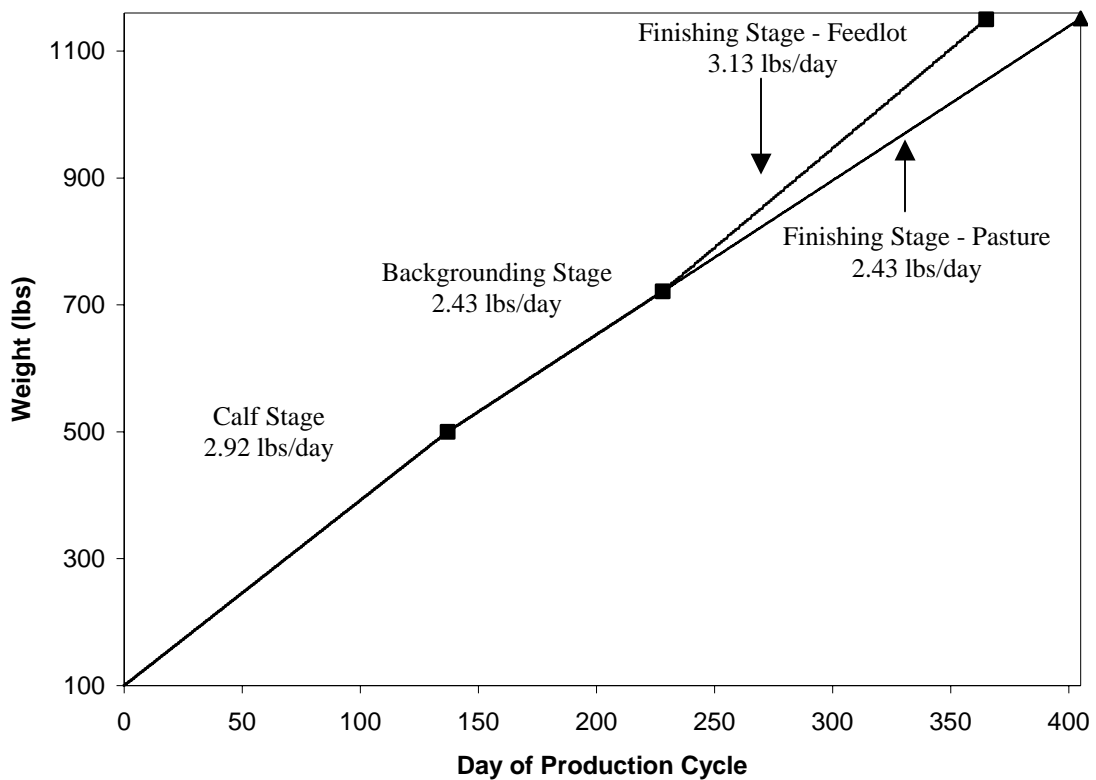
identical to the finishing stage for farrow-to-finish hogs, whether produced in confinement or on pasture. Figure 4.2, below, illustrates the stages of hog production graphically. There is no difference in the growth rate of hogs farrowed on pasture and in confinement. The two production systems differ only in terms of litter size.

4.2.1.2. Cattle Production Cycles

Each cow-calf unit is assumed to produce one calf per year. The first stage of growth takes a calf from 100 lbs (birth weight) to 500 lb at a rate of 2.92 pounds per day. This is the “calf stage” referred to in Figure 4.2. At 500 pounds, a calf is considered a feeder animal. The period during which a feeder calf is raised from 500 pounds to 720 pounds is termed the “backgrounding stage,” during which the calf grows at an average rate of 2.43 pounds per day. Throughout these two stages, all calves are assumed to be

grazing pasture, and identical growth rates are assumed across extensive and intensive production systems. The distinction between intensively and extensively produced cattle enters when a calf reaches its finishing stage. Cattle finishing may take place either in a feedlot (grain-finished) or on pasture (grass-finished). The growth rate of calves raised on pasture is assumed to be 2.43 pounds per day, while that of cattle finished on grain is 3.13 pounds per day. The finished weight of beef cattle produced using either method is 1150 lbs per head. The total length of the production cycle for grass-finished cattle from birth to sale is 405 days and that for grain-based cattle is one year (365 days).

Figure 4.3. Stages of Cattle Growth, Including Mean Growth Rate by Stage



The finishing cattle enterprise differs from a cow-calf operation in that feeder calves are purchased from outside Crawford and Shelby counties, at a weight of 500 pounds, and are raised to their finished market weight. Finishing cattle may be produced in a feedlot or on pasture. The production cycle length and growth rates are identical to the finishing stage of an animal produced from a cow-calf enterprise. Figure 4.3 illustrates the three stages of cattle growth.

4.2.2. Livestock Data

Annual head of livestock marketed by producers in Crawford and Shelby counties is an endogenous variable in the MP model. The technical livestock coefficients used to parameterize the model are therefore stated on a per-head-marketed basis. Because the data pertaining to livestock production are culled from a number of sources, they are stated in a variety of units. The assumptions made about livestock production cycles in the previous subsection are used to convert the coefficients into units that are consistent with the model formulation. The data, sources, and equations used to calculate livestock parameters are discussed in the next three sub-sections.

4.2.2.1. Feed Requirements

The livestock feed requirements per head produced are divided into three rations: a grain ration, a forage ration, and a grazing ration. The grain ration can be satisfied by corn, the forage ration can be filled by alfalfa hay/forage and/or grass-legume hay, and the grazing ration may be satisfied by continuous grass-legume pasture and/or grass-legume pasture in rotation. The mapping of the feed rations to specific crops was described in Table 3.2, in Chapter 3. The feed requirements for each animal, with the

exception of grass-finished beef cattle, are taken from the Iowa State University Extension Publication, *Livestock Enterprise Budgets for Iowa – 2004* (May, Edwards, and Lawrence, 2004). The feed requirements for the swine farrow-to-finish enterprises reported in the ISU Extension budgets require further calculation to convert them from a per-litter to a per-head requirement. To do so, the total feed requirement is divided by the weaning average per litter for each production system.⁴³

The feed requirement for grass-finished beef consists of a pasture requirement and, because the production cycle lasts for over a year, feed required to winter the animal. The wintering feed requirement for grass-finished cattle is estimated as one-third of the number of acres of pasture needed per year (the winter is assumed to last four months) multiplied by the grass-legume hay yield. The hay requirement is added to the feed requirements published in the ISU Extension enterprise budgets. The feed requirements, in units per head marketed, are outlined in Table 4.7, below.

As described in Chapter 3, livestock feed may come from one of two sources: feed crops may be exchanged between crop and livestock production activities within the two-county area, or they may be purchased on the market. To calculate the total expenditure on feed, feed crops produced within the two counties are valued at their cost of production, while purchased feed is valued at the feed crop's producer price (reported in Table 4.2) plus ten percent to account for transportation and storage costs. As was previously discussed, the grazing feed requirement is equivalent to a stocking density limitation, and must therefore be satisfied by pasture acres produced within the two-county area.

⁴³ The weaning averages, as opposed to the final number marketed, are used because mortality and inventory replacement rates are already incorporated into the published requirements.

Table 4.7. Livestock Feed and Housing Requirements per Head Marketed, by Livestock Type, Enterprise, and Production System

Livestock Enterprise	Feed Ration			Housing (acres x 10 ⁻⁴)
	Grain (bushels)	Forage (tons)	Graze (acres)	
<i>Swine</i>				
Farrow-to-Finish				
Confinement	105.0			3.87
Pasture	97.0		0.2	2.73
Finishing				
Confinement	9.6			2.02
<i>Beef Cattle</i>				
Cow-Calf*				
Feedlot	64.0	2.50	2.5	20.16
Pasture	4.0	2.12	2.5	12.60
Finishing				
Feedlot	61.0	0.65		13.90
Pasture		0.02	2.5	6.30

*All calves born domestically are raised on pasture before entering the finishing stage. At that point, the calf either continues grazing pasture (pasture-finished), or is moved to a feedlot, where it is finished on a grain/hay ration.

Sources: May, Edwards, and Lawrence (2004); Lawrence, et al. (2001); Minnesota Institute for Sustainable Agriculture (MISA) (2001); Schuster, et al. (2001); Honeyman and Weber (1996)

4.2.2.2. Housing Requirements

A housing requirement per unit of livestock produced is included to relate livestock production to the land use allocation. Housing may take the form of a physical building, as for confinement hog production, or it may be an open shelter or feedlot, as for cattle production. Housing does not include pasture required for livestock production.⁴⁴

The housing requirements per unit of livestock are compiled from two sources. Cattle requirements are taken from the ISU Extension Publication *Beef Feedlot Systems*

⁴⁴ For pasture-farrowed hogs, housing is included in the pasture requirement.

Manual (Lawrence et al., 2001). To parameterize the model, an intermediate value is chosen from a variety of cattle housing alternatives. All cattle are assumed to require 25 square feet of space inside a shelter. Cattle in a feedlot require 55 square feet of shelter and lot space, combined. For cow-calf units, 25 square feet of space is required per unit before the calf reaches its finishing stage, after which separate barn and feedlot space are required. Swine confinement housing requirements are found in the publication *Hogs Your Way* (Minnesota Institute for Sustainable Agriculture [MISA], 2001). In each stage of its production cycle, a hog is located in a different housing facility. The total housing requirement per head is calculated as the sum of the requirement in each phase. Sows require a 35 square foot area during farrowing and while lactating with their litter of piglets.⁴⁵ In the grower stage, piglets are moved to a nursery facility, where they require 2.85 square feet of space each. In the finishing stage, hogs require eight square feet in a confinement facility. The square footage housing requirements for all animals are multiplied by 1.1 to account for land area around buildings and area within buildings that animals do not occupy, such as walkways and storage rooms. The housing requirements are converted to acres using a conversion factor of 43,650 square feet per acre, and are reported in Table 4.7.

4.2.2.3. Prices and Costs of Production

As in the land use component, the median producer price per finished animal is used to parameterize the baseline mathematical programming model. Producer price data for each county are obtained from the Iowa National Agricultural Statistics Service (Iowa NASS) for the years 1994-2003. The prices are reported in dollars per hundredweight.

⁴⁵ To calculate space per head marketed, the total area per litter is divided by the weaning average per litter. This estimate applies only to confinement farrow-to-finish enterprises.

The assumed weight of each animal is used to convert the price per hundredweight into price per head. The price received per head of livestock is reported in Table 4.8.

Feeder pigs and calves are variable inputs into the production of finishing swine and cattle. The price per feeder calf is calculated as the product of its weight, in hundredweight (cwt.), and the median producer price (in dollars per hundredweight) as documented in the Iowa NASS. While price data is available for calves, is not available for feeder piglets. The price per piglet assumed in the ISU Extension budgets is used as the baseline producer price. While the prices of all other inputs into livestock production are fixed, it is unreasonable to assume that the prices of feeder animals remain constant when the prices of finished animals vary. Therefore, the cost of each type of feeder animal is varied by the same percentage as the prices of finished animals when conducting price sensitivity analyses.

The variable and fixed costs of livestock production are obtained from the same ISU Extension publication as the feeding requirements (May, Edwards, and Lawrence, 2004). Each input into livestock production, excluding feeder animals, is assumed to be available in perfectly elastic supply. The costs of livestock production are calculated as the input requirement per head multiplied by a fixed price for that input. The labor requirement, in hours per animal produced, is reported separately from all other variable costs of production. The assumed wage rate for labor in livestock production is \$9.50 per hour. “Other” variable costs include supplements and minerals, veterinary and health, machinery, equipment, marketing, and miscellaneous expenditures, as well as the interest on feed and other costs. The ownership (fixed) costs of livestock production include the depreciation and interest payments on fixed factors of production, including housing.

Table 4.8. Median Price, Labor Requirement, and Costs of Production per Head Marketed, by Livestock Type, Enterprise, and Production System

Livestock Enterprise	Median Price (\$ per cwt.)	Labor (hours)	Other Variable Costs (\$)	Ownership Costs (\$)
<i>Swine</i>	41.10			
Farrow-to-Finish				
Confinement		1.25	43.96	20.31
Pasture		1.67	47.39	12.95
Finishing				
Confinement		0.50	31.87	13.04
<i>Beef Cattle</i>	64.05			
Cow-Calf				
Feedlot		10	130.41	152.70
Pasture		12.69	134.81	168.80
Finishing				
Feedlot		3	79.28	21.00
Pasture		0.625	56.29	21.00

Sources: Iowa National Agricultural Statistics Service; May, Edwards, and Lawrence (2004)

“Other” variable costs and ownership costs are reported as a fixed dollar amount per head of livestock marketed. For farrow-to-finish swine, the labor input and costs of producing each head of livestock marketed are derived using the average litter size per enterprise, as in the feed requirement derivation. The labor requirement, variable costs, and ownership costs per head of livestock marketed from each enterprise are reported in Table 4.8.

4.2.2.4. Manure Production and Nutrient Content

Livestock manure production is a key component of the land use model. Allowing manure nutrients to substitute for purchased fertilizer inputs allows for integration between crop and livestock production activities. Moreover, the application

of manure nutrients to cropland affects the system's environmental impacts. Specifically, by ensuring that manure nutrient applications do not exceed crop nutrient requirements, excess nitrogen applications can be limited. Doing so will reduce nitrate runoff and leaching, both of which are sources of water contamination.

To specify the amount of nutrients produced per head of livestock, data from the American Society of Agricultural Engineers (ASAE) Manure Production and Characteristics Manual are used (ASAE, 2004). The manure nutrient production estimates are in total pounds per head per finishing animal and by pounds per day-animal for inventory breeding animals. Conversion of the parameters is required to ensure that the manure nutrient production coefficients correspond to the modeled unit of livestock allocation. The manure produced by inventory animals involved in the production of each head of marketed livestock must be calculated and added to the amount produced by the marketed animal.

For each inventory animal used in the production of one head of marketed livestock, the pounds of nutrient production per day are multiplied by the number of days in the stage of the marketed animal's production cycle during which the inventory animal is used. For example, a lactating sow is used in the production of a litter of piglets for a total of 41 days. To obtain the total amount of nitrogen produced by that lactating sow, nitrogen production in pounds per day per lactating sow is multiplied by 41 days. The total nitrogen produced by a lactating sow is divided by litter size to derive the amount of nitrogen per head produced during that portion of a hog's production cycle. The same exercise is completed for a gestating sow. The total amount of nitrogen produced by each hog marketed from a farrow-to-finish enterprise is the amount produced by lactating and

Table 4.9. Manure Nutrient Production in Pounds per Head Marketed, by Livestock Type, Enterprise, and Production System

Livestock Enterprise	Manure Nutrient Content			Total N Lost (%)
	Nitrogen (N)	Phosphate (P ₂ O ₅)	Potash (K ₂ O)	
<i>Swine</i>				
Farrow-to-Finish				
Confinement	12.90	2.40	6.02	26.5
Pasture	13.15	2.48	6.19	35.7
Finishing				
Confinement	10.00	1.70	4.40	26.5
<i>Beef Cattle</i>				
Cow-Calf				
Feedlot	126.31	22.99	87.76	51.1
Pasture	142.21	25.10	98.74	55.0
Finishing				
Feedlot	54.45	7.23	37.62	61.5
Pasture	70.35	9.34	48.60	55.0

Source: American Society of Agricultural Engineers (ASAE) (2004).

gestating sows (divided by pigs per litter) plus the amount produced by a pig in its nursery stage and in its finishing stage. The same calculation is performed for each livestock enterprise. Table 4.9 summarizes the amount of manure nutrients produced by each head of livestock marketed.

The nutrients available for crop production from manure differ from the coefficients presented in Table 4.9 because of losses from storage and application. For simplicity, the predominant storage and application systems for each type of livestock are assumed to be used by all producers in the study area. The storage and application losses

utilized in the model apply only to nitrogen (N).⁴⁶ It is assumed that all confinement swine manure is stored in a pit with 25 percent N losses. Swine manure is most commonly applied via injection, with an additional N loss of two percent. Manure excreted and stored on the ground, as is the case for pasture-farrowed swine, feedlot cattle, and pasture-based cattle, loses 45 percent of its original N content. Cattle manure from feedlots is most often applied using the dry broadcast method, which results in an additional N loss of 30 percent. Because pasture-based animals are essentially applying manure while grazing, there are no additional N losses beyond those from storage. For those animals that are on pasture for part of their production cycle and are in confinement for the remainder, a weighted average of the manure N losses is calculated. The weight used is the number of days in each portion of the production cycle, as a proportion of the entire production cycle. The total losses from storage and application for each head marketed, calculated as the product of storage and application losses, are presented in Table 4.9.

This section concludes the presentation of the technical parameters of crop and livestock production. The coefficients in this chapter were reported in great detail because their validity is crucial in determining the predictive ability of the mathematical programming model. The next chapter begins the model analysis by describing the baseline model allocation and testing its sensitivity to changes in the returns to commodity production.

⁴⁶ While there may be some phosphate and potash losses, estimates suggest that they are orders of magnitude less than nitrogen storage/application losses. Moreover, regulations pertaining to manure nutrient spreading apply only to nitrogen, at present.

CHAPTER 5

BASELINE MODEL RESULTS AND SENSITIVITY ANALYSIS

Chapters 3 and 4 define the algebraic structure and the technical parameters of the mathematical programming (MP) model that forms the foundation of this analysis. This chapter focuses on developing an understanding of the economic determinants of landscape-level production patterns in the study area. To facilitate the discussion, the chapter is divided into two sections. The first describes the baseline solution of the MP model, with an analysis of the extent to which the baseline replicates observed production practices. This section is used primarily to establish the validity of the baseline model. If the model replicates reality reasonably well, it provides a starting point for simulating the outcome of the policy scenarios examined in Chapter 6. The second section examines the sensitivity of the model's baseline solution to changes in the relative returns to agricultural commodities. The sensitivity analyses are used to identify the economic factors that drive the model solution. The results of these tests yield several important policy implications, in and of themselves.

5.1. The Baseline Model Solution

The MP model is solved using the BDMLP solver in the General Algebraic Modeling System (GAMS) software. The baseline model consists of 150 rows, 413 columns, and 3209 non-zero entries. The initial model solution is based on the equation structure outlined in Chapter 3 and the technical coefficients of agricultural production

from Chapter 4. If these parameters and equations are representative of reality, the model solution should correspond to observed patterns of production.

It was necessary to make one adjustment to the model structure, based on the initial model solution. The producer price of alfalfa hay is high relative to its cost of production, making alfalfa by far the most profitable crop to sell on the market. If alfalfa sales are unconstrained, the model assigns all crop acres to the six-year alfalfa rotation. The corn produced from the rotation is fed to hogs alone, so that all of the alfalfa produced, 1.41 million tons, can be sold on the market. This quantity is greater than 15 times the amount of alfalfa that was produced in 2002. Because hay and forage crops are bulky and expensive to transport, their primary use is as an input into livestock production. Based on the number of cattle produced in 2002 in the two counties and total alfalfa production, the estimated amount of alfalfa sales is 1,500 tons. This figure is used to specify an upper bound on alfalfa sales.⁴⁷

Table 5.1 presents the model's baseline solution (with limited alfalfa sales) along with published data on observed production practices in Crawford and Shelby counties. The majority of the data used to describe current conditions are obtained for each county from the 2002 Census of Agriculture (National Agricultural Statistics Service [NASS]). The estimates for each county are summed to generate the figures presented for the study region.

In several cases, the unit of measure of the published estimates does not directly correspond with that used in the MP model. The foremost discrepancy is in the description of the land use allocation. The model allocates acres to specific management

⁴⁷ Similarly, total sales of grass-legume hay are fixed at zero, although this limit is not binding in the baseline model solution.

practices, within which the proportion of crops produced is fixed. The Census provides estimates of acres harvested by crop, not by rotation. The number of acres by crop in the baseline model solution can be derived based on the number of acres allocated to each land use activity. However, the relative proportions of crop acreages in the baseline model will likely not correspond to those reported in the Census.

The method of reporting government payments, and the profit indicator used by the Census, also differ from those used in the MP model. The Census reports the total amount of Federal Farm Program (FFP) payments received by county producers, but does not disaggregate that amount by program at the county level.⁴⁸ The total amount of FFP payments reported in the Census likely includes payments from programs other than those modeled. However, the two dominant income support programs are direct and counter-cyclical payments, which accounted for 55.7 percent of total Farm Service Agency program payments in 2003 (NASS, 2004). The contribution of other programs to total government payments received in the two counties is likely to be relatively minor. Therefore, it is not unreasonable to use the aggregate payment amount as a comparison.

The profit indicator also differs substantially between the baseline and the Census: the latter estimates total net cash farm income (NCFI) for all producers in each county. The NCFI is defined as “the cash earnings realized within a calendar year from the sales of farm production and the conversion of assets, both inventories and capital consumption, into cash” (NASS, “2002 Census”). The NCFI is intended to be a measure of liquidity, and therefore does not include non-cash costs, such as depreciation, which are included in the calculus of the net return to land and management. There is no measure reported in the Census akin to the average return to land optimized in the MP

⁴⁸ Estimates of spending by program are available at the national level (NASS, “2002 Census”).

model. Data on the average cash rental rate for cropland between 1994 and 2002 is taken from an Iowa State University (ISU) Extension publication (ISU Extension, 2002). The model objective value is therefore compared on the basis of two indicators. The net return to land and management (the average return to land multiplied by the number of acres available) is compared to the NCFI, and the average return to land is compared to the median average cropland rental rate between 1994 and 2002. Although the units of measure are not perfectly consistent, these estimates are the most reliable and readily available method of evaluating the performance of the baseline MP model.

The baseline model solution allocates 695,456 acres to the corn-soybean rotation, and 26,440 acres to the six-year alfalfa rotation. The total crop acres allocated across these two rotations are reported in Table 5.1. Both corn and soybean acreages, by far the dominant land uses across the two counties are reasonably close to those observed in reality, with errors of +7.3 and +17.7 percent, respectively. However, the model does not perform as well, relative to current conditions, with the allocation of other crops. Alfalfa acreage in the model solution is 44.9 percent less than the actual acreage observed, while oat acres are over twice their reported level. The discrepancy between the ratio of oat and alfalfa acres observed in reality and that in the model solution is due to the model assumption that all alfalfa acres are grown with an oat leader crop. An alfalfa crop can also be established using herbicide, an option that is not included in the model.

No pasture acres are assigned in the baseline model solution, which can be explained by the assumption of homogeneous land quality and by the non-optimality of pasture-based livestock enterprises. In regard to the former, the exogenous supply of arable land in the model, derived from GIS images, cannot be differentiated based on its

suitability for cropping. All arable land within one slope class is assumed to be homogeneous. In reality, some land may be unsuitable for cropping but useful for pasture, such as land that is rocky. Further, the baseline model solution does not include any livestock activities that require land for grazing. Like alfalfa hay/forage, grass-legume hay/pasture is primarily used locally as an intermediate input into livestock production. In the absence of livestock, grass-legume pasture is not an economically rewarding land use activity.

Because they are intermediate inputs into livestock production, the allocation of land to alfalfa and grass-legume hay/pasture is driven by the optimal livestock allocation. Current estimates indicated that livestock are produced from each of the four representative enterprises. However, the baseline model solution allocates livestock only to farrow-to-finish swine production and finishing beef cattle. The optimal allocation does not include the production of cow-calf units, which require pasture and a greater amount of alfalfa feed than do finishing cattle. The last column of Table 5.1 reports the model allocation when head of livestock marketed livestock are fixed at their current levels.⁴⁹ In this case, the allocation of acres to alfalfa and grass-legume more closely reflects current conditions. Oat acreage remains overstated because of the assumption that all alfalfa acres are grown with an oat leader crop.

It is useful to briefly summarize the model's allocation of land use activities across the landscape. Recall that terrain in the model is assumed homogeneous within a grade, but is heterogeneous across grades. The profitability of each rotation is related to slope through a yield loss function. The return to the intensive corn-soybean rotation declines more rapidly as slope increases than do the returns to the six-year rotations and

⁴⁹ Based on estimates by Ed van Ouwerkerk, 2004 (I-FARM).

to continuous pasture. The model is expected to allocate the most profitable land use activity, the corn-soybean rotation, starting on the lowest grades and moving up the landscape until another land use activity either becomes more profitable through the yield loss function, or until a constraint on the acreage allocation becomes binding.

The model allocates crop production to those grades on which land is most productive, with slopes ranging from zero to 17. Ecoreserve acres occupy all land above that point. This reflects that the return to CRP land is invariant with increases in slope, while the return to crop production is declining. The optimal placement of livestock housing acres is on the 17 percent grade, which indicates that the model is reacting to the higher opportunity cost of converting or retiring “prime” cropland, i.e. land on lower slopes with a relatively greater per-acre crop yield potential. The only seeming anomaly in the baseline allocation is that acres in the six-year alfalfa rotation are placed alongside acres in the corn-soybean rotation on land with a zero percent grade. Because the crop yield from the six-year rotation declines less rapidly with slope than the corn-soybean rotation, the expectation is that the six-year rotation will optimally be placed on grades above the corn- soybean rotation. However, the six-year rotation is allocated to the most productive cropland because of the relatively high return to alfalfa used in livestock production.

All livestock production in the baseline solution is allocated to two enterprises: farrow-to-finish confinement swine production, and finishing beef cattle in feedlots. The total number of swine marketed in one year in the baseline model exceeds three million head, over three times the total number marketed according to the Census. This excess in

Table 5.1. Comparison of Current Conditions, as Published in the 2002 Census of Agriculture, to the Baseline Model Solution, and to the Solution when the Livestock Allocation is Fixed

	Current Conditions		Model Baseline		Fixed Livestock Allocation	
<i>Land Allocation by Crop</i>	<u>Crop</u>	<u>Acres</u>	<u>Crop</u>	<u>Acres</u>	<u>Crop</u>	<u>Acres</u>
	Corn	332,185	Corn	356,533	Corn	326,580
	Soybean	299,092	Soybean	352,144	Soybean	318,794
	Oat	2,008	Oat	4,415	Oat	7,834
	Alfalfa	24,002	Alfalfa	13,220	Alfalfa	23,454
	Grass ^a	67,567	Grass-Legume		Grass-Legume	54,083
	Ecoreserve	22,526	Ecoreserve	22,526	Ecoreserve	22,526
<i>Livestock Allocation</i>	<u>Total Head Marketed^b</u>		<u>Intensive</u>	<u>Extensive</u>	<u>Intensive</u>	<u>Extensive</u>
<i>Swine</i>	Farrow-Finish	366,304	3,388,568		366,304	
	Finishing	576,569			576,569	
<i>Beef</i>	Cow-Calf	21,633			21,633	
	Finishing	44,865	82,909		44,865	
<i>Government Payments (\$m.)</i>						
	Total DP,CCP	9.45	13.16		12.021	
	CRP	2.68	2.68		2.68	
<i>Total Soil Erosion (m. tons)</i>			6.65		4.26	
<i>Net Return to Land and Management (\$m.)</i>	64.13 ^c		86.17		57.49	
<i>Average Return to Land (\$/acre)</i>	111.00 ^d		115.53		77.09	

a: Census reports total land in pasture, which may not be a grass-legume mixture.

b: Total marketed, may include both intensively and extensively produced livestock.

c: Net cash farm income (NCFI) of operations. Does not correspond directly to the net return to land and management (NRLM).

d: Median cash rental rate for cropland, 1994-2002. Median rental rate for pasture over the same period: \$29.85 per acre.

hog production can be explained, in part, by the lack of a housing constraint in the model, and in part by the low producer price of corn. By excluding a capital constraint, it is implicitly assumed that all physical (and human) capital is perfectly adjustable, such that, if the return to hog production were sufficiently high, farmers would instantaneously build more confinement facilities in order to capture positive returns on investment.

Imposing an upper bound on the amount of confinement swine produced tests the response of the model to a housing constraint. When the amount of farrow-to-finish confinement swine operations is bounded in the model, surplus corn shifts into the next most profitable livestock production activity, finishing cattle. The shift in livestock production is driven by the low producer price of grain corn. Corn can either be sold on the market or it can be used as an input into livestock production. In the baseline model solution, all of the corn produced in the two counties is fed to swine and beef cattle, which suggests that feeding corn to livestock is relatively more remunerative than allocating it to market sales. When the producer price of corn is increased, such that selling corn is more profitable than channeling it into livestock production, swine are produced up to the maximum, and the remaining corn produced is sold.⁵⁰

The baseline swine result may be explained by the exclusion of several other factors from the model, namely cultural constraints (and rigidities), price endogeneity, and the benefits associated with risk diversification. Cultural constraints could include issues surrounding odor and producer livestock production preferences. In addition, the model assumes that commodity prices are exogenous and that there is a market for all livestock produced. This assumption is likely unrealistic if hog production were expanded to such a degree.

⁵⁰ This occurs when the corn price increases by 23 percent over the median price from 1994-2003.

The number of beef cattle allocated by the model exceeds the total number of beef cattle marketed, according to the Census, by slightly less than 25 percent. However, all beef cattle in the baseline solution are concentrated in feedlot finishing enterprises. The optimal allocation suggests that the return to cattle produced in cow-calf units is less than finishing cattle. Anecdotal evidence suggests that cow-calf enterprises are the choice enterprise of retired/leisure farmers.⁵¹ Therefore, cow-calf units may not be a profit-maximizing activity, and would not be allocated by a model that assumes producers are strict profit maximizers. Moreover, a cow-calf unit requires a substantial amount of pasture for production, about 2.5 acres per head of cattle marketed. As previously mentioned, because the model assumes homogeneous land quality within a grade, the opportunity cost of allocating land to pasture is overstated for low-quality land that exists within a slope class. By understating the relative return to pasture, the model also understates the relative return to cow-calf production.

The baseline amount of government payments received by producers in the two counties exceeds the amount reported in the Census. It should be noted that initially all crop acres in the baseline model were assumed to be registered base acres (and were therefore eligible for direct and counter-cyclical payments). However, this dramatically overstated the actual amount of payments received. Based on the Census, only 56 percent of all farms in the two counties received Federal Farm Program payments in 2002. To correct this discrepancy, payment base acres in the model are scaled down from the total amount of crop acres by a factor of 0.56.

Despite this correction, the total amount of government payments remains slightly greater in the baseline solution than in the Census because of the greater acreage

⁵¹ Based on a discussion with researchers and extension agents at Iowa State University.

allocation to program commodities (corn, soybeans, and oats). A lower level of counter-cyclical payments distributed in the model than in 2002 may mediate this overstatement. The median price of corn used to parameterize the model is \$2.16 per bushel, which is \$0.11 greater than the 2002 average price received in Iowa. The counter-cyclical payment rate, based on the difference between the market and target prices, would be lower in the model than in actuality. Assuming that the payment acres in the model and in reality are equal, the baseline model would under-predict the total amount of counter-cyclical payments received.

The final bases of comparison for the baseline model allocation are the profit indicators used to measure the objective function. Although the two measures differ, it is useful to establish that the baseline NRLM is in the same ballpark as the NCFI: the former exceeds the latter by slightly greater than \$22 million, most likely due to the overstated livestock numbers. When the livestock allocation is fixed, the NRLM more closely matches the reported NCFI. Dividing the NRLM by the total number of productive acres in the model yields the average per-acre return to land. Over the long run, the cash rental rate of cropland converges to the average return.⁵² Because the model solution represents a long-run equilibrium, the return to land is equivalent to the cash rental rate. This is reported in the last row in Table 5.1. The baseline model solution for the average return to land is reasonably close to, about four dollars per acre greater than, the published estimate. It should be noted that the per-acre return to land in the model solution is averaged across all land uses. When pasture acres are assigned, the average return to land reported in the model solution will be lower than that under an

⁵² However, the observed cropland rental rate likely does not perfectly correspond to the current return to cropland because of adjustment lags.

allocation with no pasture (and will be less than the reported return to cropland). This explains why the rental rate is higher in the baseline than under the solution with a fixed livestock allocation.

The model baseline solution does not perfectly replicate the results published in the Census, especially in the case of the livestock allocation. However, the objective of this analysis is to examine the impact of policy on landscape-level land use patterns. The baseline model land use allocation is reasonably close to observed acreages, especially in the case of the dominant crops produced within the study area. Therefore, the baseline provides a reasonable starting point from which to simulate the impact of hypothetical policy instruments. Before proceeding to the policy analysis in Chapter 6, it is useful to analyze the sensitivity of the model to changes in the initial commodity price parameters. Doing so will contribute to a better understanding of the economic factors driving the modeled land use allocation.

5.2. Sensitivity Analysis

This section presents a discussion of the sensitivity of the baseline model solution to changes in the initial parameters. As a starting point, the reaction of the model to changes in commodity producer prices is explored. The effects of price premia on pasture-farrowed hogs and grass-finished beef are also tested. The final sub-section reports the model allocation with reduced levels of government payments.

The relative commodity price changes are presented in Table 5.2 are the threshold values necessary to shift the baseline land use allocation. Each value is expressed as the percent change from the median price between 1994 and 2003. The table is organized as a matrix, with the modeled land use activities listed in the first row and the first column.

Those land use activities that are assigned zero acreage in the baseline model solution (six-year grass-legume and continuous pasture) are not included in the column listing. The table should be read as follows: starting from the corn-soybean rotation on the left, and moving to the right, the first square that contains text corresponds to the six-year alfalfa rotation. This cell contains the commodity price changes that induce a reduction in acres assigned to the corn-soybean rotation and an increase in the acres assigned to the six-year alfalfa rotation. Within this cell, each commodity that induces a shift in the land use assignment is listed, along with the direction and magnitude of the price change.

Table 5.3 is a more detailed parallel to Table 5.2. This table presents the acres assigned to each land use, the number of livestock allocated by the model, total soil erosion produced by the system, and the average return to land (ARL). This information aids in the interpretation of the model response to each threshold value, the subject of the remainder of this section.

5.2.1. Crop Price Changes

Because it is both the dominant cropping activity and the primary livestock feed, changes in the producer price of corn are expected to have the most noticeable impacts on the land use allocation. When the corn price rises, it becomes more profitable to allocate land use acres to the more intensive corn-soybean rotation, as corn constitutes a greater proportion of the rotation than the six-year options. The expected effect of an increase in the corn price is a shift out of more diversified cropping activities and into a more intensive production pattern. If crop and livestock activities are optimally nonseparable, this would also be associated with a shift out of beef cattle production (which necessitates alfalfa) and into hog production (which relies only on corn). This expectation is

supported by the results presented in Table 5.2. With a rise in the corn price of 9 percent, land shifts out of the six-year rotation and cattle production, and into the corn-soybean rotation, with an increase in the number of hogs produced.

As the producer price of corn rises further, it becomes relatively more profitable to sell corn than to allocate it to livestock feed. With an increase of another 24 percent in the corn price (for a total of 33 percent), hogs are no longer produced. All of the land in livestock housing shifts into the corn-soybean rotation, and all of the corn produced is sold. With a total increase in the corn price of 59 percent, it is optimal for producers to remove land from ecoreserve (the Conservation Reserve Program), so that more corn can be produced and sold on the market. This result follows from basic land use theory: with an increase in the return to corn, the opportunity cost of idle land increases, and marginal land is converted for use in crop production (“extensification”).

Conversely, a decline in the corn price should be associated with a shift out of intensive row cropping, and into more diversified land use activities. As the market corn price falls, its opportunity cost as a feed input also declines. In addition, purchased grain corn (which is the producer price plus ten percent for storage and transportation) becomes less costly as an input into livestock production. Both of these changes increase the relative profitability of livestock activities. As shown in Table 5.2, the sensitivity results correspond to expectation. At 21 percent below the median price, land shifts out of the corn-soybean rotation and into the six-year rotation. At this point, no hogs are produced, the number of finishing cattle marketed increases, and corn is purchased for feed. With an additional seven percent decrease in the corn price, the model pulls land out of ecoreserve for feed production and livestock housing.

Table 5.2. Minimum Percent Change in Commodity Prices Required to Shift the Land Use Allocation, Relative to the Model Baseline

Land Use Exited	Land Use Entered					
	Corn – Soybean Rotation	Six-Year Alfalfa Rotation	Six-Year Grass-Legume Rotation	Continuous Pasture	Ecoreserve	Livestock Housing
Corn – Soybean Rotation		Corn: -21 Soybean: -56 Oat: +100 Cattle: +3 Hogs: -1				Corn: -21
Six Year – Alfalfa Rotation	Corn: -56/+9 Soybean: +19 Alfalfa: -36 Cattle: -1 Hogs: +1					Corn: -56/+9 Alfalfa: -36
Ecoreserve	Corn: -28/+59 Cattle: +10 Hogs: +8	Corn: -28 Cattle: +10				Corn: -28 Cattle: +10 Hogs: +8
Livestock Housing	Corn: +33 Soybean: +19 Cattle: -1 Hogs: +1	Soybean: -56 Oat: +100 Cattle: +3				

Table 5.3. MP Model Solution with Select Threshold Price Changes, in Percent Deviation from the Median, from Table 5.2

	Crops				Livestock		
	Corn +9/ Soybean +19	Corn -28	Soybean -56	Alfalfa -36	Swine +1/ Cattle -1	Swine -1	Cattle +3
<i>Land Use Acres</i>							
Corn-Soybean Rotation	721,197	357,973	691,447	696,265	721,197	694,243	687,645
Six Year – Alfalfa Rotation	716	367,192	30,451	25,630	716	27,654	34,256
Ecoreserve	22,526	19,045	22,526	22,526	22,526	22,526	22,526
Livestock Housing	1,355	1,584	1,370	1,373	1,355	1,372	1,367
<i>Head Livestock</i>							
Farrow-Finish Swine (m.)	3.65		3.37	3.39	3.65	3.38	3.35
Finishing Beef Cattle		1.14 m	86,184	82,607		83,900	89,290
<i>Total Soil Erosion (m. tons)</i>	6.67	6.03	6.39	6.65	6.67	6.63	5.75
<i>Average Return to Land (\$/acre)</i>	111.22/137.80	152.41	82.11	115.49	120.46/115.43	110.86	116.56

When the corn price declines by 56 percent, the land allocation begins to reverse its previous transition, shifting from the six-year rotation into corn-soybean production. At first glance, this result seems counterintuitive. However, the result can be attributed to government payments. Both counter-cyclical and loan-deficiency payments depend on the divergence between the corn market price and the pre-set price floor. While there is an upper limit on the amount of payments each producer can collect in reality, there is no such limit imposed in the model. With a decline in the corn price of 56 percent, direct, counter-cyclical, and loan-deficiency payments total \$36.83 million, nearly three times the baseline amount. At this point, the model begins to import hay to fulfill the cattle forage requirement and shifts land back into more intensive corn-soybean rotation to capture the increased return to program crops.

The model allocation is far less sensitive to changes in the price of soybeans and oats than it is to fluctuations in the corn price. Oats and soybeans are assumed to be sold by producers in the two counties for processing, and later purchased as a variable input into livestock production (e.g. soybean meal). A decline in the soybean price, holding all else constant, decreases the relative profitability of the corn-soybean rotation because soybeans comprise a larger proportion of acreage in that land use activity. Similarly, an increase in the oat price increases the relative profitability of the six-year alfalfa rotation. A decline the soybean price of 56 percent and an increase in the oat price of 100 percent cause a similar model response: land shifts land out of the corn-soybean rotation and into the six-year rotation, with a decrease in swine production and an increase in finishing cattle. An increase in the soybean price of 19 percent causes the opposite response,

enhancing the profitability of the corn-soybean rotation. However, no decline in the oat price alters the baseline land use allocation.

Because the sale of alfalfa on the market is bounded in the model, an increase in the alfalfa price has no effect on the land use allocation. However, a decrease in the alfalfa price reduces the relative profitability of the six-year alfalfa rotation. When the price of alfalfa declines by 36 percent, there is only a small reduction in acreage in the six-year rotation, as alfalfa sales fall to zero. Prior to that point, alfalfa sales rested on the upper bound of 1500 tons per year. If the alfalfa price were to drop to by another seven percent, all land would shift out of the six-year alfalfa rotation and into the corn-soybean rotation. Despite this shift, beef cattle production continues with purchased alfalfa used to satisfy the forage ration (because a decline in the producer price reduces the cost of purchased feed).

Despite the fact that alfalfa and corn are both livestock feed crops, the model behaves differently to a decline in their producer prices: a reduction in the corn price encourages livestock production and the use of less intensive land use activities, while a decline in the alfalfa price causes the opposite to occur. However, in both instances a fall in the producer price of the commodity drives the land use allocation away from the rotation that is more heavily weighted towards that commodity. In the case of corn, the model allocation shifts towards the six-year alfalfa rotation and finishing beef cattle. For a decline in the alfalfa price, the solution tends towards the two-year rotation and swine production. The model behavior highlights that crop and livestock activities are optimally nonseparable. A shift that increases the relative return to the corn-soybean rotation also increases the relative return to swine production because of the grain feed

linkage. Alternatively, an increase in the return to swine increases the value-added to the corn-soybean rotation as an intermediate input and the opportunity cost of selling corn on the market. The same relationship holds true for the six-year alfalfa rotation and beef cattle.

It is also worthwhile to interpret the blank cells in Table 5.2. No change in commodity prices induces a shift into either the six-year grass-legume rotation (which includes two years of pasture) or into continuous pasture. As previously discussed, this result is driven by the non-optimality of pasture-based livestock enterprises in the model solution, as well as the model's inability to distinguish land heterogeneity within a grade (i.e. land that is suitable for pasture and not for crop production). The land use allocation cannot shift further into ecoreserve than the baseline level because CRP enrollment is limited to its current level.

The price sensitivity analysis suggests that the baseline land use allocation is largely insensitive to changes in commodity prices. With the exception of the nine percent increase in the corn price, all of the other crop price changes are outside of the range of price fluctuations observed between 1994 and 2003.⁵³ Also, because the model solution represents the long-run equilibrium, the relative price changes shown in Table 5.2 would have to be sustained over a long period of time. It is not outside of the realm of possibilities that prices could change to such a degree over the long run, but it would mark a substantial deviation from current conditions.

The inelastic response of land use change to commodity prices found here echoes the findings of previous studies (Wu et al., 2004; Zhang, Horan, and Claassen, 2003;

⁵³ Excluding the corn price in 1996, which reached \$3.51, an increase over the median price of 63 percent, the maximum corn price over the period observed was \$2.52 per bushel, a deviation from the median of 17 percent.

Claassen and Tegene, 1999). This supports Abler's assertion that because the elasticities of supply of agricultural land, individual crops, and livestock products are low, while the elasticities of substitution between land and purchased inputs are high, "changes in agricultural output are accomplished primarily through changes in purchased inputs rather than changes in land" (2004, p. 11). The policy implication is that instruments that target changes in land use activities directly are less likely to be successful than policies that attempt to motivate land use change indirectly by altering the prices of agricultural inputs. Chapter 6 tests this hypothesis by increasing the cost of soil erosion as an input into commodity production.

5.2.2. Livestock Price Changes

Livestock price changes impact the land use allocation via feed linkages when the two production activities are optimally nonseparable. A relative increase in the return to cattle is expected to increase the return to land into the six-year alfalfa rotation (to produce forage), while a relative increase in the return to swine is expected to shift land into the corn-soybean rotation (to produce grain). The sensitivity results support this argument. A three percent increase in the cattle price and a one percent decrease in the hog price shift livestock production out of hogs and into cattle. Consequently, the land allocation shifts out of the corn-soybean rotation and into the six-year alfalfa rotation. Conversely, a one percent decrease (increase) in the cattle (hog) price drives cattle production to zero, increasing hog production and pushing land out of the six-year alfalfa rotation and into the corn-soybean land use activity. With increases in the cattle and hog prices of 10 and eight percent, ecoreserve is pulled into feed crop production. These results indicate that livestock product prices are important in determining the optimal

land use allocation because the focus of production in the study area is on feed crops. However, the impact of livestock price changes is overstated because of the lack of a capital constraint and the assumption of price exogeneity, as well as several other factors discussed in the first part of this chapter.

5.2.3. Extensively-Produced Livestock Price Premia

In the baseline model solution, the price of livestock produced on pasture is assumed equal to the price of intensively produced livestock. Because consumer markets for natural livestock products are beginning to develop, it is possible that, in the future, pasture-based livestock may earn a price premium. The response of the model allocation to pasture premia on both hogs and cattle is tested. One potential impact of a premium on extensively produced livestock is that it may induce a shift in the land use allocation from the crop rotations into continuous pasture. By encouraging the conversion of cropland into pasture, increased premia on extensively produced livestock products may be an alternative means of obtaining environmental benefits.

The price premia required to induce a shift from intensive to extensive livestock production systems are 19 and four percent for cattle and hogs, respectively. Literature examining consumers' willingness to pay for natural livestock products suggest that a premium on the order of 10 to 20 percent is not unreasonable (Lusk, Feldkamp, and Schroeder, 2004; Grannis, Hooker, and Thilmany, 2000; Grannis and Thilmany, 1999). The threshold premium for hogs is low, relative to these estimates. This is because the model allows hogs to be pasture-farrowed, but assumes that extensively farrowed piglets are finished in confinement. In order to market a hog as extensively produced, it would likely have to be finished in a non-confinement system. It is reasonable to assume that,

initially the cost of extensive finishing would exceed the costs of intensive finishing. Thus, the model understates the relative cost of extensively-produced hogs and therefore understates the producer price premium necessary to induce an expansion in pasture-based swine enterprises. Incorporating an extensive hog finishing operation into the model would improve this portion of the analysis.

5.2.4. Changes in Government Payments

As discussed in Chapter 2, if different levels of negative environmental externalities are associated with different agricultural commodities, it may be possible to influence the level of externalities produced using a policy that reduces the return to more environmentally degrading commodities. Therefore, it is logical to test the impact of current support payments on the land use allocation. Because the intensive corn-soybean rotation receives a relatively larger support payment per acre, a decrease in the level of support should shift production out of this land use and into the less intensive six-year alfalfa rotation.⁵⁴ The six-year rotations produce less soil erosion, which implies that reducing current commodity payments should improve the system's performance with respect to this environmental indicator.

In the baseline model, both direct payments and counter-cyclical payments are paid to Crawford and Shelby county producers. However, the price of program commodities is not sufficiently low to allow producers to collect loan deficiency payments. To test the sensitivity of the model to government payments, the amount of direct and counter-cyclical payments are reduced by an equal percentage across land use

⁵⁴ Because corn, soybeans, and oats are the only program crops.

activities.⁵⁵ The results for three payment changes are displayed in Table 5.4. The first column to the right of the baseline allocation displays the model solution when all direct payments are removed while counter-cyclical payments are held constant (and the corn price is held at its median). The second column shows the model solution when counter-cyclical payments are removed while direct payments are held constant. The last column presents the model allocation with the elimination of all direct and counter-cyclical government payments.

A change in the level of direct payments, holding counter-cyclical payments constant, has no impact on the land allocation until the payment per acre falls to six percent of its current level. At that point, a mere 1,214 acres (0.16% of total arable land) shifts from the two-year rotation into the six-year alfalfa rotation. Total soil erosion produced by the system falls by only 0.02 million tons and the average return to land falls by \$12.83 per acre.

Reducing counter-cyclical payments to zero, with no change in direct payments, reduces the average return to land without impacting the land use allocation. However, when counter-cyclical payments are dropped to zero with a full reduction in direct payments, there is an additional transfer of land from the corn-soybean rotation to the six-year alfalfa rotation. Dropping all payments reduces soil erosion by 0.9 million tons and reduces the return to land by \$17.63 per acre relative to the baseline.

⁵⁵ The corn-soybean rotation receives a per-acre payment equal to the average of the corn and soybean payments per acre (which is the product of yield and the per-unit payment rate). The six-year alfalfa rotation receives a per-acre payment equal to the average of the corn, soybean, and oat per-acre payment rate, which are weighted by 1/3, 1/6, and 1/6, respectively. Therefore, an equal percentage reduction in the payments received for an acre in each land use activity does not translate into an equal reduction in the payment rate for each program crop.

Table 5.4. Model Allocation with Changes in Government Payment Parameters

	Baseline	Government Payment Changes		
		Zero Fixed Direct, Full Counter-Cyclical	Full Fixed Direct, Zero Counter-Cyclical	Zero Fixed Direct, Zero Counter-Cyclical
<i>Land Use Acres</i>				
Corn-Soybean Rotation	695,456	694,243	695,456	687,645
Six Year – Alfalfa Rotation	26,440	27,654	26,440	34,256
Ecoreserve	22,526	22,526	22,526	22,526
Livestock Housing	1,372	1,372	1,372	1,367
<i>Head Livestock</i>				
Farrow-Finish Swine (m.)	3.39	3.39	3.39	3.35
Finishing Cattle	82,909	83,900	82,909	89,290
<i>Government Payments (\$m.)</i>				
Fixed Direct	9.57		9.57	
Counter-Cyclical	3.59	3.58		
Loan Deficiency				
Conservation Reserve	2.68	2.68	2.68	2.68
<i>Total Soil Erosion (m. tons)</i>	6.65	6.63	6.65	5.75
<i>Average Return to Land (\$/acre)</i>	115.53	102.70	110.72	97.90

Eliminating current support payments produces a slight change in the land use allocation and soil erosion production. However, the results of this analysis demonstrate that a reduction in commodity payments has very little impact on the land use practices of producers in Crawford and Shelby counties. This result can be attributed to the relative inelastic response of land use change to commodity prices. Simply reducing the current level of income support payments is insufficient to attain significant environmental improvements. To address the dual objectives of income support and environmental improvement therefore necessitates the design of an alternative policy instrument. Chapter 6 builds on this conclusion by formulating several hypothetical policy instruments designed to discourage the production of soil erosion on agricultural working lands. By simulating these policy instruments, it is possible to evaluate whether, and to what degree, a single instrument can achieve environmental objectives while supporting producer welfare.

CHAPTER 6

GREEN POLICY ANALYSIS

The sensitivity analyses of Chapter 5 indicate that reducing the level of current income support payments, holding the portfolio of program commodities constant, cannot significantly impact the land use allocation in the study area. This result suggests that to encourage the provision of environmental benefits by agricultural commodity producers, it is necessary to consider alternative policy instruments. This chapter develops and evaluates several hypothetical policy instruments and one established regulation on the basis of their efficiency in attaining an environmental standard.

To begin, two command-and-control policy instruments are examined. The first is a nitrogen fertilizer application standard that is currently enforced by the Iowa Department of Natural Resources (DNR). It is possible to assess, *ex-post*, the cost of this regulation by simulating the land use allocation without the baseline nutrient balance. The second command-and-control scenario examines, *ex-ante*, the imposition of a soil erosion standard based on an environmental criterion. Specifically, the rate of soil erosion production, dependent on crop rotation practices and slope, cannot exceed a pre-defined tolerance value.

The second section of this chapter examines two hypothetical incentive-based policy mechanisms intended to reduce soil erosion. The first policy instrument is a per-unit tax on soil erosion production above the predefined threshold value. The second scenario analysis involves shifting current income support payments out of the relatively intensive corn-soybean rotation strategy, and administering a “green” payment to those

management practices that have greater erosion reduction properties. From the scenario analyses, inferences are drawn about the extent to which policy can influence the tradeoff between private producer welfare and the reduction of negative environmental externalities.

6.1. Command-and-Control Regulatory Instruments

Each of the command-and-control policy instruments examined in this section limits the production of an environmental externality to an exogenous standard. In both cases, that standard is set with the sole objective of improving environmental outcomes. For excess nitrogen applications and soil erosion, the unconstrained model solution is compared to the outcome under the standard. In so doing, the cost to producers of imposing the standard, equivalent to the loss in the average return to land, can be estimated. Using the results from the simulations and from the baseline, the tradeoff between producer welfare and reduced environmental externalities can be quantified and illustrated.

6.1.1. An Excess Nitrogen Application Standard

In Chapter 3, the nutrient demand-supply balances for nitrogen, phosphate, and potash are written such that the demand for nutrients cannot exceed the supply from livestock and purchased fertilizer. In the baseline model, there is an additional constraint that nitrogen supply must be in balance with crop nitrogen requirements. Enforcing this constraint ensures that crop nutrient requirements are completely satisfied, but not exceeded, by purchased fertilizer inputs and applications of livestock manure. Because livestock manure contains a greater amount of nitrogen than phosphate and potash, even

allowing for nitrogen losses in storage and application, the baseline model solution is constrained by the nitrogen demand-supply equality. In other words, the model fully satisfies the crop nitrogen requirement with nitrogen from livestock manure, and fills in the corresponding phosphate and potash deficits with purchased fertilizer.⁵⁶

The excess nitrogen constraint is specified in the baseline model because the Iowa DNR regulates the production and spreading of livestock manure based on a nitrogen standard. The standard dictates that total cropland nitrogen applications must be less than or equal to the nitrogen requirement of crops grown on that land. Livestock producers are required to submit a Manure Management Plan (MMP) documenting expected livestock manure production and details about the cropland on which the manure will be spread. At present, phosphorous and potash applications are permitted to exceed crop requirements. A phosphorous-based standard is currently under development for producers across Iowa. However, the proposed phosphorous standard will not take effect until four years after the rule becomes effective, which has not yet occurred. Moreover, the design of the standard is such that the majority of producers will still apply fertilizer and manure based on crop nitrogen requirements (Iowa Department of Natural Resources [DNR], 2004b).⁵⁷ While this analysis considers only the nitrogen standard, simulating the impact of a phosphorous standard is within the capabilities of the model used here and would be a useful future extension.

⁵⁶ The option to sell livestock manure is not incorporated into the model.

⁵⁷ The phosphorous rule is enforced only for those plots that have a high phosphorous index (P-Index). The P-Index was developed by Iowa State University, the National Soil and Tilth Laboratory at Iowa State University, and the Iowa Natural Resources Conservation Service. It is based on a number of factors, such as gross erosion, distance from the center of the field to the nearest stream, soil type, recent soil P test results, the rate and method of P applications, and management practices. For those plots that do not have an initially high P index, over-applications of P over time could eventually increase soil P concentrations, and therefore the plot's P index. While P applications may have to be tracked more carefully to guard against a rise in the P index that could lead to more careful regulation, the majority of producers could continue to use a nitrogen-based standard to determine manure application rates on their fields.

Although this regulation is already in place, the effect of implementing the nitrogen-based standard can be examined by simulating the land use allocation when nutrient applications are unconstrained. In the baseline model, where excess nitrogen applications are limited to zero, the model assigns the most profitable land use and livestock activities until that constraint becomes binding, at which point the next most profitable production activity that does not violate the constraint is allocated. When this constraint is removed, the land use allocation should shift towards the more profitable alternative.

This expectation is validated by the model solution for the unconstrained and constrained cases and for two intermediate levels of excess nitrogen production, presented in Table 6.1. As the excess nitrogen constraint is relaxed, the land use allocation shifts away from the six-year alfalfa rotation and into the intensive corn-soybean rotation, with an increase in hog production and a decrease in finishing beef cattle. When nutrient applications are unconstrained, producers apply 2.07 million pounds of nitrogen in excess of crop requirements to land in the two-county area. In total, imposing the nitrogen standard reduces the average return to land by \$1.25 per acre, or 1.07 percent.

It is also interesting, from a resource valuation perspective, to examine the shadow price of a unit of excess nitrogen. The shadow price of the nutrient constraint is the increase (decrease) in the average return to land associated with an incremental relaxation (tightening) of the excess nitrogen constraint. In the baseline model solution, the shadow price of a million pounds of excess nitrogen is an average of \$0.94 per acre.

Table 6.1. Model Solution with Constrained Application of Excess Nitrogen, Expressed as Percent of Unconstrained Level

	Level of Excess Nitrogen Applications, Relative to Unconstrained Case			
	0% (Baseline)	30%	70%	100% (Unconstrained)
<i>Land Use Acres</i>				
Corn-Soybean Rotation	695,456	703,171	713,457	720,953
Six Year – Alfalfa Rotation	26,440	18,706	8,394	879
Ecoreserve	22,526	22,526	22,526	22,526
Livestock Housing	1,372	1,392	1,417	1,436
<i>Head Livestock</i>				
Farrow-Finish Swine (m.)	3.39	3.53	3.73	3.87
Finishing Cattle	82,909	57,983	24,748	
<i>Government Payments (\$m.)</i>				
Fixed Direct	9.57	9.62	9.68	9.72
Counter-Cyclical	3.59	3.60	3.62	3.63
Loan Deficiency				
Conservation Reserve	2.68	2.68	2.68	2.68
<i>Excess Nitrogen (m. lbs)</i>	0	0.62	1.45	2.07
<i>Total Soil Erosion (m. tons)</i>	6.65	6.66	6.66	6.64
<i>Average Return to Land (\$/acre)</i>	115.53	115.91	116.41	116.78

Between the constrained and unconstrained levels of excess nitrogen applications, the shadow price of excess nitrogen declines as the resource becomes less scarce.⁵⁸

It is worth noting that, while constraining excess nitrogen encourages diversification in the aggregate land use allocation, it does not simultaneously provide a reduction in soil erosion. The six-year alfalfa rotation provides reductions in soil erosion relative to the corn-soybean rotation on higher slopes. However, as explained in Chapter 5, the optimal allocation of the six-year alfalfa rotation in the baseline is to cropland with a slope of zero degrees, on which the six-year rotation yields only slight reductions in soil erosion relative to the corn-soybean rotation.⁵⁹ This suggests that reduced nitrogen applications and soil erosion are not complementary policy objectives.⁶⁰

6.1.2. A Soil Erosion Production Standard

The second command-and-control policy instrument is a soil erosion standard. The standard limits per-acre soil erosion to a threshold value of five tons per acre. This value was chosen by members of the interdisciplinary team from Iowa State University, and constitutes a substantial reduction in soil erosion over current levels. The regulatory constraint is constructed as follows:

$$6.1 \quad TEROSSION_{yn} \leq YACRES_{yn} * TVALUE$$

where

⁵⁸ In Table 6.1, the loss in the average return to land (ARL) is \$0.38 per acre when the nitrogen constraint is relaxed from zero to 30 percent of the unconstrained level. When it is relaxed from 70 percent to 100 percent of the unconstrained level, the loss in the ARL falls to \$0.37 per acre.

⁵⁹ This land use allocation is driven by the relatively high value of feed produced in the six-year rotation. Because of the high return to alfalfa feed, this land use activity is placed on the most productive land, i.e. that for which the per-acre alfalfa yield is greatest.

⁶⁰ However, a nutrient application standard based on the P index would likely impact both environmental indicators, as soil erosion is an important determinant of the potential for phosphorous to runoff into surface water supplies (Iowa Natural Resources Conservation Service [NRCS], 2004).

6.2 $YACRES_{yn} * EROSION_{yn} = TEROSION_{yn}$

The variable YACRES is the number of acres assigned to each land use activity in each slope class. The level of soil erosion in tons per acre by land use activity and grade, EROSION, is an exogenous parameter and is determined by regressing the annual level of per-acre soil erosion on slope grade, as described in Chapter 4. TEROSION is total soil erosion, and is an endogenous variable, as it depends on the spatial allocation of land use activities. TVALUE is the tolerance value for soil erosion defined above. The soil erosion constraint is indexed over land use activity and grade, where land in ecoreserve and livestock housing produce no erosion. There are a total of 196 separate constraints on the production of soil erosion.

Table 6.2 presents the detailed model solution for the baseline (unconstrained) and the constrained scenario, as well as for two intermediate levels of soil erosion production. Constraining soil erosion encourages a shift in the model allocation away from the two-year corn-soybean rotation and hog production. The land use allocation shifts towards a more diversified system of production, with an increase in six-year alfalfa rotation acres and increased beef cattle production. In the fully constrained case, land is allocated to the six-year grass-legume rotation and to pasture, land use activities that are relatively less profitable than the corn-soybean and six-year alfalfa rotations.

The land use allocations for the command-and-control policy scenarios are represented visually in Figures 6.1 through 6.3. Figure 6.1 illustrates the baseline model solution (where excess nitrogen applications are constrained and soil erosion is unconstrained). The second map shows the simulated land use allocation when the

Table 6.2. Model Solution with Constrained Production of Soil Erosion, Expressed as Percent of Unconstrained Level

	Level of Soil Erosion, Relative to Unconstrained Case			
	24.7% (Constrained to T-Value)	30%	70%	100% (Baseline)
<i>Land Use Acres</i>				
Corn-Soybean Rotation	302,837	344,439	630,039	695,456
Six Year – Alfalfa Rotation	340,377	377,296	91,838	26,440
Six Year – Grass Rotation	46,174			
Pasture	32,435			
Ecoreserve	22,526	22,526	22,526	22,526
Livestock Housing	1,444	1,533	1,391	1,372
<i>Head Livestock</i>				
Farrow-Finish Swine		92,844	2.82 (m.)	3.39 (m.)
Finishing Cattle	1.03 (m.)	1.08 (m.)	248,235	82,909
Pasture-Finished Cattle	19,125			
<i>Government Payments (\$m.)</i>				
Fixed Direct	6.99	7.49	9.18	9.57
Counter-Cyclical	2.82	3.00	3.48	3.59
Loan Deficiency				
Conservation Reserve	2.68	2.68	2.68	2.68
<i>Excess Nitrogen (m. lbs)</i>				
	0	0	0	0
<i>Total Soil Erosion (m. tons)</i>				
	1.64	2.00	4.66	6.65
<i>Average Return to Land (\$/acre)</i>				
	103.66	107.77	114.22	115.53

Figure 6.1. Baseline Land Use Allocation, Constrained Excess Nitrogen Production, Unconstrained Soil Erosion Production

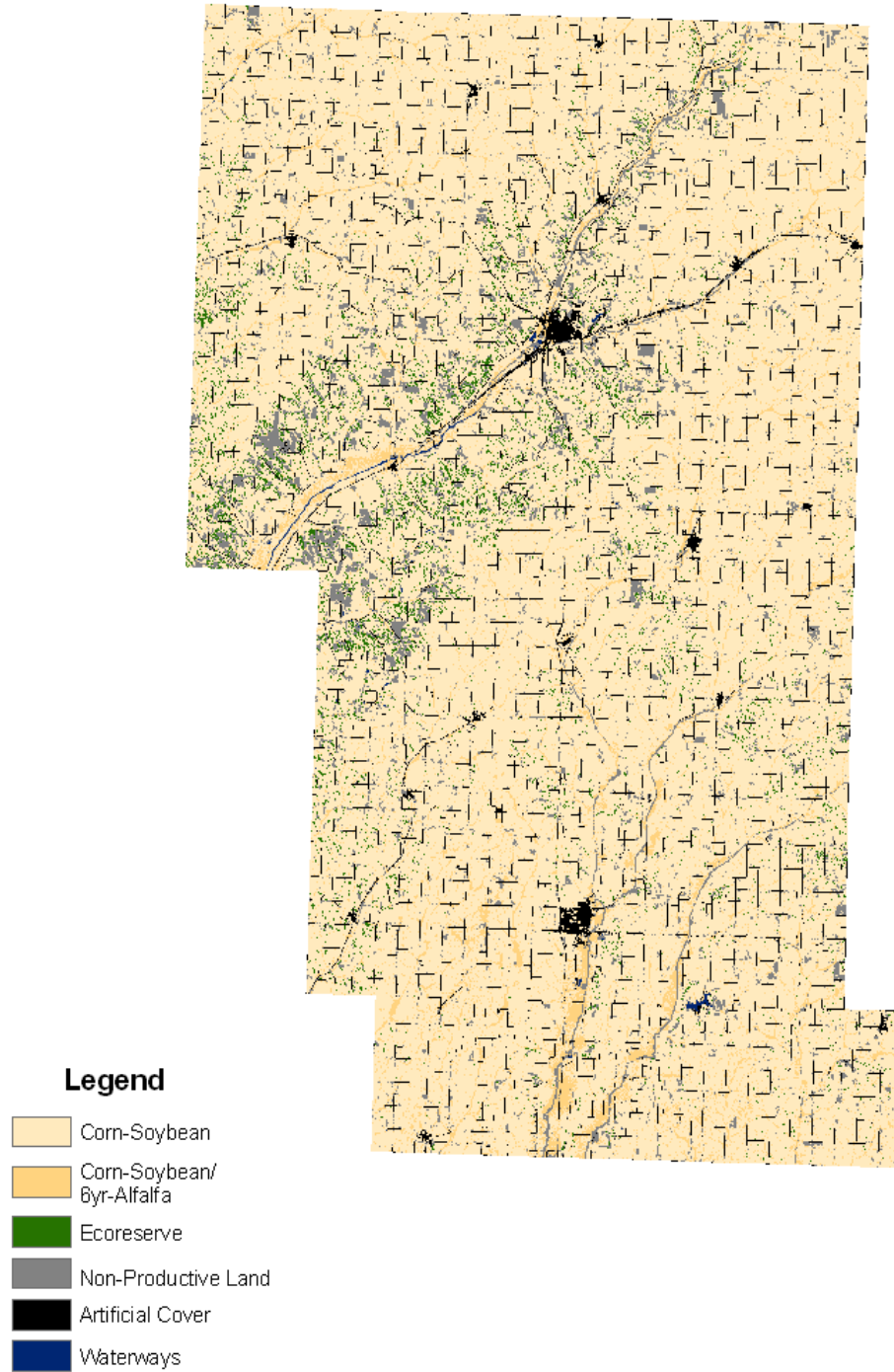


Figure 6.2. Land Use Allocation, Unconstrained Excess Nitrogen Production (Unconstrained Soil Erosion Production)

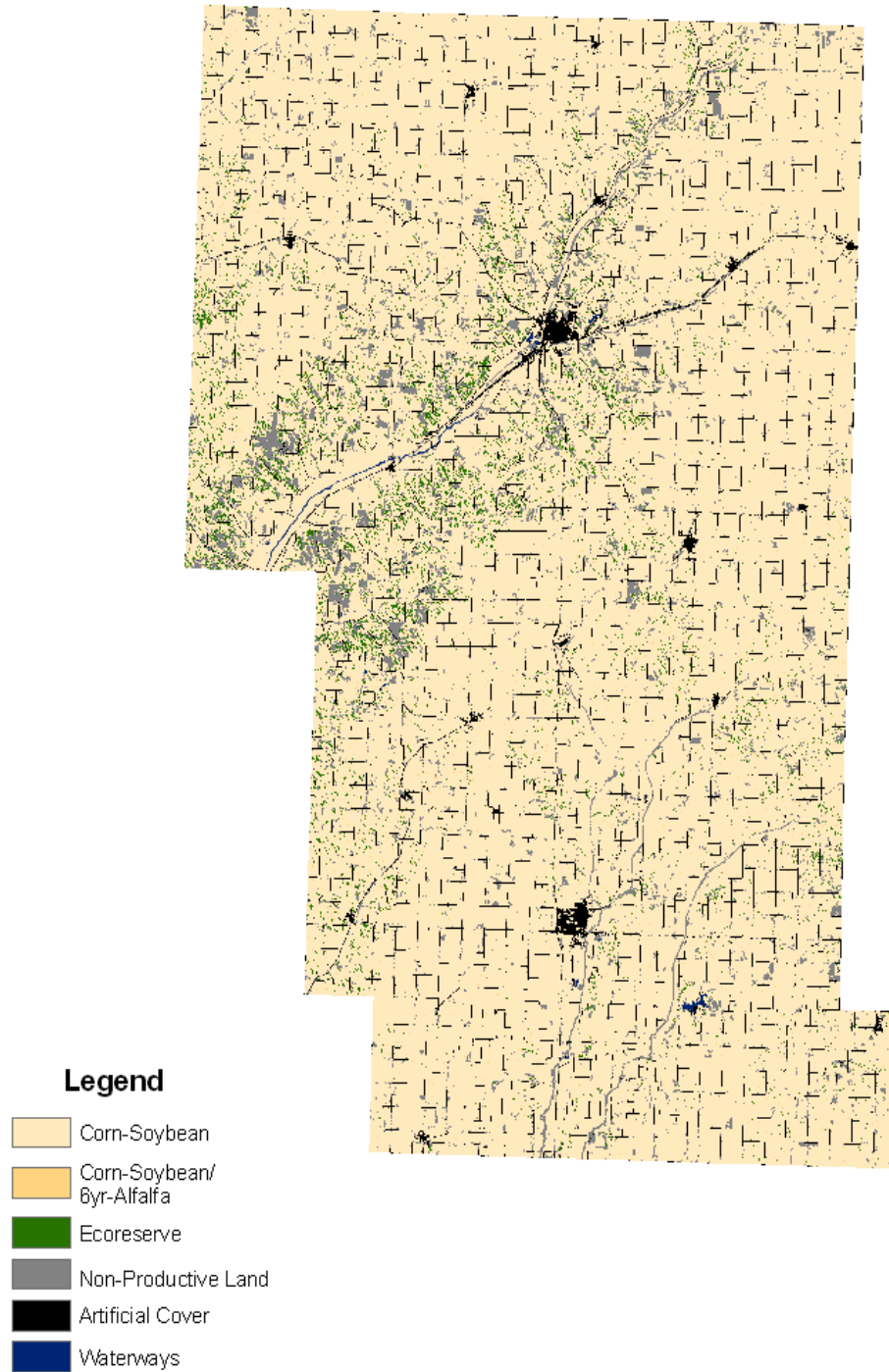
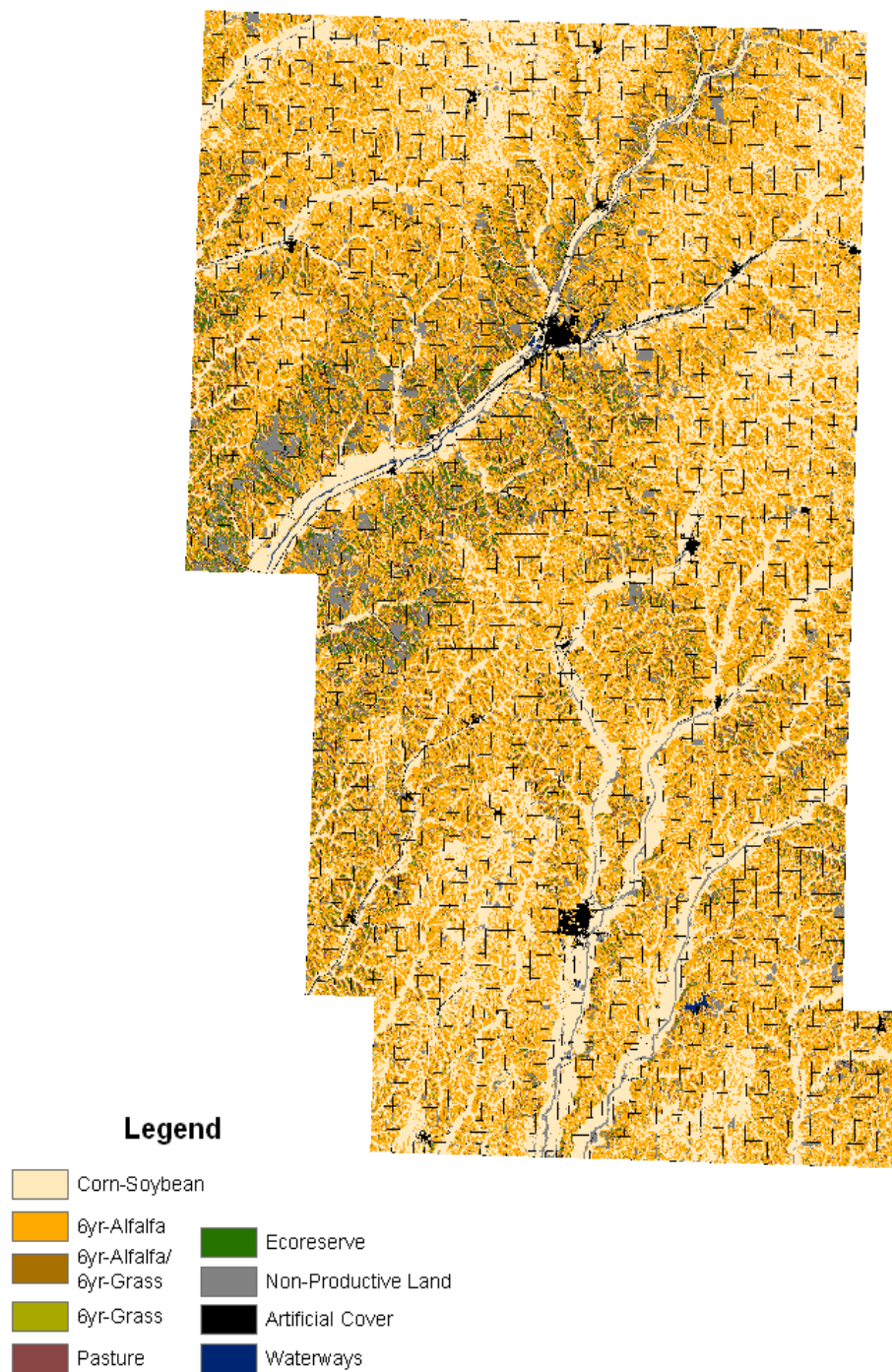


Figure 6.3. Land Use Allocation, Constrained Soil Erosion Production (Constrained Nitrogen Production)



excess nitrogen standard is removed. Finally, Figure 6.3 shows the land use allocation for the constrained soil erosion scenario.

The maps in Figures 6.1 through 6.3 are created using ArcMAP software. Recall that the MP model assigns land use activities by slope. Combining a cropland raster data layer with a topography layer creates a base map in which each pixel of arable cropland has an associated degree of slope. The model solution for acres of each land use activity, by slope class, is exported from GAMS into an Excel file. There, each slope class is assigned an identification number that represents the land use activity assigned to that slope class. For example, an ID of 1 indicates that all land in that slope class is in a corn-soybean rotation, an ID of 2 indicates that land in that slope class is a combination of corn-soybean acreage and acres in the six-year alfalfa rotation, and so on. The Excel file, which contains a unique identifier for land cover for each slope class, is converted to a Database file (.dbf) and imported into ArcMAP. The Database file is then joined to the base map (by slope grade), and the map display is manipulated such that each land use activity is distinguished by a unique color. A lighter shade of yellow represents land in a corn-soybean rotation. Areas in darker orange are in the six-year alfalfa rotation, with gradations between the two representing a mix of the activities within one slope class. Shades of mauve and brown are used to visually display land in the six-year grass-legume rotation and continuous pasture. Land in the Conservation Reserve Program is shown in dark green.

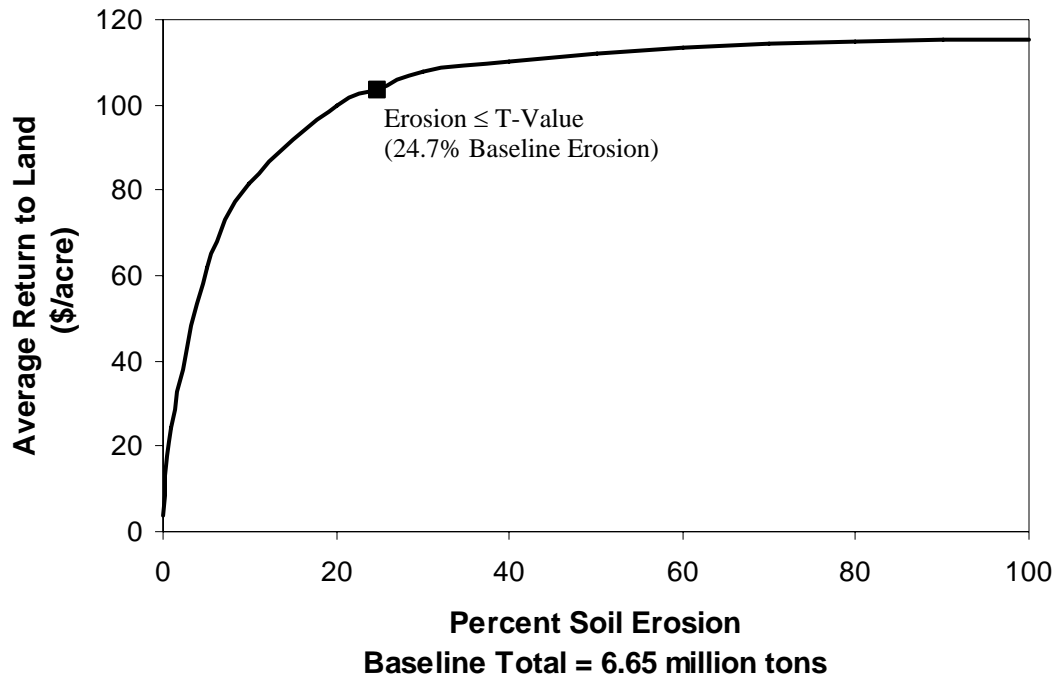
The series of maps illustrate what has already been described. In the baseline model solution, the six-year alfalfa rotation, represented by a darker orange, is placed along with the corn-soybean rotation on land with a zero degree grade. It is apparent

from the map that that land is located adjacent to waterways. The corn-soybean rotation occupies all land between one and 17 degrees of slope, after which ecoreserve acres are assigned. When excess nitrogen applications are unconstrained, shown in Figure 6.2, nearly all of the land up to 17 degrees is allocated to the intensive corn-soybean rotation. The map illustrates the increased homogeneity of the land use allocation. Figure 6.3, the map of the constrained soil erosion scenario is the most visually striking. Aside from the lowest grades that surround waterways, nearly all land is allocated to the longer-term rotations. This is also the most diverse land use pattern, with land in both six-year rotations and continuous pasture. It is clear that limiting soil erosion has dramatic implications for the pattern of land use in Crawford and Shelby counties.

The total amount of soil erosion produced in the baseline is 6.65 million tons per year. When limited to the tolerance value, the total level of soil erosion is 1.64 million tons per year. The difference in the average return to land between the two cases is \$11.87 per acre. Figure 6.4 illustrates the tradeoff between reduced soil erosion and the average return to land. It is apparent that the cost of soil erosion reductions increases at an increasing rate. Moreover, the threshold value of soil erosion is attained before the cost curve enters the range over which the average return to land declines most steeply in response to further soil erosion reductions.

The shadow price of the soil erosion constraint when erosion is limited to the threshold value differs by land use activity and by grade. For example, increasing the soil erosion constraint by one ton per acre for land in the corn-soybean rotation on a grade of six percent increases the average return to land more than increasing the soil erosion constraint for the six-year alfalfa rotation on a grade of 15 percent (\$113.03

Figure 6.4. Average Return to Land Associated with a Reduction in Total Soil Erosion, Relative to the Baseline



versus \$74.62 across all acres).⁶¹ For each land use activity, the shadow price of soil erosion above the threshold is decreasing as the grade increases, reflecting the decline in the profitability of each land use activity defined by the yield loss function.

6.2. Incentive-Based Policies to Reduce Soil Erosion

In the previous section, a command-and-control soil erosion policy instrument was specified using an ecological criterion. By limiting the land area that each management practice may occupy, the standard achieves the desired soil erosion reduction at a cost of \$11.87 per acre in the average return to land. Economic theory predicts that this same soil erosion standard can be achieved at lower cost with an incentive-based policy instrument. The foundation for this argument lies in the

⁶¹ These are the grades on which the soil erosion constraint becomes binding.

heterogeneity in soil erosion abatement costs between producers. While a standard mandates an identical level of soil erosion reduction for each producer, an incentive-based instrument specifies a total amount of soil erosion reduction for all producers. The latter allows those producers with relatively lower abatement costs to reduce soil erosion by a greater amount than high abatement cost producers, reducing the total cost of attaining the standard.

This chapter analyzes the impact of two incentive-based policy mechanisms to reduce soil erosion. The first instrument discussed is a per-unit tax on excess soil erosion. The second policy alternative is a green payment for crop rotations that provide greater soil erosion reduction benefits than the predominant corn-soybean rotation. The taxation and subsidy schemes differ in that the former punishes the use of more intensive production practices, while the latter rewards the expansion of more diversified land use activities. They are, respectively, a “stick” and a “carrot” approach to regulating soil erosion. The relative advantages and disadvantages of these two policy mechanisms, as well as a comparison to the regulatory standard, are discussed throughout.

6.2.1. A Per-Unit Tax on Excess Soil Erosion

According to Baumol and Oates, a tax to attain a given standard is justified “where there is reason to believe that the existing situation imposes a high level of social costs *and* that these costs can be significantly reduced by feasible decreases in the levels of certain externality-generating activities” (1988, p. 174). It is widely recognized that soil erosion imposes a social cost in the form of water degradation, both through sedimentation and nutrient runoff (Iowa DNR, 2004b). Decreasing erosion is particularly beneficial in terms of improving local water quality, and may contribute to improvements

on a larger geographic scale (Wu et al., 2004). Thus, a tax may be a viable and justified instrument to encourage the provision of environmental benefits by producers within the study area.

Under certain conditions, a tax instrument may also be a least-cost means of attaining a given environmental standard. However, the conditions necessary for that result to hold are often violated. For example, a per-unit tax on soil erosion must differ across producers to reflect heterogeneity in their marginal contribution to environmental damages. Within the context of the model, that would necessitate a separate tax by slope class and land use activity. Further, the tax rate must reflect the impact of erosion on social welfare, which may differ from the observed amount of soil erosion production. These conditions, among others, make it difficult to practically implement a least-cost tax mechanism.

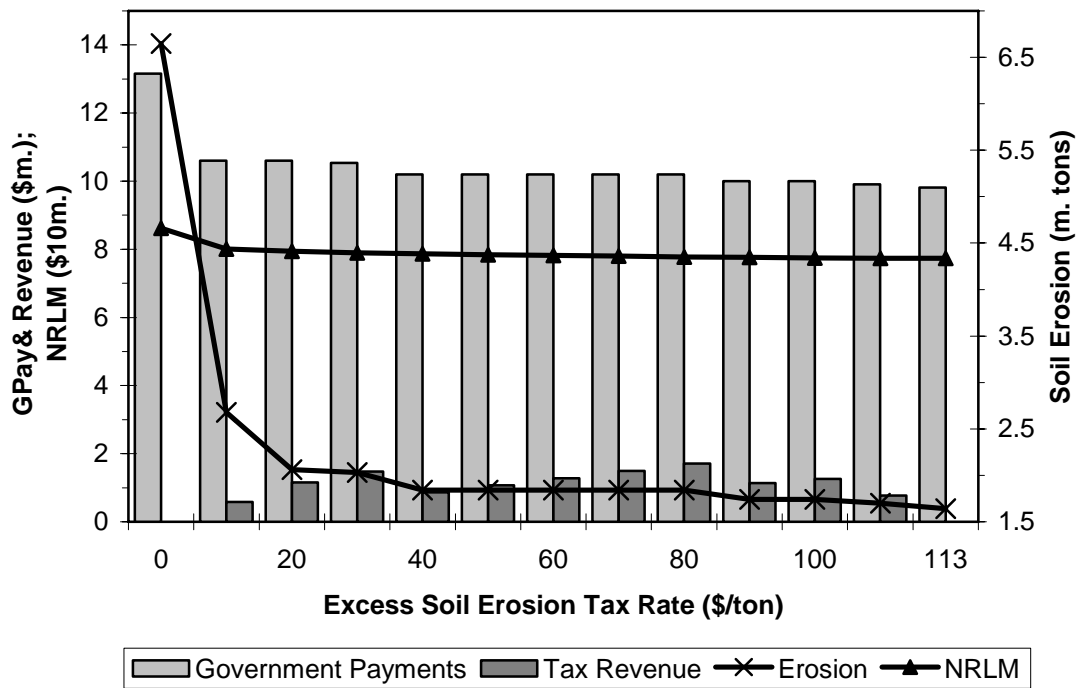
While a per-unit tax on excess soil erosion may not be able to attain the soil erosion standard at least-cost, it may still be a more efficient policy option than a command-and-control standard. The hypothetical tax instrument considered here is a homogeneous per-ton tax on soil erosion above the threshold value. It achieves neither efficiency nor optimality in the economic sense, but is an administratively viable mechanism for reducing soil erosion production. Holding all else constant, a tax rate of \$113.00 per ton of excess soil erosion results in a land use pattern that attains the target level of soil erosion reduction. This land and livestock allocation is identical to that reported in Table 6.2 when the soil erosion standard is enforced.

While the end results of the two policies are identical, the means by which the standard and the tax instrument attain that end differ. The standard prohibits the

assignment of land use activities on grades on which they produce excess soil erosion but it does not affect the relative profitability of land use activities. In contrast, the tax mechanism reduces the relative return to land use activities that produce excess soil erosion, which in turn drives a change in the land use allocation. As the tax rate is increased from zero to \$113.00 per ton, the land use allocation shifts such that the intensive corn-soybean rotation is progressively removed from the highest grades (those on which it produces the most excess erosion). The land allocation ceases to shift when there is no excess soil erosion produced and no tax assessed. As the two-year rotation becomes less profitable on higher grades, the six-year rotations, which produce less soil erosion, become relatively more profitable land use activities and are allocated to those grades. Pasture, the least remunerative land use activity in the baseline, becomes profitable on the highest grades because it never produces erosion in excess of the threshold level.

Figure 6.5 graphs the net return to land and management (NRLM), total government payments (excluding CRP payments because they are constant), tax revenues, and total soil erosion against the excess soil erosion tax rate. The line that charts the relationship between the tax rate and erosion can be thought of as the tax effectiveness curve. This curve illustrates that the greatest reduction in soil erosion from the baseline is attained with a tax of \$10 per ton of excess erosion. This is also the tax rate that generates the largest reduction in government payments and the greatest loss in the NRLM, relative to the baseline. These changes are caused by a shift from the corn-soybean rotation into the six-year alfalfa rotation, which is less heavily weighted towards

Figure 6.5. Soil Erosion, Net Return to Land and Management, Government Payments, and Tax Revenue for Various Excess Soil Erosion Tax Rates



Federal Farm Program crops. Past this point, increasing the tax rate leads to modest and decreasing reductions in soil erosion, the net return to land, and subsidy payments. Total tax revenue varies over the range of tax rates and is closely related to the land use allocation. In the baseline case, when the tax rate is zero, and at a tax of \$113 per ton, when excess erosion is equal to zero, no tax revenue is collected. For intermediate tax rates, when the land use allocation shifts such that there is a large reduction in soil erosion, total tax revenue declines. However, an increase in the tax rate that does not alter the land use allocation generates an increase in total tax revenue. This is most clearly seen for taxes ranging from \$40 to \$80 per ton of excess erosion. A tax rate could be specified to achieve a different objective than the target soil erosion reduction, i.e. to maximize tax revenues.

The land use allocation with the \$113/ton excess soil erosion tax and that with the standard are identical, as is the cost to producers (an \$11.87 per acre decrease in the average return to land). In the context of the model, the taxation instrument is no more cost-efficient in reducing soil erosion to the threshold level because producers have only one means of reducing soil erosion, a change in the land use allocation. To reduce erosion to the threshold level, land use activities must be removed from those grades on which they produce excess erosion, the cost of which is equal across producers within a grade. However, the tax and the standard differ in that the former generates revenue when excess soil erosion is produced. In practice, tax revenues can be used to offset administrative costs, which may imply that a tax is preferable to a regulatory standard. In addition, because producers have alternative methods of reducing soil erosion, aside from a land use change, an incentive-based instrument will likely be more efficient than a standard in attaining an environmental objective. Examples of other remediation activities may include some combination of land retirement activities and conservation practices for working land.

6.2.2. Green Payments for Reduced Soil Erosion

In the previous scenario analysis, the structure of government payments is held constant. The consequence of the land use change mandated by the ecological standard is a decline in the average return to land of over ten percent relative to the baseline. If the distribution of government payments were shifted towards non-program crops, it may be possible to reduce the total cost of imposing the soil erosion standard. This scenario analysis investigates the change in the land use allocation and soil erosion that can be effected by shifting government payments away from the intensive corn-soybean rotation

and into the longer-term rotations and continuous pasture. The green payment instrument examined in this section is similar in essence to the Conservation Security Program (CSP). It is formulated as a payment for changing management practices on working lands. The results of this analysis are therefore particularly relevant in terms of present policy issues.

The baseline total government payment per-acre for each land use activity is reported in Table 6.3. Under current conditions, support payments favor the intensive corn-soybean rotation by slightly less than eight dollars per acre. To begin the scenario analysis, fixed direct and counter-cyclical payments are eliminated. The model allocation with no payments is that discussed in the sensitivity analysis of chapter 5, and is reported again in the first row of Table 6.4. A per-acre payment, henceforth referred to as a Conservation Security Program (CSP) payment, is then applied to the two six-year rotations and pasture, and incrementally increased. Throughout, ecoreserve acres are assumed to receive their current level of CRP payments. The land and livestock allocations for various payment levels are reported in Table 6.4.

The land use allocation does not change until a payment rate of \$30 per acre is applied to the six-year alfalfa, six-year grass-legume, and continuous pasture management practices. At that point, the land allocation shifts out of the corn-soybean rotation and into the six-year alfalfa rotation and continuous pasture. Optimal livestock production consists of a mixture of confinement swine, finishing cattle in feedlots, and cow-calf units finished on pasture. The trend towards the six-year alfalfa rotation and continuous pasture continues with increases in the subsidy rate beyond \$30 per acre. Each increase in the CSP payment rate shifts land out of the corn-soybean rotation on

Table 6.3. Current Per-Acre Government Payment Rate, by Land Use Activity*

Payment Instrument	Land Use Activity			
	Corn-Soybean	Six-Year Alfalfa	Six-Year Grass-Legume	Continuous Pasture
Direct	13.475	7.555	7.426	-
Counter-Cyclical	5.034	3.353	3.353	-
Loan Deficiency	-	-	-	-
Total	18.509	10.908	10.779	0.00

*Assumes average county yield per acre for 1994-2003 (Iowa NASS), and that 47.6 percent of acreage in each land use activity is eligible to receive payments (56% of total land in farms is claimed as base acreage, and 85% of that is the total payment acreage).

higher grades, placing the six-year alfalfa rotation on intermediate slopes and pasture on the most highly sloped terrain.

The land use allocation across CSP scenarios differs markedly from that under either the standard or tax. Specifically, the land and livestock allocation with green payments is more heavily weighted towards pasture-based activities. Eliminating payments for the corn-soybean rotation and administering a green payment for the long-term rotations reduces the relative return to corn production and increases the return to forage and pasture production. The green payment program therefore reduces the relative return to livestock that rely on a larger grain ration. As a result, the livestock allocation shifts towards cow-calf units finished on pasture, which require less corn and more forage and pasture than other animals. Figures 6.6 and 6.7 illustrate the land use allocation for two CSP payment rates. These maps visually reinforce the expansion of pasture acreage (in shades of brown) incentivized by the green subsidy.

Table 6.4. Model Solution with a Per-Acre Payment for the Six-Year Rotations and Continuous Pasture

CSP Payment (\$/acre)	Land Use Activities (acres)				Livestock Activities (head marketed)			Total CSP Payments (\$m.)	Total Erosion (m. tons)	ARL (\$/acre)
	Corn-Soybean	Six-Year Alfalfa	Six-Year Grass	Continuous Pasture	Farrow-Finish Swine (C)* (m.)	Finishing Cattle (C)*	Cow-Calf Units (P)*			
0.00	687,645	34,256			3.35	89,290		0.00	5.75	97.90
10.00	687,645	34,256			3.35	89,290		0.34	5.75	98.36
20.00	687,645	34,256			3.35	89,290		0.69	5.75	98.82
30.00	641,328	57,448		23,191	3.01	124,917	9,276	2.42	4.71	99.37
35.00	528,974	112,354		80,801	2.17	211,091	32,321	6.76	2.95	100.27
39.00	386,995	179,785		155,561	1.09	319,645	62,224	13.08	1.60	101.71
40.00	302,837	218,881		200,752		383,844	80,301	16.79	1.09	102.17
45.00	246,014	244,849		231,695		427,120	92,678	21.45	0.85	105.21
50.00	246,014	244,849		231,695		427,120	92,678	23.82	0.85	108.41
61.00	246,014	244,849		231,695		427,120	92,678	29.07	0.85	115.44

*(C) and (P) indicate confinement and pasture-based production systems, respectively.

Figure 6.6. Land Use Allocation with Conservation Security Program Payment of \$39 per Acre

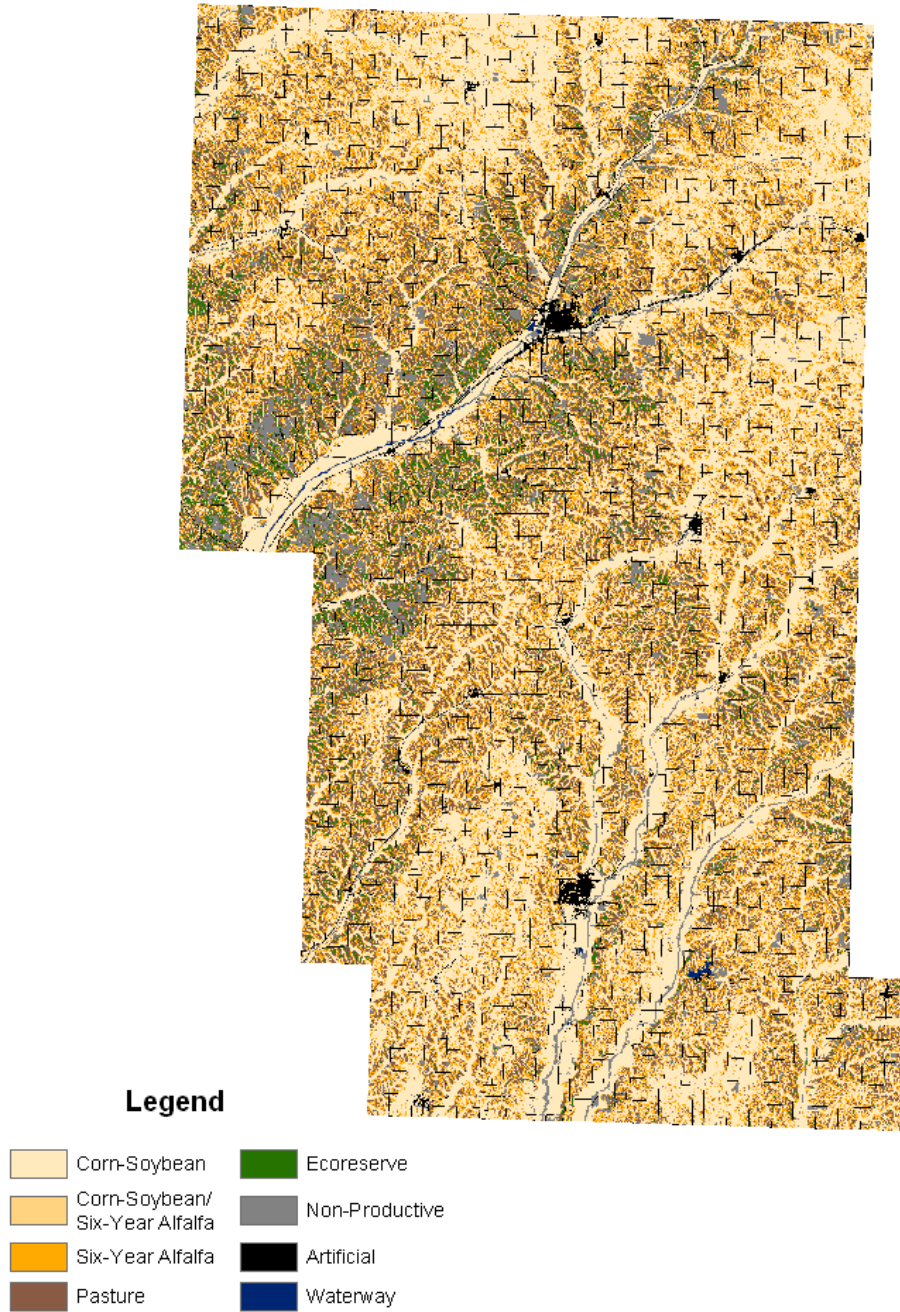


Figure 6.7. Land Use Allocation with Conservation Security Program Payment of \$61 per Acre

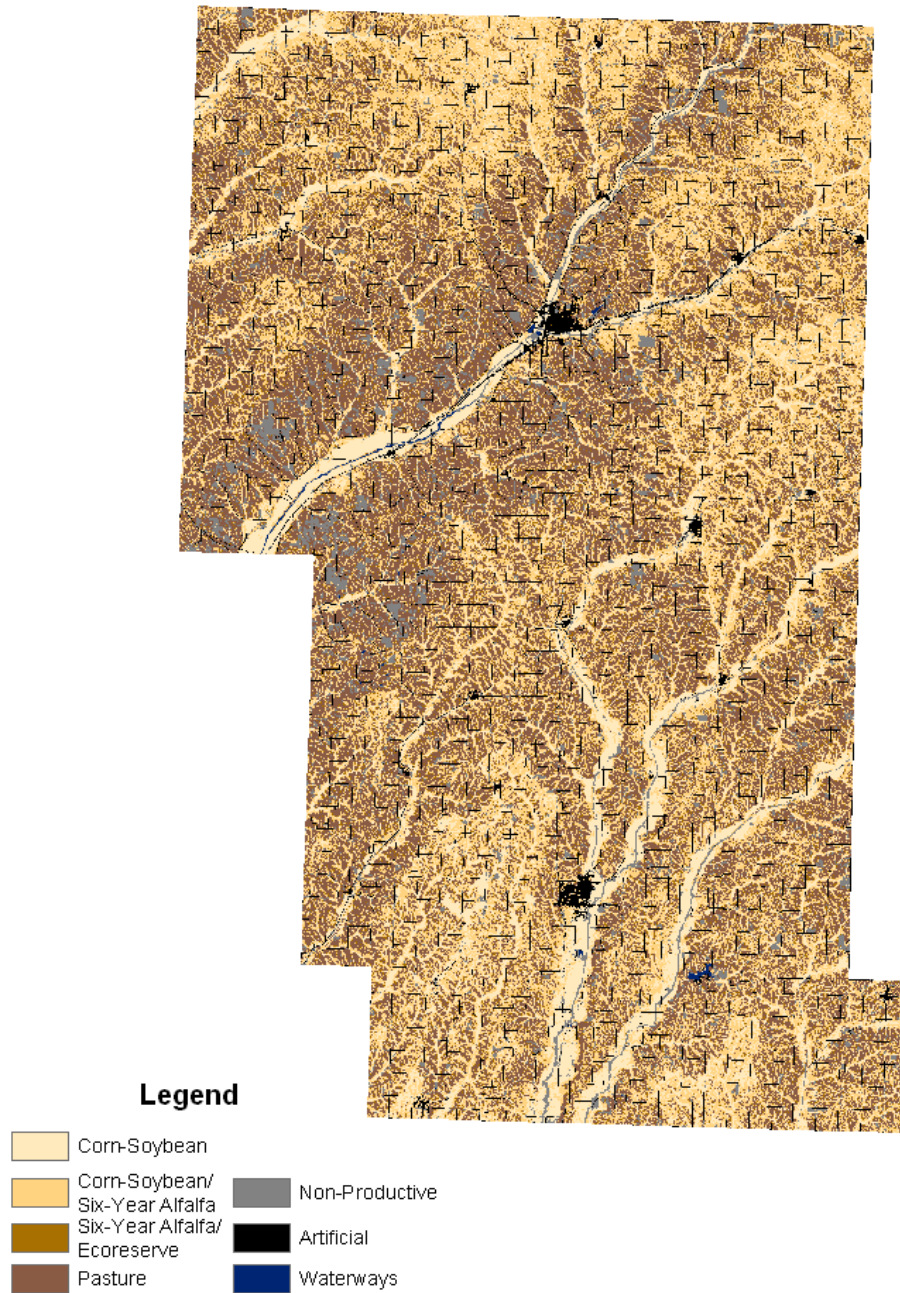


Figure 6.6 shows the land allocation with a CSP payment rate of \$39 per acre. In this scenario, the model allocation is such that total CSP payments, \$13.08 million, are nearly identical to the baseline level of government payments, \$13.16 million.⁶² At this payment level, total soil erosion production is slightly less than the level produced under the regulatory standard. This scenario analysis can be thought of as approaching the problem from a Marshallian perspective, as in Callaway and McCarl (1996). Holding total government expenditures constant, the cost to producers of providing soil erosion reduction is a decline in the average return to land of \$13.82, approximately \$2 per acre greater than the loss associated with the regulatory standard or tax. This scenario suggests that solely shifting the current level of payments cannot attain the total soil erosion standard at less cost to producers.

While the CSP payment above limits total soil erosion to the level of the standard, it is important to note that erosion above the per-acre threshold is still produced on some land in the study area. The land allocation is such that the corn-soybean rotation is placed on grades of zero to seven degrees. Above five degrees, a corn-soybean rotation generates greater than five tons of erosion per acre. However, pasture is allocated to grades of eleven to sixteen percent. On those grades, pasture produces less than the threshold level of erosion per acre. Therefore, the total erosion standard is attained despite the production of some excess erosion. This is in contrast to the tax and regulatory standard, under which no per-acre excess erosion production is permitted within the study area.

⁶² Excluding Conservation Reserve Program payments of \$2.68 million.

The subsidy transfer analysis can also be conducted from a Hicksian perspective, i.e. determining the payment rate that maintains current producer welfare, while allowing the level of total government payments to vary. CSP payment rates between \$45 and \$61 per acre do not alter the land use allocation, but simply increase the average return to land. Administering a subsidy payment of \$61 per acre for the six-year rotations and continuous pasture nearly attains the baseline average return to land (\$115.44 per acre). The land allocation under this scenario is described in Table 6.4 and is illustrated in Figure 6.7.

To maintain the baseline return to producers, total government payments must be more than doubled relative to their current level. However, note that in this scenario total soil erosion production is reduced to half of the target level. This scenario therefore likely generates an increase in social welfare from increased environmental benefits. Without assessing both the social and private implications of land use change, the net impact of the government payment instrument cannot be determined, and a cost-benefit analysis cannot be conducted. Overall, this analysis demonstrates that a green payment to reward conserving practices on working lands cannot attain environmental improvements with less private cost to producers.

CHAPTER 7

CONCLUSIONS

The objective of this thesis is to analyze the role of public policy in influencing the provision of environmental benefits on agricultural working land. Specifically of interest is the tradeoff between producer welfare, which currently depends on levels of commodity production, and social welfare, which is influenced by levels of environmental externalities produced. As previously discussed, jointness in the production of commodity and environmental outputs has ramifications for the form of public policy that can affect this tradeoff. If commodity and environmental services are linked in production, through either technical processes or shared inputs, a single instrument may more efficiently support both economic and environmental objectives than separate policy mechanisms. This theoretical hypothesis provides the motivation behind this analysis. Based on the results of Chapters 5 and 6, this section discusses the conclusions that can be drawn about the ability of green policies to support producer welfare while encouraging a reduction in environmental damages.

7.1. Policy Implications

To examine the tradeoff between producer welfare and the provision of environmental benefits, a spatially heterogeneous land use allocation model is formulated as a mathematical programming problem. The model differs from those used in the existing literature in several formidable ways. First, both crop and livestock production activities are explicitly modeled as either separable or nonseparable. The advantage to

doing so is that it gives the model the flexibility to choose the optimal degree of integration between the two. Another methodological advantage of the model is that it is closely coupled, i.e. it includes a shared set of exogenous and endogenous variables that determine both economic and environmental outcomes. Closely coupling the interdisciplinary elements is expected to improve the predictive ability of the model relative to analyses that maintain a separation between economic and ecological elements. Finally, the study area chosen is an intermediate scale relative to previous analyses, and therefore contributes a new perspective to the literature.

At the outset of this analysis, three policy objectives were specified. The first was to identify the economic factors that influence production practices in the study area. The sensitivity analyses presented in Chapter 5 address this objective. The results suggest that the land use allocation in the study area is insensitive to changes in commodity prices. This is evident in the large commodity changes necessary to influence land use patterns, and echoes the conclusions of several previous analyses (Abler, 2004; Wu et al., 2004). The primary policy implication is that it may be more efficient to encourage the provision of environmental benefits with policies that target productive inputs rather than commodity outputs.

The second objective was to evaluate the tradeoffs between commodity production and reduced production of environmental externalities. The command-and-control policy scenarios illustrate the tradeoff between producer welfare and attaining an environmental standard, holding subsidy payments constant. Prohibiting excess nitrogen applications and excess soil erosion production decreases the average return to land by one and ten percent, respectively. These estimates can be interpreted as the value of

excess soil erosion and nitrogen applications as commodity inputs. In either case, for reductions between the baseline and the standard, the marginal costs of abatement increase at an increasing rate. Therefore, initial reductions can be obtained at lower cost to producers than further reductions. The analysis also demonstrates that limiting nutrient contamination and reducing soil erosion are not complementary environmental objectives. Therefore, jointness between multifunctional outputs is not uniform and separate policy instruments may be necessary to ensure the provision of different environmental benefits.

The final objective was to examine the relative efficiency of various public policy instruments in attaining economic and environmental objectives. Because the model does not incorporate heterogeneity in abatement technologies, a standard to reduce soil erosion is no more efficient than a tax to attain the same standard. In reality, the availability of alternative erosion reduction technologies, such as no-till corn and soybean production or the use of CRP practices, implies that a tax can likely attain the erosion standard at lower cost to producers than the results suggest. Moreover, a tax instrument generates government revenues that may be used to offset the administrative costs of the policy. For these reasons, a tax may be preferred to a standard in practice. The last policy scenario of Chapter 6 examines the use of green payments to encourage less erosive management practices. Holding total government payments constant, a program of green payments cannot attain erosion reductions at less cost to producers than either a tax or the standard. Within the context of this analysis, it is not possible to attain the given environmental standard and simultaneously maintain producer welfare at its current level: there is no win-win situation.

7.2. Weaknesses of the Current Study and Directions for Future Research

The primary weaknesses of the current study are its assumption of commodity price exogeneity and the lack of a capital constraint in livestock production. Although the study area is relatively small, the market likely could not absorb the increased production of livestock in many of the model simulations without endogenous price effects. Maintaining these two assumptions causes the model to overstate the response of the system to changes in the relative return to livestock products. Consequently, the model may overstate the average return to land under various scenarios and underestimate the tradeoff between economic and environmental objectives. Incorporating price response functions and a livestock capital constraint into the programming model would improve its predictive ability. In addition, accounting for price endogeneity would increase the model's usefulness as a policy analysis tool. The model could be expanded to consider the impact of policies administered on a state, regional, or watershed scale.

It would also be useful to incorporate more production options into the model. Limiting the set of available crop production activities may tend to overstate the inelasticity of land use activities with respect to commodity policies. In addition, limiting the means available to producers to abate environmental damages also understates the efficiency of incentive-based policy instruments relative to regulatory standards. Other means of reducing soil erosion may include combining CRP practices with practices for working lands (i.e. incorporating grass filter strips on harvested cropland). Thus, introducing a broader set of land use production technologies and conservation practices may alter the outcome of the green policy simulation.

There are numerous multifunctional outputs associated with commodity production that are not considered within the context of this model. Targeting soil erosion reductions may have unintended consequences not only for other environmental indicators, but also for multifunctional outputs of the public goods type. The results highlight the importance of prioritizing the objectives of agricultural policy:

...there may be impacts on agricultural functions outside of those addressed by the policy objectives that conflict with social preferences. For example, regulatory requirements designed to reduce soil erosion and water pollution may inadvertently make the preservation of family farms more difficult by increasing production costs. Ideally, the objectives emphasized by 'multifunctional' policies should reflect social preferences across all functions of agriculture. (Goodhue, Gruere, and Klonsky, 2002)

This analysis examines only two environmental indicators because they were those for which data was most readily available and because they are the most pertinent policy concerns in the study area at present. The model could be expanded in the future to consider the impacts of policies on other multifunctional outputs. However, doing so may be limited because of the difficulties associated with identifying and measuring non-market products.

Finally, this study considers neither the transaction costs nor the distributional impacts of the hypothetical policy instruments analyzed. Transaction costs may be particularly important in determining the relative efficiency of using one or many policy instruments to address multiple objectives (Abler, 2004). Absent transaction costs, it may be more efficient to use separate mechanisms to attain different goals. However, in practice, using a single program may reduce administrative costs. Moreover, transaction costs may influence the type of program chosen. Although a commodity-based policy may not be most effective in attaining environmental objectives, it may be preferable if

the cost of administering an agri-environmental program is relatively high (*Ibid.*). Subsidy targeting may also play an important role in determining overall transaction costs. If environmental improvements are targeted via commodity policy, transactions costs apply to all producers, regardless of the level of environmental benefits provided by each. On the other hand, targeting programs to reflect producer heterogeneity may increase the administrative costs of the program.

Distributional impacts are also important to the political and social palatability of implementing an alternative policy instrument. If payments are administered on the basis of environmental benefits provided, the geographic distribution of payments will likely not correspond to the current pattern of commodity program payments. For example, the green payment program examined in this analysis would transfer income from farmers producing a corn-soybean rotation on lower grades to those producing longer-term rotations on higher grades. The overall impact on the income distribution would depend on farm location. On a national scale, shifting to a system of green payments would imply an income transfer from the most intensive commodity production regions, such as the Midwest, to areas of the country that are more environmental sensitive, i.e. the Mid-Atlantic (Batie, 1999). While the equity implications are not explicitly considered in this analysis, they are important to consider in any evaluation because of the political implications.

In the future, the model could be constructed to reflect the dynamics of transforming land use patterns in the study area. The model here is static, and therefore solves for the long-run equilibrium given that the set of exogenous conditions, including commodity prices, remain constant. By using a static framework, important aspects of

the land use transition cannot be examined. For example, there may be capital rigidities that create lags in the adjustment of the land use allocation. Moreover, there are a host of unconsidered factors that may influence the land use transition, such as the development of social capital under a new system of production. This analysis examines land use change from a purely economic perspective, and therefore addresses only one small portion of a larger, interdisciplinary problem.

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APPENDIX

MATHEMATICAL PROGRAMMING CODE

The code for the mathematical programming model is included in full so that the analysis can be replicated. Explanatory text is included in italics.

Option solprint = off;
Option limrow = 0;
Option limcol = 0;

SETS

Sets

y landuse activities /2yr, 6yr_a, 6yr_g, pasture, ecoreserve, livestock/
**6yr_a: alfalfa rotation; 6yr_g: grass/legume rotation.*

c crops /corn, soybean, oat, alfalfa, hay, grasslg, cgrasslg/
**Cgrasslg is continuous grass-legume pasture. Grasslg denotes grass-legume
pasture in rotation.

feed(c) feed inputs and outputs /corn, alfalfa, hay, grasslg, cgrasslg/

ration livestock feed ration /grain, forage, graze/

feedration(ration,feed) livestock feed-ration mapping

/grain. (corn)
forage. (alfalfa,hay)
graze. (grasslg,cgrasslg)/

lvstock livestock activities /hogs, bfcattle/

type livestock activity types /domestic, finishing/

production livestock production systems /confine, pasture/

lpp(lvstock,type,production) livestock-type-production mapping

/hogs. (domestic). (confine,pasture)
hogs. (finishing). (confine)
bfcattle. (domestic). (confine,pasture)
bfcattle. (finishing). (confine,pasture)/

io inputs and outputs in crop and livestock production /land, labor, N, P, K, piglet, calf,
othervar, ownership, erosion/

**Pasture as an input into livestock production is grazed only.*

env(io) environmental inputs /erosion/

fert(io) fertilizer inputs and outputs /N, P, K/

other(io) other inputs and outputs /land, labor, piglet, calf, othervar, ownership/

grade slope gradient /0*49/

cropgrade(grade) crop grades - for C&C erosion constraint /0*16/

PRICE PARAMETERS

Parameters

cprice(c) base crop producer prices (\$ per unit) /corn 2.16, soybean 5.79, oat 1.58, alfalfa 87.63, hay 84.75, grasslg 0, cgrasslg 0/

**Alfalfa, hay in tons; grasslg, cgrasslg in acres; all else in bushels.*

**Median prices from USDA NASS Agricultural Statistics Database, 1994-2003, for IA.*

pinputs(io) base input prices (\$ per unit) /labor 9.5, othervar 1, piglet 41, calf 431, ownership 1, land 0, erosion 0/

**Labor in hrs; othervar, piglet, calf, ownership in \$. Median calf price*

**from IA NASS, 1994-2003; assumes 500lb feeder. Piglet price from IAState*

**Livestock Enterprise Budgets, 2004.*

pmanure(fert) price of nutrients in livestock waste-reflective of disposal cost /N 0, P 0, K 0/

pimnutr(fert) price of purchased nutrient inputs (\$ per lb)

/N .25, P .28, K .15/

**Fertilizer prices from IAState Livestock Enterprise Budgets, 2004.*

plocalfeed(feed) incremental price of feed grown within county above COP /corn 0, alfalfa 0, hay 0, grasslg 0, cgrasslg 0/

Scalar

feedpremium premium on purchased feed above crop producer price /1.10/;

**Assume 10% above producer price for transportation/storage costs.*

Parameter

pimfeed(feed) price of purchased feed inputs (\$ per lb-ton or acre);

pimfeed(feed) = cprice(feed)*feedpremium;

pimfeed('grasslg') = 52;

pimfeed('cgrasslg') = 52;

Table lprice(lvstock,production) base livestock producer prices (\$ per lb.)

	confine	pasture
hogs	.4110	.4110
bfcattle	.6405	.6405 ;

**Livestock median prices from Iowa NASS, 1994-2003.*

Parameter

grasspremium(lvstock) price premium for grass-fed livestock /hogs 1.0, bfcattle 1.0/
lprice(lvstock,'pasture') = lprice(lvstock,'pasture')*grasspremium(lvstock);

CROP PRODUCTION PARAMETERS

Table rotation(y,c) proportion of each acre of land use activity in each crop

	corn	soybean	oat	alfalfa	hay	grasslg	cgrasslg
2yr	0.5	0.5					
6yr_a	0.333	0.167	0.167	0.5			
6yr_g	0.333	0.167		0.167	0.333		
pasture					1.0		

ecoreserve

livestock

;

**6yr_a consists of a C-S-C-A/O-A-A rotation, where A/O is alfalfa*

**established with an oat leader crop. Alfalfa is used for forage in all*

**three years (harvested, not grazed).*

**6yr_g consists of a C-S-C-H-P-P rotation, where H is hay (harvested grass/*

**legume pasture), and P is grass/legume pasture. Hay is used for forage,*

**pasture acres are used for grazing in the final two years.*

**Pasture acres in rotation differ from continuous pasture because of the*

**length of the production cycle (continuous pasture is grown in a five year*

**cycle). Note that acreage proportions in 6yr_a do not sum to one because oat*

**and alfalfa are double-cropped in alfalfa's establishment year.*

Parameters

rotation6yr(c) proportion of an acre of 6yr_a rotation in each crop

/corn 0.333, soybean 0.167, oat 0.167, alfalfa 0.333/

**This ensures that proportions sum to one in the 6-year rotation, and is used*

**to prevent double counting when assigning the cost of production to this*

**land use activity.*

avgyield(c) county average yields 1994-2002 (units per acre) /corn 132.2, soybean 44.55,
oat 67.62, alfalfa 3.75, hay 3.52, grasslg 1, cgrasslg 1/

**County average yields from Iowa NASS.*

**Yield data compiled from ISPAID soils database, modified by Burkart & James.*

**Yield estimated as a linear function of slope degree, for 0-30 degree slope.*

**Assumes that relationship holds for slopes of greater than 30 degrees.*

baseyield(c) base yield - intercept (units per acre)

/corn 134.58, soybean 45.17, oat 74.03, alfalfa 4.19, hay 3.92, grasslg 1, cgrasslg 1/

yieldloss(c) yield loss coefficient (units per acre per grade)

/corn 1.3861, soybean 0.4645, oat 0.7626, alfalfa 0.0458, hay 0.0370, grasslg 0, cgrasslg 0/

slope(grade) slope of land in each grade

/1 1, 2 2, 3 3, 4 4, 5 5, 6 6, 7 7, 8 8, 9 9, 10 10, 11 11, 12 12, 13 13, 14 14, 15 15, 16 16, 17 17, 18 18, 19 19, 20 20, 21 21, 22 22, 23 23, 24 24, 25 25, 26 26, 27 27, 28 28, 29 29, 30 30, 31 31, 32 32, 33 33, 34 34, 35 35, 36 36, 37 37, 38 38, 39 39, 40 40, 41 41, 42 42, 43 43, 44 44, 45 45, 46 46, 47 47, 48 48, 49 49/

cyield(c,grade) crop yield as a function of slope (units per acre)

yield(y,c,grade) crop yield by land use activity and slope (units per acre);

cyield(c,grade) = baseyield(c)-(yieldloss(c)*slope(grade));

yield(y,c,grade) = rotation(y,c)*cyield(c,grade);

Table nutruse(c,fert) crop nutrient requirements (lbs per unit)

	N	P	K
corn	1.1	0.375	0.3
soybean		0.8	1.5
oat	0.75	0.4	1.0
alfalfa		12.5	40
hay		13.625	61
grasslg		13.625	61
cgrasslg		13.625	61 ;

**Assumes that hay, grasslg, and cgrasslg are 25% alfalfa, 75% orchardgrass.*

**Source: IA DNR Manure Management Plan Form Appendices A5 & A6 (2004). Corn*

**N usage rate is that for Zone 2, which contains Crawford and Shelby counties.*

Parameter

legumeNcredit(y) N credit from legume crops (lbs per acre) /6yr_a 28.333, 6yr_g 9.167/

**Legume credit is 140 lbs per acre for alfalfa, 55 lbs per acre for grass-*

legume mix in preceeding year. Legume credit is 30 lbs per acre for alfalfa

**2 years prior. Therefore, for 6yr_a, the legume credit earned for the first*

**year of corn is (1/6)*per acre N credit for preceeding year's alfalfa +*

**(1/6)*per acre N credit for two-years ago alfalfa. For 6yr_g, the legume*

**credit earned for the first year of corn is (1/6)*per acre N credit for*

**preceeding year's grass-legume mix.*

Scalar soyN N credit from soybeans (lbs per bu) /1/;
**Soy N credit is one pound per bushel soybean production in the previous year.*
**Cannot exceed 50 lbs/acre.*

Parameters

soyNcredit(y,grade) N credit from previous year's soybean crop (lbs per acre)
totalNcredit(y,grade) total N credit for rotation (lbs per acre);
soyNcredit(y,grade) = 50;
soyNcredit(y,grade)\$(yield(y,'soybean',grade)<50) = soyN*yield(y,'soybean',grade);
totalNcredit(y,grade) = soyNcredit(y,grade)+legumeNcredit(y);

Parameters

nutreq(y,c,grade,fert) nutrient requirement (lbs per acre)
nutneed(y,grade,fert) nutrient requirement by land use (lbs per acre);
nutreq(y,c,grade,fert) = yield(y,c,grade)*nutruse(c,fert);
nutreq(y,'corn',grade,'N') = (nutreq(y,'corn',grade,'N')-
totalNcredit(y,grade))\$(nutreq(y,'corn',grade,'N')>totalNcredit(y,grade));
nutneed(y,grade,fert) = SUM(c, nutreq(y,c,grade,fert));

**Erosion data generated by Burkart & James using NRI data points for 17
*counties encompassing the 26 watersheds affected by production in Crawford
*and Shelby counties. Erosion estimated as a quadratic function of slope
*degree, for 0-30 degree slope. Assumes that relationship holds for slopes of
greater than 30 degrees.

Parameters

intc(y) regression intercept /2yr 0.9289, (6yr_a,6yr_g) 0.2713, pasture 0.0507/

slpcoeff(y) slope coefficient /2yr -0.0115, (6yr_a,6yr_g) 0.0507, pasture 0.0042/

slp2coeff(y) slope squared coefficient /2yr 0.1304, (6yr_a,6yr_g) 0.0194, pasture 0.001/

envinput(y,grade,env) erosion (tons per acre per year);
envinput(y,grade,env) = intc(y) + slpcoeff(y)*slope(grade) +
slp2coeff(y)*(slope(grade)**2);

**Tolerance soil loss value defined by Burkart & James.*

Scalar tvalue tolerable soil loss (tons per acre per year) /5.0/;

Parameter

exerosion(y,grade,env) erosion above 5 tons per acre per year;
exerosion(y,grade,env) = (envinput(y,grade,env) -
tvalue)\$(envinput(y,grade,env)>tvalue);
Display exerosion;

Table cinputs(c,other) crop production inputs and costs (per acre)

	labor	othervar	ownership	land
corn	2.6	129.49	39.78	1
soybean	2.45	84.92	27.04	1
oat	4	51.70	40.86	1
alfalfa	1.33	27.65	72.79	1
hay	4.85	46.08	35.15	1
grasslg	1.5	2.55	39.30	1
cgrasslg	1.57	5.38	22.04	1 ;

*Corn, soybean costs of production for conventional till. "Oat" COP is the
 *cost of producing alfalfa with an oat leader, alfalfa is the cost of producing
 *alfalfa once it is established. The establishment costs for alfalfa are
 *prorated over 3 years, with a real interest rate = 4.7%. "Hay" COP is the
 *cost of producing grass/legume pasture for forage in its establishment year,
 *grasslg is the cost of maintaining grass/legume pasture for grazing once it is
 *established. The establishment costs for hay/grasslg are prorated over 3 years.
 *The cost of producing cgrasslg is the cost of renovating/establishing pasture,
 *and the cost of maintaining that pasture for the following four years. The
 *establishment costs for cgrasslg are prorated over 5 years at the same interest
 *rate. The COP for cgrasslg is a weighted average of the COP in the
 *establishment and maintenance years (1/5 in est, 4/5 in maint).
 *Assume alfalfa, hay harvested in large round bales, 2 cuttings/yr, target
 *yield of 4 tons/acre.
 *Labor in hours; land in acres; othervar, ownership in \$.
 *By zeroing out the price of land, the model calculates the net return to
 *land and management (NRLM).

Parameter yinputs(y,other) land use production inputs and costs (per acre);

yinputs(y,other) = SUM(c, rotation(y,c)*cinputs(c,other));

yinputs('6yr_a',other) = SUM(c, rotation6yr(c)*cinputs(c,other));

Parameter

tland(grade) available land in each slope class (acres)

/0=56776, 1=43684, 2=53042, 3=55145, 4=56843, 5=58504, 6=59827,
 7=60827, 8=57208, 9=54471, 10=50050, 11=43289, 12=36466, 13=29105,
 14=22314, 15=16844, 16=12449, 17=8983, 18=6354, 19=4508, 20=3298,
 21=2327, 22=1641, 23=1142, 24=819, 25=575, 26=421, 27=293,
 28=194, 29=144, 30=97, 31=72, 32=55, 33=36, 34=26, 35=18,
 36=12, 37=11, 38=9, 39=5, 40=3, 41=2, 42=2, 43=1, 44=2,
 45=1, 46=1, 47=0, 48=1, 49=0/;

tland(grade) = .9347*tland(grade);

Parameter

totalland total land available for allocation (acres);

totalland = SUM(grade, tland(grade));

Display totalland;

**The above adjustment to the total amount of land available is made to account for land that is not in production, i.e. land on which crops failed or were abandoned, land in house lots, ponds, roads, and wasteland. It is assumed that this land is evenly distributed across the landscape.*

Parameter clu(c) current land allocation (acres)

/corn 332185
soybean 299092
oat 2008
alfalfa 24002
hay 13484
cgrasslg 27115
grasslg 26968/

**From the 2002 Census of Agriculture.*

Parameters

pcland(c) land prices for different crops (\$ per acre)
/(corn,soybean) 140, (alfalfa,oat) 78, (hay,grasslg,cgrasslg) 52/

pland(y) land prices for different land uses;

pland(y) = SUM(c, rotation(y,c)*pcland(c));
pland('6yr_a') = SUM(c, rotation6yr(c)*pcland(c));
pland('ecoreserve') = 52;
pland('livestock') = 140;

LIVESTOCK PRODUCTION PARAMETERS

Parameter lb(lvstock) livestock weight at time of sale (lbs per head)

/hogs 250, bfcattle 1150/

**Beef cattle raised on pasture differentiated from those raised in feedlot by length of production cycle.*

Table feedreq(lvstock,type,production,ration) feed requirements (units per head)

			grain	forage	graze
hogs.	domestic.	confine	11.67		
hogs.	domestic.	pasture	12.13		0.025
hogs.	finishing.	confine	9.6		
bfcattle.	domestic.	confine	64	2.5	2.5
bfcattle.	domestic.	pasture	4	2.118	2.5
bfcattle.	finishing.	confine	61	0.65	
bfcattle.	finishing.	pasture		0.018	2.5 ;

**Corn in bu; alfalfa in tons; pasture in acres.*

Table Ivinputs(lvstock,type,production,io) livestock production inputs (per head)

			labor	land	othervar	ownership
hogs.	domestic.	confine	1.22	.000371	42.98	19.85
hogs.	domestic.	pasture	1.625	.000273	46.21	12.63
hogs.	finishing.	confine	0.5	.000202	31.87	13.04
bfcattle.	domestic.	confine	10	.002016	130.41	152.70
bfcattle.	domestic.	pasture	12.69	.00126	134.81	168.80
bfcattle.	finishing.	confine	3	.00139	79.28	21.00
bfcattle.	finishing.	pasture	0.625	.00063	56.29	21.00

+			piglet	calf
hogs.	domestic.	confine		
hogs.	domestic.	pasture		
hogs.	finishing.	confine	1	
bfcattle.	domestic.	confine		
bfcattle.	domestic.	pasture		
bfcattle.	finishing.	confine		1
bfcattle.	finishing.	pasture		1 ;

*Labor in hrs; land in acres; othervar, pig, calf, ownership in \$.

*Land/housing requirement - pasture finished cattle require 25 sq.ft. barn

*space, cattle finished in feedlot require 55 sq.ft. barn and lot space,

*cow-calf unit requires 25 sq.ft. barn space + space for finishing

*cattle-either pasture or feedlot; hogs finished in confinement require

*8 sq.ft. space, farrowing sows 35 sq.ft., nursery pigs 2.85 sq.ft. Housing

*requirement for pasture-farrowed hogs consists only of nursery pig and

*finishing hog space. Housing for farrowing is included as a pasture req.

*All square footages multiplied by 1.1 to account for non-occupied

*space in and around buildings. Conversion factor: 1acre=43,650sq.ft.

Table Ivmoutputs(lvstock,type,production,fert) livestock manure outputs (lbs per head marketed)

			N	P	K
hogs.	domestic.	confine	12.86	2.39	6.00
hogs.	domestic.	pasture	13.10	2.46	6.15
hogs.	finishing.	confine	10	1.70	4.40
bfcattle.	domestic.	confine	141.66	26.48	98.70
bfcattle.	domestic.	pasture	157.72	28.61	109.79
bfcattle.	finishing.	confine	55.00	7.30	38.00
bfcattle.	finishing.	pasture	71.06	9.43	49.09 ;

*Manure nutrient coefficients taken from ASAE publication D384.1, Manure

*Production and Characteristics, typical as-excreted manure characteristics.

*See manure.xls for details on computation of statistics by head marketed.

Table storage(lvstock,production,fert) proportion manure nutrient content available after storage (lbs)

		N	P	K
hogs.	confine	0.75	1.0	1.0
hogs.	pasture	0.65	1.0	1.0
bfcattle.	confine	0.55	1.0	1.0
bfcattle.	pasture	0.55	1.0	1.0 ;

**Assumes that confinement hog manure is stored in a pit (25% N lost),*

**pasture-farrowed manure nutrient loss is a weighted average of losses when*

**manure is excreted on pasture, for 172 days of total production cycle*

**(45% N lost), and pit storage, for last 161 days of total production cycle*

**(25% N lost). For cow-calf units and finishing cattle, 45% is lost either*

**on pasture or in feedlot. Manure loss coefficients obtained from I-FARM.*

Table apply(lvstock,type,production,fert) proportion manure nutrient content available after spreading (lbs)

			N	P	K
hogs.	(domestic,finishing).	confine	0.98	1.0	1.0
hogs.	(domestic,finishing).	pasture	0.99	1.0	1.0
bfcattle.	domestic.	confine	0.89	1.0	1.0
bfcattle.	domestic.	pasture	1.0	1.0	1.0
bfcattle.	finishing.	confine	0.70	1.0	1.0
bfcattle.	finishing.	pasture	1.0	1.0	1.0 ;

**Assumes that hog manure is spread using liquid injection (2% N lost), pasture-*

**farrowed manure nutrient loss is a weighted average of losses when manure is*

**excreted on pasture (0% additional losses), and when it is injected. For*

**beef cattle on pasture, no additional N losses. For confinement produced*

**cattle, manure is spread using dry broadcast, which results in a loss of*

**another 30% N. Cow-Calf units finished in confinement is a weighted average*

**of time on pasture (158+70 days) with 0% application losses, and time in*

**feedlot (137 days) with 30% application losses.*

Table clva(lvstock,type,production) livestock marketed in 2002 (head)

		confine
hogs.	domestic	366304
hogs.	finishing	576569
bfcattle.	domestic	21633
bfcattle.	finishing	44865 ;

**From the 2002 Census of Agriculture.*

**Number of farrow-finish and finishing swine derived as follows:*

**Farrow-finish hogs = (# breeding sows)(1.8 litters/yr)(7.8 piglets/litter).*

**Finishing hogs = Total head marketed - Farrow-finish hogs - (0.28)(# breeding sows).*

**The second term accounts for the total number of piglets born within the*

**two counties, including a death rate of 0.2 head per litter, and the third*

**term deducts the sale of cull sows, which is not explicitly considered as a*

**source of revenue in the model.*

**Number of calves from cow-calf units and finishing cattle derived as follows:*

**Cow-Calf Calves = (# breeding cows)(.777 calf/year)*

**Finishing cattle = Total head marketed - Cow-Calf Calves -*

**(0.123)(# breeding cows).*

**The second term accounts for the total number of calves born within the two*

**counties, including a death rate of 4%, unsuccessful insemination rate of 4%,*

**and replacement of cows with heifers every 7 years, with an additional death*

**rate of 2% (or 0.143 head per cow-calf unit). The third term deducts the sale*

**of cull cows (every 7 years), which is not explicitly considered as a source*

**of revenue in the model.*

GOVERNMENT PAYMENT PARAMETERS

Scalars

CRP CRP payment rate (\$ per acre) /119/

enroll CRP enrolled acres (as of 7-03) /22526/

payacre payment acres (proportion) /0.85/

base base acres as proportion of total acres /0.56/;

**Base scalar used to scale down total government payments to more accurately*

**reflect current amount of payments distributed.*

Parameters

dpay(c) direct payment rates for program crops (\$ per bu.)

/corn .28, soybean .44, oat .024/

**2002-2007 direct payment rates, USDA (2003).*

bsyld(c) direct payment base yields (bu per acre per year);

bsyld(c) = avgyield(c);

Parameter

dpayac(y) direct payment rate by land use (\$ per acre);

dpayac(y) = SUM(c, rotation(y,c)*bsyld(c)*dpay(c));

**Assumes that acres in each crop receive their respective payment (corn acres*

**eligible for corn payments, etc.).*

Parameters

target(c) target rate for counter-cyclical payments (\$ per bu)

/corn 2.60, soybean 5.80, oat 1.40/

loanr(c) national loan rate for c-c payments (\$ per bu)

/corn 1.98, soybean 5.00, oat 1.35/

**2002-2003 target and loan rates, USDA (2003). 2004-2007 rates differ slightly.*

efp(c) effective price for c-cps (\$ per bu.);
 efp(c) = dpay(c)+cprice(c);
 efp(c)\$ (loanr(c)>cprice(c)) = dpay(c)+loanr(c);

Parameter

ccpayac(y) counter-cyclical payment rate by land use (\$ per acre);
 ccpayac(y) = SUM(c, rotation(y,c)*bsyld(c)*(target(c)-efp(c))\$(target(c)>efp(c)));

Parameter

ldppayr(c) loan deficiency payment rate (\$ per unit)
 ldpayac(y,c,grade) loan deficiency payment rate (\$ per acre);
 ldppayr(c) = (loanr(c)-cprice(c))\$(loanr(c)>cprice(c));
 ldpayac(y,c,grade) = yield(y,c,grade)*ldppayr(c);
**Maximum amount of ldps that could be collected given that the commodity price
 falls below the national loan rate.

Scalar

erosiontax tax on excess soil erosion (\$ per ton) /0.00/;

Parameter

taxloss(y,grade,env) total tax by land use and grade (\$);
 taxloss(y,grade,env) = erosiontax*exerosion(y,grade,env);

Parameter

csppayac(y) CSP payment (\$ per acre)
 /(6yr_a,6yr_g,pasture) 0.00/;

VARIABLES, BOUNDS, AND EQUATIONS

Positive Variables

yacres(y,grade)	land use activity (acres)
landuse(y)	land allocation
cacres(y,c)	crop acres by land use activity
tcacres(c)	total crop acres
csales(c)	crop sales
cfeeds(c)	crop feed supply (units)
head(lvstock,type,production)	livestock activity (head)
purfeed(feed)	purchased feed inputs (units)
lsnutrs(fert)	livestock nutrient supply (lbs)
purnutr(fert)	purchased nutrient inputs (lbs)
exerode(y,grade,env)	soil erosion in excess of tvalue (tons)
exN	excess nitrogen produced (lbs)
revenue	revenue (\$)
dp(y)	direct payments (\$)

ccp(y)	counter-cyclical payments (\$)
ldp(y)	loan deficiency payments (\$)
conspay	CRP payments (\$)
erodetax	total erosion tax (\$)
csp(y)	CSP payments (\$)
tcfeed	total cost for purchased feed
ncost	nutrient costs
envcost	erosion costs
lcost	total land cost
tcost	variable-labor-ownership costs (\$);

Variable	
profit	producer surplus (\$m) ;

**VARIABLE BOUNDS*

*head.fx(lvstock,type,production)=clva(lvstock,type,production);
 csales.up('alfalfa')=1500;
 csales.fx('hay')=0;
 csales.fx('grasslg')=0;
 csales.fx('cgrasslg')=0;
 cfeeds.fx('soybean')=0;
 cfeeds.fx('oat')=0;
 purfeed.fx('grasslg')=0;
 purfeed.fx('cgrasslg')=0;
 landuse.up('ecoreserve')=enroll;

Equations

**ALLOCATION SUMMARY EQUATIONS*

benchmark(y)	land use acreage allocation
cropacres(y,c)	acres in each crop by land use activity
tcropacres(c)	total acres by crop

**ALLOCATION CONSTRAINTS*

landcon(grade)	land use constraint
housedensity	livestock housing balance
grazedensity	pasture grazing requirement

**LANDUSE-LIVESTOCK BALANCES*

cropusebal(c)	crop demand-supply balances
feedbal(ration)	livestock feed balance
lsnutrsup(fert)	livestock nutrient production identity
nutrientbal	unconstrained nutrient demand-supply balance
excessN	excess nitrogen produced by livestock
Nconstraint	IADNR constraint - excess N equal to zero

**COMMAND & CONTROL LAND USE CONSTRAINT - SOIL EROSION*

excesserosion(y,grade,env)	excess erosion over t-value
erosioncon(y,grade,env)	soil erosion constraint

ecocon constrain ecoreserve acres to highest grades
 *ACCOUNTING EQUATIONS - REVENUE AND GOVERNMENT PAYMENTS
 arev crop revenue accounting
 drpay(y) direct payment accounting
 ccppay(y) counter-cyclical payment accounting
 ldppay(y) loan deficiency payment accounting
 crppay CRP payment accounting
 *INCENTIVE POLICY ACCOUNTING EQUATIONS - EROSION TAX AND CSP
 PAYMENTS
 erosion total erosion tax accounting
 csppay(y) CSP payment accounting
 *ACCOUNTING EQUATIONS - COSTS
 feedcost feed cost accounting
 nutrcost nutrient cost accounting
 envircost erosion cost accounting
 landcost land cost accounting
 totalcost variable-labor-ownership costs
 *OBJECTIVE FUNCTIONS
 surplus producer surplus
 surplusax producer surplus with erosion tax
 surpluscsp producer surplus with CSP payments;

 BENCHMARKING AND LAND USE SUMMARY CONSTRAINT

***Acres by land use*

benchmark(y).. SUM(grade, yacres(y,grade)) =e= landuse(y);

***Acres by land use and by crop*

cropacres(y,c).. SUM(grade, yacres(y,grade)*rotation(y,c)) =e= cacres(y,c);

***Acres by crop (greater than land use acres because of oat/alfalfa double
 **cropping)*

tcropacres(c).. SUM(y, cacres(y,c)) =e= tcacres(c);

 LAND USE AND ROTATION CONSTRAINTS

***Land demanded is less than supply*

landcon(grade).. SUM(y, yacres(y,grade)) =l= tland(grade);

***Livestock housing land allocation constraint*

housedensity.. SUM((lvstock,type,production)\$lpp(lvstock,type,production),
 head(lvstock,type,production)*
 lvinputs(lvstock,type,production,'land')) =l= landuse('livestock');

***Livestock pasture land allocation constraint*
 grazedensity.. SUM((lvstock,type,production)\$lpp(lvstock,type,production),
 head(lvstock,type,production))*
 feedreq(lvstock,type,production,'graze')) =l= landuse('pasture')+tcacres('grasslg');

****LAND USE - LIVESTOCK BALANCES**

***Crop usage balance: crops sold plus crops fed to livestock LE total produced*
 cropusebal(c).. csales(c)+cfeeds(c) =l= SUM((y,grade),
 yacres(y,grade)*yield(y,c,grade));

***Feed usage balance: feed supplied by crop production plus purchased feed GE*
***feed demanded for livestock production*
 feedbal(ration).. SUM(feed\$feedration(ration,feed), cfeeds(feed)+purfeed(feed)) =g=
 SUM((lvstock,type,production),head(lvstock,type,production))*
 feedreq(lvstock,type,production,ration));

***The 3 constraints below are used to evaluate the cost of limiting excess*
***nitrogen applications. The first balance, alone, constitutes the*
***unlimited case: manure applications can exceed crop requirements by whatever*
***amount is optimal. By manipulating the third equation, intermediate cases*
***between the completely constrained and unconstrained cases can be simulated.*

lsnutrsup(fert).. SUM((lvstock,type,production)\$lpp(lvstock,type,production),
 head(lvstock,type,production)*lvoutputs(lvstock,type,production,fert))*
 storage(lvstock,production,fert)*apply(lvstock,type,production,fert)) =e=
 lsnutrs(fert);

***Nutrient usage balance: nutrients needed for crop production GE less than*
***or equal to amount supplied by livestock manure plus total purchased*
 nutrientbal(fert).. SUM((y,grade), yacres(y,grade)*nutrneed(y,grade,fert)) =l=
 purnutr(fert) + lsnutrs(fert);

***Excess nitrogen applications identity*
 excessN.. lsnutrs('N') - SUM((y,grade), yacres(y,grade)*nutrneed(y,grade,'N')) =e= exN;

***Baseline: nitrogen supplied by livestock cannot exceed crop requirements.*
 Nconstraint.. exN =e= 0;

COMMAND & CONTROL SOIL EROSION CONSTRAINTS

***Excess soil erosion identity by land use and grade*

excesserosion(y,grade,env).. yacres(y,grade)*exerosion(y,grade,env) =e=
exerode(y,grade,env);

***Soil erosion constraint: total erosion by land use and grade cannot exceed*

***the tolerance value of 5 tons per acre*

erosioncon(y,grade,env).. exerode(y,grade,env) =e= 0;

***Requires model to assign ecoreserve acres on the highest grades*

ecocon.. SUM(cropgrade, yacres('ecoreserve',cropgrade)) =e= 0;

REVENUE ACCOUNTING IDENTITIES

***Revenue summation*

arev.. SUM(c, csales(c)*cprice(c)) +

SUM((lvstock,type,production)\$lpp(lvstock,type,production),

head(lvstock,type,production)*lb(lvstock)*lprice(lvstock,production)) =e= revenue;

***Government payments calculations*

***Direct payment calculation*

drpay(y).. SUM(grade, base*payacre*yacres(y,grade)*dpayac(y)) =e= dp(y);

***Counter-cyclical payment calculation*

ccppay(y).. SUM(grade, base*payacre*yacres(y,grade)*ccpayac(y)) =e= ccp(y);

***Loan deficiency payment calculation*

ldppay(y).. SUM((c,grade), base*yacres(y,grade)*ldpayac(y,c,grade)) =e= ldp(y);

***Conservation Reserve Program payment calculation*

crppay.. SUM(grade, yacres('ecoreserve',grade)*CRP) =e= conspay;

INCENTIVE-BASED SOIL EROSION REGULATION

***Total erosion tax*

erosion.. SUM((y,grade,env), yacres(y,grade)*taxloss(y,grade,env)) =e= erodetax;

***Government payment function for reductions in soil erosion*

csppay(y).. SUM((grade,env), yacres(y,grade)*csppayac(y)) =e= csp(y);

COST ACCOUNTING IDENTITIES

***Feed cost summation*

feedcost.. SUM(feed, cfeeds(feed)*plocalfeed(feed)+purfeed(feed)*pimfeed(feed)) =e= tfeed;

**Fertilizer cost summation*

nutrcost.. SUM(fert, lsnutrs(fert)*pmanure(fert) + purnutr(fert)*pimnutr(fert)) =e= ncost;

**Erosion cost summation*

envircost.. SUM((y,grade,env)\$ (envinput(y,grade,env)>tvalue),
yacres(y,grade)*envinput(y,grade,env)*pinputs(env)) =e= envcost;

**Explicit cropland cost summation*

landcost.. SUM(y, landuse(y)*pland(y)) =e= lcost;

TOTAL COST SUMMATION

***Crop production costs: other variable, ownership, erosion and nutrient*

totalcost.. SUM((y,grade,other), yacres(y,grade)*yinputs(y,other)*pinputs(other))+
envcost+
ncost+

***Livestock costs: other variable, ownership, land in housing and feed*

SUM((lvstock,type,production,other)\$lpp(lvstock,type,production),
head(lvstock,type,production)*lvinputs(lvstock,type,production,other)*pinputs(other))+
landuse('livestock')*pland('livestock')+
tfeed =e= tcost;

***Producer surplus accounting: objective function*

surplus.. (revenue+SUM(y, dp(y)+ccp(y)+ldp(y))+conspay-tcost)/1000000 =e= profit;

***Producer surplus accounting: erosion tax scenario*

surplustax.. (revenue+SUM(y, dp(y)+ccp(y)+ldp(y))+conspay-erodetax-tcost)/1000000
=e= profit;

***Producer surplus accounting: CSP payments scenario*

surpluscsp.. (revenue+SUM(y, csp(y))+conspay-tcost)/1000000 =e= profit;

****MODEL STATEMENTS**

Model

iowa baseline model - flexible land allocation

**land allocation constraints*

/benchmark,cropacres,tcropacres,landcon,housedensity,grazedensity,cropusebal,

***nutrient and feed balances (crop-livestock interaction)**

feedbal,lsnutrsup,nutrientbal,excessN,Nconstraint,
**revenue and cost summations*
arev,drpay,ccppay,ldppay,crppay,feedcost,nutrcost,envircost,totalcost,
**objective function*
surplus/

currentlv livestock production fixed at current levels
**land allocation constraints*
/benchmark,cropacres,tcropacres,landcon,housedensity,grazedensity,cropusebal,
***nutrient and feed balances (crop-livestock interaction)**
feedbal,lsnutrsup,nutrientbal,
**revenue and cost summations*
arev,drpay,ccppay,ldppay,crppay,feedcost,nutrcost,envircost,totalcost,
**objective function*
surplus/

iowaccs command & control standard for soil erosion
**land allocation constraints*
/benchmark,cropacres,tcropacres,landcon,housedensity,grazedensity,cropusebal,
***nutrient and feed balances (crop-livestock interaction)**
feedbal,lsnutrsup,nutrientbal,excessN,Nconstraint,
***erosion constraint (not to exceed t-value)**
excesserosion,erosioncon,ecocon,
**revenue and cost summations*
arev,drpay,ccppay,ldppay,crppay,feedcost,nutrcost,envircost,totalcost,
**objective function*
surplus/

iowaN unconstrained nitrogen production
**land allocation constraints*
/benchmark,cropacres,tcropacres,landcon,housedensity,grazedensity,cropusebal,
***nutrient and feed balances (crop-livestock interaction)**
feedbal,lsnutrsup,nutrientbal,excessN,
**revenue and cost summations*
arev,drpay,ccppay,ldppay,crppay,feedcost,nutrcost,envircost,totalcost,
**objective function*
surplus/

iowatax tax for excess soil erosion
**land allocation constraints*
/benchmark,cropacres,tcropacres,landcon,housedensity,grazedensity,cropusebal,
***nutrient and feed balances (crop-livestock interaction)**
feedbal,lsnutrsup,nutrientbal,excessN,Nconstraint,
**tax incentive*
erosion,

**revenue and cost summations*
arev,drpay,ccppay,ldppay,crppay,feedcost,nutrcost,envircost,totalcost,
**objective function*
surplustax/

iowaincentive green payments for soil erosion
**land allocation constraints*
/benchmark,cropacres,tcropacres,landcon,housedensity,grazedensity,cropusebal,
***nutrient and feed balances (crop-livestock interaction)**
feedbal,lsnutrsup,nutrientbal,excessN,Nconstraint,
**incentive payments*
csppay,
**revenue and cost summations*
arev,crppay,feedcost,nutrcost,envircost,totalcost,
**objective function*
surpluscsp/ ;

****Model solve statement**
Solve iowa using lp maximize profit;

****Post-optimal parameters**
Parameter
nutrientdemand(fert) nutrients demanded for crop production
totalsoilloss soil loss (tons per year)
laboruse total labor use (hours per year);
nutrientdemand(fert) = SUM((y,grade), yacres.l(y,grade)*nutrneed(y,grade,fert));
totalsoilloss = SUM((y,grade,env), yacres.l(y,grade)*envinput(y,grade,env));
laboruse = SUM(y, landuse.l(y)*yinputs(y,'labor')) + SUM((lvstock,type,production),
head.l(lvstock,type,production)*lvinputs(lvstock,type,production,'labor'));

****Land use/livestock allocations**
Display landuse.l, tcacres.l, head.l;
****Feed supply and demand**
Display csales.l, cfeeds.l, purfeed.l;
****Nutrient supply and demand**
Display nutrientdemand, lsnutrs.l, purnutr.l;
****Soil erosion, labor use**
Display totalsoilloss, laboruse;
****Government payments**
Display conspay.l;
Display dp.l, ccp.l, ldp.l;
****Producer surplus**
Display profit.l;

***Scenario Variables*

**Display exerode.l;*

**Display erodetax.l;*

**Display csp.l;*

***Output files to Excel spreadsheets: 2 files, first is summary of results,*

***second is summary of land use allocation by slope class, used to create*

***maps of land use allocation using ArcGIS software.*

File IOUT /RESULTS.XLS/

Put IOUT;

IOUT.PC=5;

***Create column names*

Put 'LANDUSE' 'ACRES' Put/;

***Output values*

Loop(y, Put y.tl, landuse.l(y):6:0 Put/);

Put #9

Put 'CROP' 'ACRES' 'SALES' 'FEEDS' Put/;

Loop(c, Put c.tl, tcacres.l(c):8:0, csales.l(c):8:0, cfeeds.l(c):8:0 Put/);

Put #18

Put 'FEEDCROP' 'PURFEED' Put/;

Loop(feed, Put feed.tl, purfeed.l(feed):8:0 Put/);

Put #25

Put 'LIVESTOCK' 'TYPE' 'SYSTEM' 'ANIMALS' Put/;

Loop((lvstock,type,production), Put lvstock.tl, type.tl, production.tl,
head.l(lvstock,type,production):7:0 Put/);

Put #35

Put 'FERTILIZER' 'PURFERT' Put/;

Loop(fert, Put fert.tl, purnutr.l(fert):8:0 Put/);

Put #40

Put 'LANDUSE' 'DIRECT' 'COUNTERCYCLICAL' 'LOANDEF' Put/;

Loop(y, Put y.tl, dp.l(y):8:0, ccp.l(y):8:0, ldp.l(y):8:0 Put/);

Put #48

Put 'CONSPAY' 'EROSION' 'TAX' 'LABOR' 'NRLM' Put/;

Put conspay.l:8:0, totalsoilloss:8:0, erosiontax:5:0, laboruse:8:0, profit.l:6:3 Put/;

File ISLPOUT /SLPRESULTS.XLS/

Put ISLPOUT;

ISLPOUT.PC=5;

Put 'LANDUSE' 'GRADE' 'YACRES' Put/;

Loop((y,grade), Put y.tl, grade.tl, yacres.l(y,grade):8:0 Put/);

BIOGRAPHY OF THE AUTHOR

Kelly Cobourn was born in Fairfax, Virginia on September 9, 1979. After attending various schools in Virginia and New Mexico, she returned to Reston, Virginia, and graduated from South Lakes High School in 1997. She attended the University of Virginia and graduated in 2001 with a bachelor's degree in Economics. She earned the award of High Distinction in the Department of Economics Distinguished Majors Program with her thesis "The Employment and Wage Effects of Environmental Regulation: An Empirical Analysis of the Porter Hypothesis." During her third year of undergraduate study she was inducted into the Phi Beta Kappa National Honors Society.

In the fall of 2002, Kelly entered the Resource Economics and Policy graduate program at the University of Maine. She was awarded a Provost's Fellowship to support her first year of graduate study. From September of 2003 to May of 2004, she worked with the Maine State Office of Policy and Legal Analysis as a Legislative Intern for the Committee on Agriculture, Conservation and Forestry. During her appointment she designed, administered, and analyzed a survey of the food purchasing habits of Maine's state institutions. The internship culminated with the distribution and presentation of the Legislative report, "A Study of the Use of Maine Produced Foodstuffs in Public Institutions."

After receiving her degree, Kelly plans to pursue a Ph.D. in Agricultural Economics with a concentration in international development. Kelly is a candidate for the Master of Science degree in Resource Economics and Policy from The University of Maine in December, 2004.