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DESIGNING PRODUCTION CONTRACTS TO REDUCE AGRICULTURAL NONPOINT SOURCE POLLUTION

By

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ABSTRACT

DESIGNING PRODUCTION CONTRACTS TO REDUCE AGRICULTURAL NONPOINT SOURCE POLLUTION

By

Mei-Chin Chu

The restructuring of U.S. agriculture toward more contract arrangements between the agribusiness firm and the producer could provide new opportunities to control nonpoint source pollution (NPSP). This research addressed two issues: *Can a production contract be used as a means to reduce NPSP? If yes, what incentives can be incorporated to induce the contracted producers to achieve voluntary NPSP abatement?* A seed corn contract in St. Joseph County, Michigan, is employed as a case study to explore contract specifications that can reduce nitrate leaching. Seed corn is widely grown in St. Joseph County, where significant nitrate levels have been found in groundwater.

The analysis shows that certain contract specifications, such as a high price premium on marginal gains in seed corn yield and grower concern over risk of contract loss, could be directly related to high nitrogen application rates. These rates, in turn, could result in excessive nitrate leaching. Other agronomic practices, such as crop rotation, also affect nitrate leaching outcomes.

Four categories of alternative contract designs are discussed. They are: a) restricting agronomic practices or nitrate leaching, b) charging a fee on nitrate leaching or nitrogen use, c) reducing the variable payment, and d) providing appropriate agronomic information for nitrate reduction. These contract designs are evaluated with respect to nitrate leaching and profitability for a representative seed corn processing firm and contracted-grower within a principal-agent model. These evaluations are implemented using a grower whole-farm optimization model, based on 42 years of simulated yield and nitrate leaching data. Two forms of dominance analysis, contract acceptability dominance and cost effectiveness dominance, are used to evaluate the feasibility and efficiency of alternative contracts.

The results show that contracts can be redesigned to reduce nonpoint source pollution. Contract designs that targeted nitrate leaching directly or agronomic practices both succeeded in reducing expected nitrate leaching. These contract designs can be mutually acceptable to both the processor and the contracted grower; however, the choice of the leaching threshold level as well as incidence of cost bearing are crucial.

The results also indicate that targeting only a single contracted crop does not necessarily reduce whole-farm leaching levels. Enforceability is a key issue in determining the feasibility of alternative contract designs to reduce NPSP voluntarily. Given that low cost techniques to monitor NPSP are not available, targeting observable agronomic practices such as crop rotation was the preferred contract design.

Key words: production contract, seed corn, nitrate leaching, whole-farm model, principal-agent theory, safety-first programming, quadratic programming

Dedicated to my beloved parents Fu Chu and Ming Wu

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CHAPTER 1

INTRODUCTION

Within the last two decades, the share of U.S. agricultural output produced under contract has increased dramatically (Drabenstott, 1994). At the same time, the public has a growing concern about agro-environmental problems. The structural change of increased contracting provides an opportunity to use contract specifications to achieve agricultural nonpoint source pollution control.

The objective of this research is to explore whether and how to use agricultural production contracts as a means to reduce nonpoint source pollution. This dissertation examines the problems associated with agricultural nonpoint source pollution, and then explores the significance of contractual production in the U.S. agriculture, how contracts may be related to nonpoint source pollution, and how contracts can be redesigned to achieve nonpoint source pollution abatement.

1.1 The Problems of Agricultural Nonpoint Source Pollution

Agricultural nonpoint source pollution is now widely recognized as a serious source of water quality problems in the United States. Pesticides and nitrates have been found in both ground and surface water (Hallberg, 1989; U.S. Environmental Protection Agency, 1990; Kellogg et al., 1992), as have animal fecal contaminants and sediments (National Research Council, 1993). Such pollution imperils both human and animal health, and may also affect ecosystem functions.

In response to the concerns about water pollution, many state and national policies have been developed to address these issues (Fox et al., 1991). For instance, the 1972 "Clean Water Act" as well as the 1974 "Safe Drinking Water Act" address national surface and groundwater contamination issues. Also, as of 1997, forty-four states had implemented state groundwater protection strategies (EPA, 1997). These concerns are also embodied in governmental farm programs. The Conservation Compliance and Conservation Reserve Program, initiated in the 1985 farm bill, was designed as a "carrot and stick approach" to curtail agricultural nonpoint source pollution. In addition, the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and the Food Quality Protection Act (FQPA) of 1996 require a rigorous pesticide registration process (Swinton et al., 1997; Benbrook et al., 1996; Marshall, 1988).

Agricultural nonpoint source pollution (NPSP) is an unintended side effect of agricultural production. It is produced by many polluters without easily identified discharge sites, and the concentration of pollutants is affected by random factors, such as weather. Within the economics discipline, NPSP is characterized as a "non-exclusive" and "non-rival" good. It is impossible or costly to exclude or to separate each individual's contribution of pollution.

In order to implement successfully policies to control NPSP, information on the physical and economic dimensions of NPSP is required. Physical dimensions include production technologies, pollution-generating processes and environmental fate.

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Economic dimensions include profit from production and damages caused by nonpoint source pollutants. These data are difficult to obtain because of the high transaction costs to collect information on the characteristics of the locations affected as well as on individual agronomic practices. Furthermore, determining the extent and the sources of pollution is difficult. Due to these heterogeneous characteristics, results generalized from small area studies might not be suitable for other locations. These difficulties have made environmental quality regulation costly and administratively problematic (Russell and Shogren, 1993; Tomasi et al., 1994).

Applied economic research to date has focused on public policy remedies to control NPSP. This approach stems from a welfare economics perspective that identifies NPSP as an externality which results when the private cost of a given action is less than the social cost. Standard remedies that have received recent empirical examination include input taxes and bans, effluent taxes, effluent standards, tradeable pollution permits, and subsidies for pollution-reducing practices (Crutchfield et al., 1992; Hrubovcak et al., 1990; Johnson et al., 1991; Ribaudo and Bouzaher, 1994; Swinton and Clark, 1994; and Taylor et al., 1992). However, these NPSP control policies are difficult to enforce in many circumstances due to asymmetric information between regulators and polluters, where the latter hold more information than the former (Segerson, 1988; Tomasi et al., 1994). The high cost of obtaining appropriate monitoring information makes these standard environmental policies impractical to enforce (Braden and Segerson, 1993; Xepapadeas, 1991 and 1992).

This research introduces an alternative approach to control NPSP via contracts

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between private parties. It explores whether agricultural production contracts can be redesigned to induce contracted farmers voluntarily to reduce agricultural nonpoint source pollution. As contractual production becomes more important in U.S. agriculture, this approach deserves examination.

1.2 Significance of Production Contractual Arrangements

Using production contracts to control NPSP was first proposed by the National Research Council in 1993. The Council recognized that, when agricultural production takes place under contracts, there may be little incentive for producers to adopt less polluting practices even when the technology is readily available. They further recognized that contractual arrangements could potentially be used to prevent or to control agricultural NPSP (National Research Council, 1993).

The rapid growth of contractual production is driven by advanced technology, the changes of consumer preferences for "branded" or "identity preserved" products, as well as the pursuit of lower costs of production (Urban, 1991). This trend has caused a "quiet revolution", industrializing the U.S. agribusiness and food systems (Schertz and Daft, 1994). Contracts are used most commonly in broilers, processing vegetables, hogs, and specialty crops, such as seed corn (Drabenstott, 1994). Contractual arrangements account for 25 percent of farm operator household income in the U.S. (ERS/USDA, 1993).

Vertical coordination under production contracts provides control across segments of a production/marketing system in the agriculture sector (Schertz and Draft, 1994; Barkema et al., 1991; Boehlje, 1996). The production contract has two characteristics: 1) it links the processor to production activities; and 2) it reduces the needed number of processing firms while increasing the operation size of each firm to capture the economies of scale in production. A contract often requires contractor-farmers either to adopt certain specific production practices or to use some specific inputs to meet the quantity, quality, and timing requirements of the operation. The processing firm keeps close supervision on the contracted grower in order to ensure that the requirements are met. Consequently, processors often have detailed information about production processes. For the processors, this arrangement can minimize risks by ensuring predictable supplies and consistent quality. For the producers, the arrangement can offer price stability and access to specialized expertise, information, and inputs (Hamilton, 1995).

In a certain circumstances, contracted farming can pose a risk to environmental quality (Ervin and Smith, 1994). First of all, industrialization often leads to more geographically concentrated operations which can concentrate agricultural pollutants, such as pesticides or livestock wastes. Second, if farmers' environmental stewardship is closely tied to their autonomy (and majority ownership of capital assets), their loss of power through vertical coordination within a contract may undermine farm-level actions to conserve natural resources or enhance environmental quality. Third, the financial incentive provided by the processing firm to meet output specifications may undermine the incentives offered by voluntary agro-environmental programs under existing abatement policies. When production practices are partially dictated by the processing

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firms, contracted-growers may lack the flexibility to make substantial changes to meet the environmental goals.

One example is that the agricultural production contracts provide contracted farmers high price premiums on high output. This encourages the contracted farmers to use inputs intensively in order to achieve high output goals. The heavy use of some inputs, such as fertilizers and pesticides, can cause NPSP, thus degrading environmental quality. For instance, contracted seed corn production in southwestern Michigan has been linked with nitrate contamination of the groundwater (Peterson and Corak, 1994).

There are two potential reasons for agricultural processors to consider the environmental impacts of contracted production processes (Batie, 1997). The first is to avoid future governmental regulations that might be developed to curtail pollution. Processors face the risk that more stringent governmental regulations, or liability rules could be extended to cover contracting processor firms as well as growers through legislative vehicles such as the Clean Water Act or the Comprehensive Environmental Response, Liability, and Compensation Act (CERLCA) (Segerson, 1994). The second reason is to appeal to changing consumer preferences. As consumer demand for environmentally benign products increases, more businesses are seeking to build a "green" reputation, including food and agricultural firms (Porter and van der Linde, 1995).

If regulations or voluntary incentives can target the processing firms, making them responsible for pollution, the governmental cost for monitoring each individual

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firm to meet NPSP standards will be reduced. The number of processing firms under an industrialized sector is much less than the number of farmers (Ervin and Smith, 1994), making it easier to track environmental performance of each firm. These processing firms tend to have more information than regulatory agencies on contracted-growers' activities (NRC, 1993). Studies from some sectors suggest that large processing firms adopt profitable new technologies earlier and at a faster pace than traditional farm businesses (Porter and van der Linde, 1995). Furthermore, when policies target the ambient environmental quality, processors in the same area can engage in cooperative pollution control at lower transaction costs than individual farmers because the number of processors are smaller.

Using contracts as a means to control or prevent NPSP implies the need to change the contract specifications. Each type of contract requires different analysis, depending on the principal pollutants and the production process. In hog or dairy production, the focal pollutant would be manure; for vegetable and fruit production, it would more likely be excessive nutrients and pesticides.

This research explores contractual specifications to reduce nitrate leaching into groundwater that is associated with seed corn production. It is developed as a representative case study in St. Joseph County, Michigan, where seed corn is widely grown and where significant nitrate levels have been found in groundwater. Seed corn production is an important case because seed corn has the largest revenue share in U.S. seed industry ($1.6 billion; Grooms, 1993) and all seed corn is produced from contractual arrangements.

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1.3 Significance of Nitrate Leaching

Nitrate (NO_3^-) is the most common agricultural nonpoint source water pollutants in the United States (Kellogg et al. 1992; CAST, 1985). Surveys from the U.S. Cornbelt show that nitrate concentration in groundwater has increased over time since the 1960s (Keeney, 1986; Hallberg, 1986). Nitrate is soluble and highly mobile, converted from nitrogen in the soil environment. It can be leached through the crop root zone and eventually into the groundwater.

Nitrate concentrations can affect both surface water and groundwater. The major health risk from excess nitrate in drinking water is clinical infant methemoglobinemia or "blue baby syndrome". Nitrate consumed by infants reduces blood oxygen levels. Other potential impacts, yet unproven, are cancer and inhibited reproduction in humans and other animal species (Fan et al., 1987; CAST, 1985; Keeney, 1986). In order to avoid damage, the U.S. Environmental Protection Agency (EPA) has set the safe drinking water standard of nitrate at 10 ppm.

Numerous sources of nitrogen in the soil, including crop residue, manure, buried organic matter, septic systems and geologic sources, can contribute nitrate to ambient groundwater nitrates. However, agricultural activities, such as nitrogen fertilizer applications in crop production and animal manures in livestock production, are increasingly being held responsible for contributing excess nitrate to groundwater (Follett et al., 1991). Particularly, the increase in nitrogen fertilizer applications have been highlighted as a major source of groundwater nitrate in the United States (Hallberg, 1986; Kellogg et al., 1992). The Cornbelt states, Texas and California

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accounted for two-thirds of the nitrogen fertilizer consumption in 1984. Among all crops, 43 percent of the fertilizer was applied to corn land (Vroomen, 1987). These data indirectly suggest that high-fertilizer nitrogen application to corn in these areas may be a major source of groundwater nitrates (Hallberg, 1986).

Concerns about nitrate leaching has grown recently in Michigan's St. Joseph County, with evidence of rising groundwater nitrate levels that frequently exceed permissible maximum contaminant levels (Martin, 1992; Weight, 1996). The problem appears linked to intense agricultural production that is practiced on a sandy soil over a shallow groundwater aquifer (Loudon, 1988). Although livestock production and other crops play a role, seed corn production has been identified as major part of the problem (Martin, 1992).

1.4 Research Objectives

The general objective of this research is to design and evaluate alternative contracts that can induce production contracted-growers voluntarily to reduce agricultural nonpoint source pollution. The NPSP to be analyzed is the nitrate leaching from contractual seed corn production. The specific sub-objectives include:

1. To identify the relationships among contract specifications, input use, output, and nonpoint source pollution. Specifically, this research will examine the relationships among contract terms, nitrogen use, yield, and nitrate leaching in the case of seed corn production.
2. To identify production practices that will reduce nonpoint source pollution and

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major obstacles to adopt these practices within a contractual relationship.

3. To identify possible contractual terms that can be modified to reduce nonpoint source pollution.

4. To structure a set of alternative contracts that could potentially reduce nonpoint source pollution. The specific model employed will focus on fertilizer management and nitrate leaching, especially for seed corn production.

5. To develop an empirical principal-agent model to analyze and evaluate the economic impacts of alternative contractual specifications. The impact on the welfare changes of a representative seed corn processor and seed corn contracted-grower will be examined.

1.5 Organization of the Dissertation

Chapter 2 reviews the characteristics inherent in NPSP and related policy issues, since these elements are essential in designing an effective contract that reduces NPSP. Possible NPSP abatement strategies are identified. Several evaluation criteria have been used in the literature to rank these strategies. A conceptual structure that illustrates a general relationship between the processor and contracted-growers is outlined to examine how this relationship can be used to control NPSP. Possible changes in contractual specifications for more effective NPSP abatement are reviewed. Nitrate in groundwater is discussed as an example, including related environmental impacts, agronomic practices that reduce nitrate leaching, obstacles to the adoption of less nitrate leaching practices, and suggested institutional arrangements to reduce nitrate

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leaching are examined as well.

Chapter 3 presents information on geographic characteristics of the research area, current seed corn contracts in St. Joseph County, Michigan, and related seed corn production practices. The relationship between current contract specifications and nitrate leaching will be explored as well.

The principal-agent framework for alternative contract design is outlined in Chapter 4. Four types of contract designs are examined: restricting agronomic practices, imposing a user fee on agronomic practices, adjusting incentive payment schemes, and providing information on nitrogen use.

In order to evaluate the impacts of alternative contracts, the physical-economic relationships are examined in an empirical principal-agent model that is developed in Chapters 5, 6, 7, 8 and 9. Three components are included: a crop growth simulation model, a deterministic whole-farm planning model, and risk programming model.

Chapter 5 illustrates the use of the crop growth simulation model--DSSAT 3.0--to examine yield and nitrate leaching relationships under different nitrogen treatments. The main features and validation of this model are reviewed. The impacts on crop yields and nitrate leaching, resulting from the use of rotations, are also simulated in this model. All of these data are subsequently incorporated into a math programming model in order to evaluate the physical impacts from alternative contract designs.

Chapter 6 outlines a way to use a principal-agent model. A whole-farm mathematical model (PC-LP) is used to examine the behavior of a representative profit-maximizing grower. The grower's behavior is examined under alternative "green" contract designs. Data collection, model parameters, model structure, and results from various contract specifications will also be examined. The impacts under various contract specifications for both the processor and the grower are examined.

Chapter 7 uses a safety-first programming (in GAMS) to incorporate two major contract risk concerns into an empirical principal-agent framework. Growers are concerned about risk of losing seed corn contracts when their yields fall below a norm established by the processing company. The second concern stems from stochastic characteristics of nitrate leaching reduction. The leaching reduction goal can be to restrict the probability that nitrate leaching exceeds a certain public safety threshold. Both concerns are modeled using probabilistic safety-first constraints.

Income risk is another important component for contract design. Risk-attitudes of both processors and contractors will affect optimal decisions as well as risk-sharing. Chapter 8 examines the case where the contractor-grower is risk-averse. How to incorporate risk components in a mathematical programming model is first reviewed, and one particular risk model -- mean-variance analysis -- is selected for use in a quadratic programming analysis. Results for the alternative contract designs are examined based on acceptability and cost efficiency criteria.

Finally, Chapter 9 summarizes the major findings of this study. The conclusions, implications, and suggested future research are drawn as a guideline for using contract designs to control agricultural nonpoint source pollution.

CHAPTER 2

ISSUES FOR DESIGNING PRODUCTION CONTRACTS TO REDUCE AGRICULTURAL NONPOINT SOURCE POLLUTION

In order to explore and evaluate available contract specifications to control NPSP, the managerial issues associated with NPSP have to be identified. This chapter first outlines the special characteristics inherent in NPSP control in order to understand the key regulatory difficulties. A conceptual processor-grower relationship is examined to discuss modeling issues and the information needed in designing incentives to control NPSP within a contractual arrangement. Several alternative ways to influence contracted-growers' behavior and ultimately improve environmental quality are reviewed. This chapter uses nitrate leaching as an example to discuss available nitrate leaching reduction strategies that can be incorporated into a production contract.

2.1 Problems of Agricultural NPSP

This section reviews some characteristics inherent in NPSP. Figure 2.1 outlines a general framework that includes detailed information on the sources and the ultimate impacts of pollutants within a pollution-generating process under a contractual relationship. A pollution-generating process includes the initial input or technology choice that results in production, emissions, ambient pollution, and ultimate

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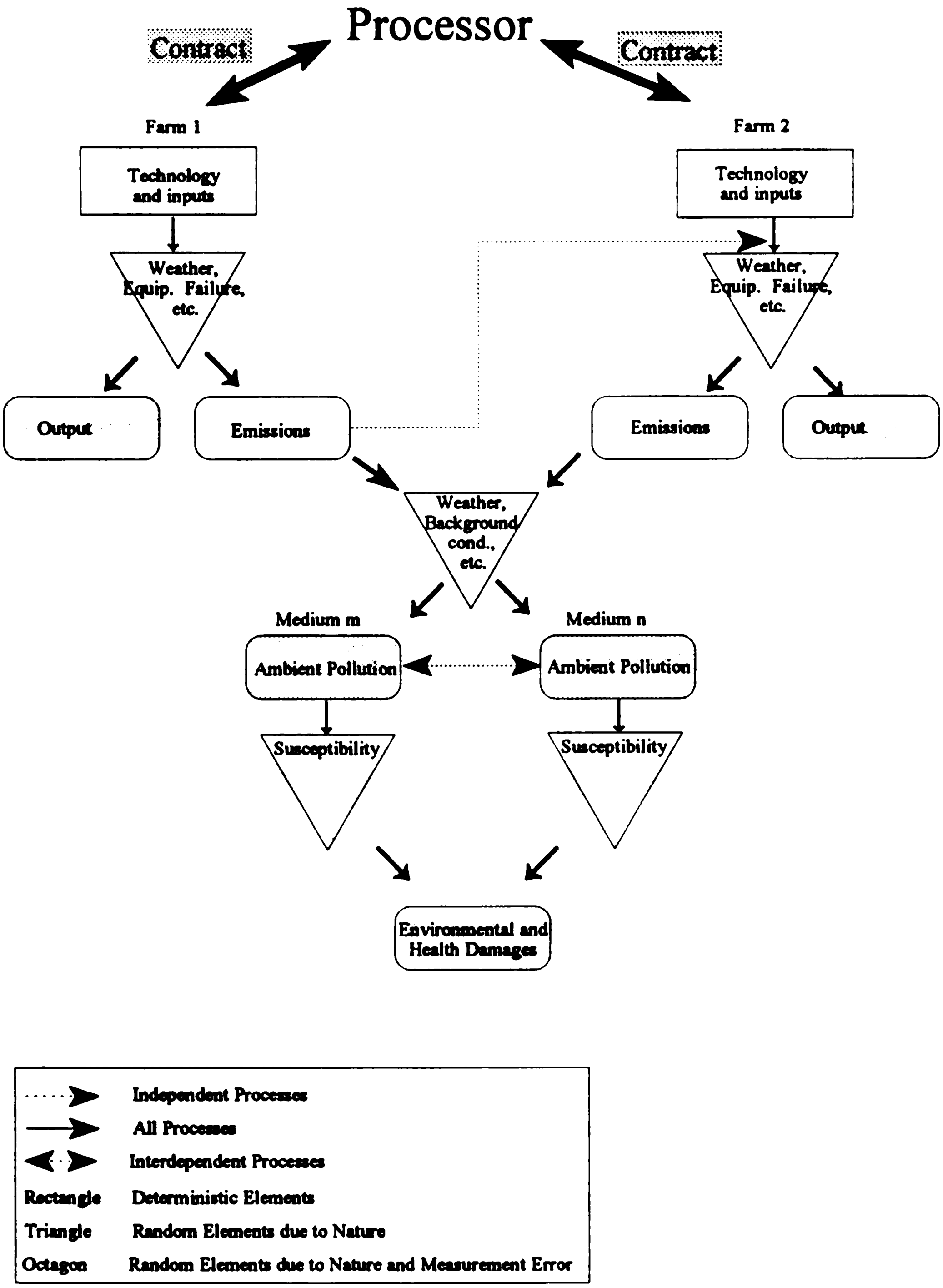

Figure 2.1: Sources of randomness in pollution relationships (modified from Braden and Segerson, 1993, p5)

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environmental or health damages. Emissions can consist of different types (such as nutrients and pesticides) from multiple sources, which may affect several environmental media (such as surface and ground water). The combined emissions determine the ambient pollution level and ultimately may cause health and environmental damages. The pollution-generating process of one farm (Farm 1) might affect another farm's production process (Farm 2) (dotted line). Exposure to contamination beyond the susceptible level of humans, animals, or the ecosystem leads to damages.

The relationship in Figure 2.1 also illustrates the physical uncertainty within NPSP, stemming from climatic and topographic conditions as well as mechanical operations. A particular abatement practice and discharge level may result in different ambient outcomes under different locations and at different times. Therefore, a range of possible ambient levels will be associated with any given abatement practice and discharge level at any given time. From the processor's perspective, the observable outcomes are output and, possibly, ambient pollution levels as well as environmental and health damages (shadowed areas). It is difficult to know the input and abatement effort made by each individual farm from the processor's viewpoint.

2.1.1 Sources of Variation in Outcomes

Pollution processes are affected by various natural sources of variability. These include weather, mechanical malfunctions, and susceptibility to damages (Braden and Segerson, 1993). Due to this natural variability, each discharge level or abatement practice tends to generate a range of possible ambient levels. This range can be

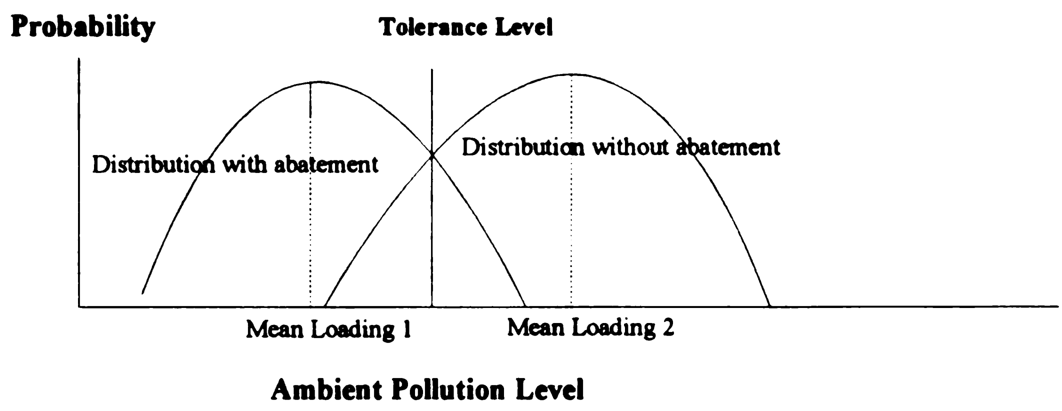

Figure 2.2: Distribution of ambient pollution level under two abatement levels
(Source: Segerson, 1988)

represented by the probability density function in Figure 2.2, which gives the probability of the ambient pollutant levels at a specific time.

In Figure 2.2, two ambient pollution distributions are affected by level of abatement. The distribution with low mean loading represents the probability distribution of ambient level with abatement, while high mean loading represents the distribution without abatement. This figure shows that the probability of the ambient level exceeding the tolerance level without abatement is greater than that with abatement (Segerson, 1988).

Another type of variation relates to spatial differences, including locations and soil structures. Local circumstances and enduring variation over time affect the relative curvatures of benefit as well as cost of abatement, and then determine the efficiency of the NPSP reduction strategies.

Timing is also an important element in controlling NPSP. There is a time lag betv

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between when decisions are made and when actual NPSP occurs, making instant monitoring impractical. For instance, corn growers in high rainfall regions tend to apply nitrogen fertilizers in the early spring while most of nitrate leaching occurs in the winter. A leaching reduction strategy should consider this time lag between nitrogen applied (action) and leaching occurred (outcome).

2.1.2 Imperfect Monitoring and Measurement

In the context of agricultural NPSP, imperfect monitoring arises from the unobservability of emissions. Because emissions are diffused, monitoring of NPSP emissions from an entire field tends to be impractical. The associated monitoring costs are prohibitively expensive and the inability to observe emissions impedes the use of emission standards, emission taxes, and the application of liability (Miceli and Segerson, 1991). These reasons also reduce the abatement incentives from each individual.

Two information issues related to NPSP control have been identified in the literature. They are moral hazard and adverse selection (Tomasi et al., 1994). Moral hazard results when a contracted-grower makes management choices that advance his/her interests rather than those of the processor. Adverse selection refers to the case when the processor cannot observe farm types, where some of them have low abatement costs while others have high abatement costs. In both cases, farmers have more information than processors about the production process of the commodity as well as the abatement. In economics, this situation is known as "asymmetric in

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information". Under this situation, the actions taken by the contracted-grower may not result in the outcomes that are preferred by the processor.

A suggested approach to resolve these information problems is to design an incentive scheme to induce the grower to undertake the actions that are preferred by the processor. In designing a production contract to control NPSP, moral hazard may be the only issue raised because the processor tends to have information on the contracted-grower's managerial ability.

Due to natural variability as well as imperfect monitoring and measurement, effectively controlling NPSP is a complicated issue to policy makers. Some studies have suggested that one way to account for variation in pollution outcomes is to have regulatory policies set a threshold level on the ambient environmental quality plus a safety margin. This objective is expressed as a maximum acceptable frequency above the ambient threshold (Lichtenberg and Zilberman, 1988; Braden et al., 1991) such that:

$$Prob(W \geq W^*) \leq w \tag{2.1}$$

where W is measured environmental contamination; W^* is the environmental threshold level; and w is the permissible cumulated probability of environmental contamination W exceeding the threshold W^*. This strategy is designed to account for not only the mean realizations of abatement (threshold level), but also the deviation of the pollution above the threshold level.

Other studies proposed indirect NPSP abatement strategies that target output level, input use (with state policies, such as taxes or subsidies on pesticide use), or ambient pollution levels (down-line policies) (Braden and Segerson, 1993; Dosi and Moretto, 1993). The reason is that emissions could be partially correlated with some other observable part of the production or pollution process, such as output levels, input uses, technology or ambient quality (Nichols, 1984). In order to examine how to incorporate these strategies within a contract design, NPSP abatement modeling needs to be explored.

2.2 Elements in Modeling NPSP Abatement

Most NPSP literature models abatement issues from a regulatory perspective. However, the same concepts can be applied in a processor-grower relationship. A principal-agent model is commonly proposed as an analytical framework to resolve the asymmetric information problem occurred in NPSP abatement. A regulator (or processor) is considered as the principal and polluters (or growers) are the agents. The objective of the principal is to reduce NPSP, which is a side-effect from production processes generated by several agents (Segerson, 1988; Meran and Schwalbe, 1987; Xepapadeas, 1992; Peterson & Boisvert, 1995; Wu and Babcock, 1995; Wetzstein and Ahouissoussi; 1996; Bystrom and Bromley, 1996). Within the principal-agent model, the principal designs an incentive scheme, such as a fee or a direct payment, to induce the agent to undertake NPSP abatement. The incentive scheme could be within an individual contract (Segerson, 1988; Xepapadeas, 1992) or a group contract (Bystrom and Bromley, 1996; Devuyst, 1997).

Several elements need to be included when modeling the relationship between the regulator and polluters in a NPSP context. The first element to be considered is the physical-economic dimension of a nonpoint source pollutant. This physical dimension includes the relationship between environmental/health damages and input uses, technology, emissions, as well as ambient levels. Crop growth simulation models, like DSSAT (Tsuji et al., 1994), are often used to estimate the agri-chemical components of pollution, such as the relationship among input uses, yields, and nitrate leaching (emission). These emissions will determine the ambient pollution level according to their environmental fate (Mapp et al., 1994). These data are then incorporated into an economic model to predict the relationships between NPSP and farm profitability. A representative farm linear (or nonlinear) programming model can be used as an economic model to examine the tradeoff between environmental quality and farm profitability (Thomas and Boisvert, 1995; House et al., 1995 and1996; Devuyst, 1997).

The second element concerns the number of polluters. An ambient level of agricultural NPSP at a given location is often contributed to by many farms. The existence of multiple and heterogeneous polluters raises a number of regulatory difficulties. As the number of farms increases, it becomes more costly to trace the source and extent of the pollution, because it is impossible to separate activities from each individual farm from ambient pollution level (Tomasi et al., 1994). Insufficient information creates potential for "free-riding" because it is difficult to identify and penalize non-compliant polluters. In addition, each farm tends to perceive its own pollution contribution to be small relative to the group (Batie, 1983). Therefore, a la

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large number of farms reduces the likelihood of cooperation among farms to reduce ambient pollution levels.

The third element is the spatial heterogeneity among farms. The extent of the damage is site-specific, depending on variables such as soil structure, animal and plant population density, and the technology used. The abatement costs for polluters across different locations are different.

Technological differences, including production technologies and abatement technologies, are the fourth element that needs to be considered. Such differences stem from climate, soil type, slope, depth of groundwater and intervening geologic structure. Although there is some correlation between production and pollution levels, this correlation differs under different technology. A uniform and mandatory required management practice or emission standard for a certain pollutant will have different cost impacts on each farm and will not lead to equating marginal costs across farms.

Both spatial and technological differences are also related to stochastic influences. Weather is the most important stochastic element that influences crop production and environmental effects. Other stochastic elements include input and output prices, which affect farmers' choices of input use and pollution outcomes.

Other elements in modeling NPSP abatement include dynamic perspectives: carryover effects and accumulated experiences. Environmental quality is affected by the accumulation of pollutant ("stock") that is carried-over from previous periods and are accumulated over time. In addition to carryover effects, the NPSP reduction process is also influenced by accumulated learning experience in terms of abatement coope

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cooperation and technological advance. Such experience affects transaction costs from negotiation among parties and administrative efforts (Tomasi et al., 1994).

In conclusion, modeling NPSP issues within a contractual framework should consider many perspectives. It is important to recognize physical dimensions starting from input use to pollutant concentration and the number of polluters contributing to ambient pollution at a given location and potential contribution of each farm. Additional factors include site-specification, technological heterogeneity across farms, the role of stochastic influences in determining ambient pollution as well as production, and long-term dynamic elements.

2.3 NPSP Abatement in a Contractual Production Relationship

Figure 2.1 illustrates a general conceptual framework of a processor-grower relationship, where a processor contracts with two farms. In a scenario where the processor is concerned with future liability or his or her "green" image, the processor will include product output and environmental quality in his or her objectives (Batie, 1997). The levels of both output and environmental quality depend upon the decisions made by contracted-growers. The processor observes individual output levels from each farm and a combined ambient pollution level from the emissions from both farms. The individual inputs, technology, and emission may not be observable from the processor's perspective. Therefore, a contract design needs to specify an incentive scheme based on observable outcomes to achieve preferable results.

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production decisions. These decisions are primarily determined by a grower's objectives, though also affected by other factors such as input and output prices, site characteristics, degree of risk aversion, governmental programs, and contract terms. A grower's objective(s) can include expected utility from profits, preference over environmental quality, financial punishment, and stewardship. These decisions are also constrained by feasible technology, other grower's decision, and available information on input use.

The processor, however, can influence the contracted-growers' behavior through contract term specifications. For instance, a contract with high price premiums on yields will encourage a contracted-grower to use inputs intensively in order to achieve high yield goals. The environmental problems and production practices associated with NPSP abatement depend on the nature of pollutants. Therefore, NPSP abatement strategies and their corresponding enforceability vary. The next section uses an example to explore the potential alternatives of a processor to design a lower leaching contract.

2.3.1 Issues Related to Nitrate Leaching Reduction

Excessive nitrogen applications are the most direct factor contributing to nitrate leaching. Other factors include weather (rainfall, temperature, solar radiation, etc.), soil dynamics (such as soil texture), timing of application, and various agronomic practices, including nitrogen application schedules, irrigation schedules, tillage systems, rotation carryover, form of nitrogen fertilizer, and cover crops. These factors

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intertwine to determine the extent of nitrate leaching.

Management strategies for nitrate NPSP recommended for areas which are vulnerable to nitrate leaching are available for farmers (Loudon, 1988). The strategies involve setting realistic yield goals based upon previous crop histories for a specific field; crediting all nitrogen sources, including soil organic matter content, crop residue, manure applications, nitrogen in irrigation water, as well as fertilizer nitrogen in determining the total amount which will be available to the crop; using appropriate application methods; and incorporating nitrogen into soil to prevent volatilization and surface runoff.

Several factors influence the adoption of these nitrogen management strategies (Supalla et al., 1995). These factors include information in the recommended nitrogen application rate, knowledge of irrigation scheduling and water quality, available nitrogen application technology, institutional arrangement, and other demographic factors (such as years of schooling and farming experience).

Recommendation for fertilizer application levels based on experimental results have been provided to farmers by extension agents and consultants. There are several drawbacks related to using these fertilizer recommendations. First, the recommended fertilizer application lacks the representativeness of the experimental response (SriRamaratnam et al., 1987; Perrin, 1976). Variations in soil type, soil fertility levels, and the level of management and technological advances in crop yield potential are not considered in extension recommendations in some cases. Second, reconciling results from different sites and different years may not adequately estimate a nitrogen-yield relationship for a specific area (Anderson, 1974). Third, farmers might set an unrealistic yield goal that results in over-application (Babcock and Blackmer, 1994). Farmers tend to use high nitrogen fertilizer rates to ensure an adequate supply of nutrients in case the growing season turns out to be favorable (Babcock and Blackmer, 1994; Babcock, 1992). As a result, farmers may "over-apply" nitrogen fertilizer relative to needs for an average year.

The Supalla et al. study (1995) also indicates that institutional arrangements are potentially responsible for providing incentives to set high yield goals. Examples were the governmental deficiency payment that tied payment with yield levels, and high price premiums paid to the contracted-grower who produces higher yield levels within a contractual arrangement (Swinton and Clark, 1994; Batie, 1994).

2.3.2 Strategies for Nitrate Leaching Reduction

This section explores potential strategies that can be incorporated into a "green" contract design to reduce nitrate leaching. Most NPSP reduction strategies in the literature are conceived from a regulator's perspective, because it is assumed that only the government will undertake NPSP control due to its externality property. Five general approaches are discussed in the NPSP or leaching reduction literature. They are: A) emission control strategies; B) output-based strategies; C) strategies based on purchased inputs or management; D) ambient- or performance-based strategies; and E) legal liability for damages (common or statutory law).

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A. Emission-Based Strategies

The standard textbook remedies for an externality are based on effluent emissions. In the case of reducing nitrate leaching, this strategy could be to charge an emissions tax (Pigouvian tax), or to specify a permissible amount of nitrate leaching. Another strategy is to design an incentive payment to induce the polluter to achieve a nitrate leaching reduction goal.

B. Output-Based Strategies

A strategy designed to target agricultural output levels presupposes that NPSP is correlated with output levels. For example, it is typically assumed that high nitrate leaching is correlated with crop yields. High levels of nitrate leaching could result from institutional arrangements that encourage intensive fertilizer use. Two common examples are governmental farm programs and contractual crop production. Both examples provide subsidies or premiums for achieving high yield goals, which is likely also to increase NPSP. Therefore, one way to reduce NPSP is to reduce price premiums on per unit output (Supalla et al., 1995; and Swinton and Clark, 1994).

C. Purchased Input- or Management-Based Strategies

Controlling inputs to reduce NPSP was proposed by Griffin and Bromley (1982) and Shortle and Dunn (1986). This approach suggests that a "user fee" or standard on the input use could serve as a substitute for an emission fee. This instrument of controlling input use assumes that input use is highly correlated with pollution

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emissions and input consumption is more easily observed. Management-oriented instruments, including requiring different cropping patterns, have been suggested to reduce agricultural pollution (Drake, 1993; Fleischer et al., 1989). This strategy includes charging a fee or imposing a restriction on either nitrogen fertilizer use or agronomic practices such as rotation, spring nitrogen application only, split application, and the planting of winter crops. Another strategy is to design a "green" payment that is directly related to environmental friendly practices, such as the use of best management practices (BMP).

D. Nitrate Concentration-Based Strategies

This strategy involves specifying a financial punishment (or incentive) based on the ambient nitrate concentration in the groundwater when it exceeds a certain threshold level (such as 10 ppm). Segerson (1988) and Xepapadeas (1991 and 1992) theoretically show that this approach can provide the correct incentives for individual polluters within a group to undertake socially efficient abatement measures. In this case, the variation among individual polluters is not important, if and only if, the ambient level does not exceed the targeted threshold level.

E. Liability-Based Strategies

A liability-based strategy makes polluters liable for damages caused by NPSP (Segerson, 1988; Meran and Schwalbe, 1987; and Xepapadeas, 1992). In this case, farmers in the same region might share the same liability for any health or environmental damage caused by nitrate contamination.

All the strategies mentioned above can potentially reduce nitrate leaching. Enforcement is key to the design of an effective water-quality improvement strategy that is site- and time-specific. The monitoring and measurement depend on the availability of appropriate technology. Crop yield can be easily measured. Technologies to measure crop nitrogen need could justify fertilizer application with good nutrient uptake. The available techniques include soil nitrate test, plant tissue, and remote tests (such as leaf reflectance, canopy reflectance, aerial photography) (Silva, 1996). Well sampling can provide a measure of ambient water nitrate levels. However, all of these measures cannot accurately measure the exact amount of leaching.

Since each of the above strategies has its own strength in dealing with NPSP, a set of criteria is needed to evaluate the efficiency of these strategies.

2.3.3 Evaluation for Alternative NPSP Strategies

Braden and Segerson (1993) have identified three criteria to evaluate the effectiveness of NPSP abatement strategies: A) ability to target; B) ability to enforce; and C) correlation with improved environmental quality. All three are applicable to nitrate leaching.

A. Ability to Target

NPSP is inherently variable, so the impacts of pollution-related decisions will vary over both time and space. In general, efficiency is increased by a strategy that can be targeted to sensitive areas or times. Here, a strategy that can induce site- or time-specific responses is preferred to one that induces uniform responses.

B. Ability to Enforce

Enforcement requires both detection and the ability to sanction noncompliance. The administration and monitoring costs are also critical in determining enforceability. The inability to perfectly monitor pollution-related decisions suggests the need to design alternative strategies that are based on other observable targets, such as input uses or agronomic practices.

C. Correlation with Environmental Quality

The strategies should ultimately improve environmental quality, reducing pollution-related damages. For instance, if nitrogen fertilizer is employed as a reference of likely pollution, randomness (weather) and substitution effects (other sources of nitrogen) in the production process are two factors that might affect its relationship with environmental quality. The correlation between policy tools and environmental quality needs to be considered.

Table 2.1 summarizes the effectiveness of five leaching reduction approaches from a regulatory perspective based on the first three criteria: A) ability to target, B) ability to enforce, and C) correlation with environmental quality (Segerson et al., 1993; Segerson, 1990).

Table 2.1: Evaluation of nonpoint source pollution abatement strategies

Fee/Payment/Restriction on	Rating with respect to:		
	Ability to Target	Ability to enforce	Correlation with Water Quality
1) Output Product	L	H	L
2) Purchased Inputs	L (charges) M (regulations)	H (charges) M (regulations)	M
3) Emissions/Management Practices	H	M	M
4) Ambient Concentration	H	L (charges) M (payments)	H
5) Use of Liability	H	L	H

Note: L: low; H: high; and M: medium (Source: Braden and Segerson, 1993, p16)

Output-based or yield-based strategies are relatively easy to enforce given current marketing systems. However, this approach cannot be easily targeted to sensitive areas or times. Furthermore, water quality problems may not stem from the output level *per se*, but also from the way or place in which the output is produced. In addition, output-based strategies might induce output-substitution without inducing input-substitution. If this happens, the water quality may not be improved.

Nitrogen fertilizer inputs can directly contribute to water quality degradation. However, it will not necessarily cause excessive nitrate leaching if farmers follow proper agronomic practices. A strategy based on a particular input use could diminish efficiency by biasing the selection of inputs or by failing to account for differences in emissions from different agronomic practices or from different locations. Without careful monitoring, taxation or regulation of easily observable inputs may only distort the chosen input mix and induce inappropriate substitutions.

Ambient nitrate levels are relatively easy to measure, but inferring emissions from a given ambient level for a particular source is difficult due to natural randomness and influence of other neighboring polluters. Ambient standards ensure targeting and consider site-specific differences in making pollution-reduction decisions to meet water quality goals. However, the effectiveness of this strategy also depends on individual farmers perceiving their own contribution toward achieving the standard (Batie, 1983), yet by the nature of NPSP, this is unlikely. A charge-based approach may be difficult because it is impossible to measure each individual's performance. Alternatively, subsidies for compliance with the standard will reduce enforcement difficulties because farmers will voluntarily provide information in order to obtain payments.

Legal liability might result from polluting activities, thus avoiding the risk of liability might induce polluters to consider site- and time- specific NPSP damages. However, it may be difficult to identify a responsible party for the damages. Moreover, because agricultural inputs are approved for use by federal agencies and are part of "normal" farming practices in U.S. agriculture, farmers have been granted exemptions from general liability requirements under Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and some state laws (Mill,1992; Segerson, 1995). These exemptions make the liability rule approach difficult to enforce in agricultural production.

Table 2.1 suggests that no single strategy instrument is likely to yield efficient pollution abatement decisions. Those strategies that rank highest in ability to target linkage with water quality tend to be the most difficult to enforce. Strategies that are easy to enforce cannot be easily targeted, nor directly related to water quality. Because of these tradeoffs, multiple instrument approaches have been proposed as alternative strategies by past studies (Miltz et al, 1988; Segerson, 1988; Xepapadeas, 1991, 1992; Braden and Segerson, 1993). For instance, Segerson (1988) examined combinations of liability rules and taxes to reduce nonpoint source pollution, and Xepapadeas (1991) proposed an environmental policy that combined fines and subsidies to overcome moral hazard issues under imperfect information.

An alternative approach is to provide incentives to induce farmers to reduce NPSP voluntarily. This approach has been adopted in the current governmental programs, such as the "green" payment scheme or the Conservation Reserve Program. This strategy makes an incentive payment to a farmer who can prove his or her "compliance". Incentive payments can reduce the transaction costs of monitoring NPSP, making the target more enforceable (Batie, 1994; Wu and Babcock, 1995; Peterson and Boisvert, 1995), since farmers hold the information about the production practices. However, this policy may trigger large governmental expenditures.

2.3.4 Lessons from Regulatory Policy Designs

The above discussions on NPSP abatement are mainly based on regulatory literature; however, several lessons can be learned for private production contract designs. First, a principal-agent framework proposed in the literature can be used to design incentive schemes to induce the polluters (growers) to reduce NPSP. This approach can be employed to design a production contract. Second, the NPSP abatement schemes used in a regulatory literature can be applied to provide contract designs.

Using the processor-grower relationship outlined in Figure 2.1 has several strengths to potentially reduce administration cost. First of all, the processor needs less data because it might need only examine the particular good and pollutant produced by the contracted producer. Second, the information is easier for the processor to monitor than for a regulator, because the processor already monitors the contracted-grower's production process. The marginal cost of additional monitoring for the processor is less than for a regulatory agency.

Apart from the three effectiveness evaluation criteria listed in section 2.3.3, the magnitude as well as distribution of abatement cost between grower and processor needs to be considered in designing alternative contracts to induce voluntary nitrate leaching reduction. This cost, including abatement cost as well as monitoring cost, determines the acceptability of alternative contracts. If either cost is too high, then it is difficult to design contracts that are acceptable to both contracted parties.

Each strategy tends to have different impacts on the processor and the grower . A charge on nitrate leaching, for example, could increase growers' production costs while increasing the processor's revenue, although the processor would bear the costs of monitoring. An incentive payment could increases farmer revenue at the expense of the processor; in this case, the grower would provide information in order to receive payments. In regulatory context, who bears the abatement as well as monitoring costs depends upon the ownership assigned by the institution[1]. For instance, if the strategy is to pay growers for leaching reduction, growers implicitly "own" environmental quality. That is, they have a right to pollute and must be compensated if forced to control pollution. Who should bear abatement and monitoring costs becomes an important equity issue in designing NPSP control strategies. Organization of Economic Cooperation and Development (OECD), for instance, has proposed a polluter-pay-principle criteria as an equity criterion. It requires polluters to pay for damages caused by their pollutants or for abatement costs.

2.4 Summary

This chapter reviewed the literature on NPSP abatement. Asymmetric information between regulators and polluters is due to nature variability as well as imperfect monitoring and measurement. A principal-agent model can be used to design an incentive scheme to induce polluters to undertake NPSP abatement under an asymmetric information situation. In addition to the objectives of regulators and polluters, a NPSP abatement model needs to consider the physical dimensions of pollutants, number of farmers, spatial heterogeneity, technological feasibility, and stochastic influences. A bio-economic (or physical-economic) model is often employed in analyzing the relationship between the environmental quality and profitability.

The specification of a "green" contract design depends on the type of pollutant.

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[1]"Institution" is defined as collective actions, including laws, customs, contracts, and other social norms (Schmid, 1987).

Several strategical tools can be employed to reduce nitrate leaching. They target outputs, input uses, management practices, emission levels, ambient concentration in the groundwater, or make farmers liable for damages caused by NPSP contaminations.

The effectiveness of these policies depends upon their ability to target, their enforceability and their correlation with environmental quality. The magnitude and distribution of abatement costs are also important in determining the acceptability of redesigning contract to reduce NPSP. The rest of this research will use a seed corn contract as a means to examine how to structure production contract incentives in order to induce growers to reduce nitrate leaching voluntarily.

CHAPTER 3

CONTRACTUAL PRODUCTION: A SEED CORN CONTRACT IN ST. JOSEPH COUNTY, MICHIGAN

In order to explore how production contracts can be designed to control nonpoint source pollution, information on contractual production practices and contract specifications is important. This chapter first reviews the role of production contracts in U.S. agriculture. Categories and compensation schemes commonly used in production contracts are examined as background information. Contracts are important in seed corn production due to the concern over genetic security. The seed corn industry and seed corn production are examined in order to identify the market structure, which affects the negotiation power between the processor and the grower. A leading seed corn production contract in St. Joseph County, Michigan, is analyzed as a case study that outlines the linkage between nitrate leaching (agricultural nonpoint source pollution) and contract designs within a production process.

3.1 Contractual Production

Contract production has rapidly increased in U.S. agriculture during the last four decades (O'Brien, 1994; Manchester, 1994). Contracts have long been used in the seed, vegetables and horticultural crops, as well as poultry industries. They are now spreading into other commodities, including swine and traditional grains (Drabenstott, 1994; Hurt, 1994).

Hamilton (1995) defined an agricultural production contract as:

> "... a legally binding agreement of a fixed term, entered before production begins, under which a producer either: agrees to sell or deliver all of a specifically designated crop raised on identified acres in a manner set in the agreement to the contractor, and is paid according to a price or payment method, and at a time, determined in advance; or agrees to feed and care for livestock or poultry owned by the contractor until such time as the animals are removed, in exchange for a payment based on the performance of the animals...." (Hamilton, 1995, p3)

This statement defines a main feature of a production contract; it locks in marketing commitments between a buyer (processing firm) and a seller (grower) before or during the production process. There are two major reasons for contractual production (Hamilton, 1994 and 1995; Barkema, 1994). One is risk management; contracting provides an attractive way to reduce and manage financial risks for both parties. Another reason is because of new marketing opportunities, such as growing demands for "identity-preserved" or "value-added" crops, and the availability of new bio- and information-technology that makes such crops possible (Horstmeier, 1993; Phillips, 1994; Urban, 1991).

From a contracted-grower's perspective, production contracts provide a form of risk management, including reducing financial risk and stabilizing income. Contracts often provide higher output prices for raising new crops or for using certain production methods. Production contracts also offer opportunities for contracted-growers to access capital, new technology, and new markets.

From a processing firm's viewpoint, contracts have several advantages over non-contracted production processes. First, a production contract provides control over production methods, and thus helps to ensure the uniformity and quality of the commodity. Second, contracts offer a mechanism to control quantities and the way crops are marketed to processors and consumers, thus assuring adequate supply. Contracts allow the company to lock in a guaranteed supply to meet potential demand. Third, contracts promote adoption of marketing-related technologies or production methods, thereby providing opportunities for economic linkages (such as "packages" of seeds, chemicals, and marketing). Fourth, in seed corn production, contracts give the company control over the specialized crop genetics that create the added-value trait, allowing the contract to serve as a form of intellectual-property protection. Other advantages of contractual production include marketing protection, pricing confidentiality, the reduction of risks and higher profits.

The advantages listed above make contract farming an attractive alternative compared with traditional marketing approaches. The processing firm often requires the contracted-grower to adopt certain management practices within a contract in order to obtain high quality products. The management requirements vary across firms depending on commodities and production methods.

Based on the flexibility of management practices, production contracts can be categorized into three groups: marketing contracts, production management contracts, and resource providing contracts (Mighell and Jones, 1963). The processing firm and its contracted-grower bear different degrees of risk under each type of contract.

3.1.1 Categories of Production Contracts

A market specification contract provides the contracted grower with an assured buyer for a specific product at a given price, quantity, and quality before it is produced. Under this type of contract, a contracted-grower retains most production decisions while being assured of a market for his or her product. However, a contracted grower still bears risk associated with production, although the price risk is reduced (Mighell and Jones, 1963; Eide, 1997).

A production management contract gives the contracting company direct control over farm production practices. This type of contract is often used to guarantee "identity preservation" (Hamilton, 1995). In this case, a contracted grower is required to adopt certain management practices as well as inputs. Meanwhile, the processing firm usually maintains close supervision of the production practices in order to guarantee output quality. Price premiums are provided as a compensation for required production costs, as well as an incentive mechanism to motivate the grower for superior performance. Production risk is shared between the processing firm and the contracted grower under a production management contract.

A resource-providing contract gives the processing firm greater control over the whole production process. It is often used when the production of a commodity requires special inputs, technology information, or special investment. Under this contract, the processing firm supplies all or most of the inputs, as well as technology information and certain custom services. The ownership of the commodity belongs to the processing firm. A contracted-grower, therefore, has less flexibility over the production processes. The processing firm is responsible for most of the risk associated with production of this commodity (Eide, 1997).

The processing firm has different control over production processes, depending on the type of contract. These three types of contracts can be combined in a production contract design. A processing firm tends to tailor its contract based on the product characteristics and specific production information requirements.

3.1.2 Compensation Methods

A contracted-grower receives a payment from the processing firm through different compensation schemes, including fixed price (cash-rent), piece-rate, and competitive compensation schemes. The payment scheme serves as an incentive mechanism to induce the contracted-grower to undertake the action preferred by the processing firm as well as a way to provide risk-sharing between these two parties.

Under a fixed payment compensation (rent), the processing firm pays a fixed, predetermined fee to the grower, regardless of the grower's performance. A contracted-grower's income is ensured under this compensation scheme. A fixed payment scheme might not provide the contracted-grower with adequate incentive to achieve the goal preferred by the processing firm. For instance, moral hazard can arise when the processing company cannot perfectly monitor the grower's actual behavior and the performance outcome is greatly influenced by random elements.

A piece-rate compensation scheme makes payments to a contracted grower based on actual performance outcomes. A contract grower earns a specified per-unit output payment. Under this payment, the grower bears a large proportion of risk (Knoeber, 1989). This result may not be efficient under an optimal risk-sharing rule, which requires risk to be shared between two parties according to the degrees of risk-aversion.

Both fixed payment and piece-rate compensation methods compensate the contract-grower's performance based on an absolute standard. They may fail either to provide incentives to avoid moral hazard under imperfect monitoring, or to consider risk-sharing. When these two elements occur, a third compensation scheme has evolved. It is a competitive compensation scheme, based on the contracted-grower's relative performance (Knoeber, 1989; Knoeber and Thurman, 1994; Martin, 1995).

A competitive compensation scheme, or relative performance payment scheme, compares the contracted-grower's performance to the performance of other growers or to a fixed standard. This compensation method makes payment either through "tournaments" or linear relative performance measures (Knoeber, 1989; Knoeber and Thurman, 1994). Tournament contracts base compensation on a predetermined scale such as x cents per pound for first place, y cents per pound for second place, and so forth. For instance, linear relative performance measures base a contracted grower's reward on a linear function of the difference between his or her performance and other growers' (Martin, 1995). Therefore, the payment received by a grower is not predetermined, but instead, depends on the performance of other growers.

Competitive compensation has an advantage over fixed payment and piece-rate compensation schemes in that moral hazard becomes less important. All growers in the same area face the same shocks inherent in a production process, therefore, the information on other growers' performance enables the processing firm to differentiate and screen producers of varying managerial ability (Nalebuff and Stiglitz, 1983; Knoeber, 1989). For this reason, competitive compensation schemes are the most widely used method in designing agricultural contracts, particularly where weather has a great influence on output and the grower's efforts are difficult to observe.

A compensation method along with specific management requirements within a production contract could generate undesirable environmental impacts (Martin and Zering, 1997). To illustrate this point, a seed corn production contract is used in the next section as a case study to examine potential linkages between contract production and environmental quality.

3.2 Contractual Seed Corn Production

Plant genetics play an important role in keeping commodity grain production costs competitive and high quality. Production contracts have traditionally been used in the seed industry to ensure genetic purity and protect genetic security. Use of contracts to control grain production is part of a larger trend of agricultural industrialization in the United States. (Hamilton, 1994).

3.2.1 Seed Corn Industry in the United States

The seed industry is defined as that industry which sells seed to farmers, dealers and distributors. U.S. seed revenues for major seed segments were estimated to be about $4.9 billion in 1992. Seed corn is the largest crop segment in the seed industry (Grooms, 1993).

The size of seed corn companies varies greatly. Many are small, local, family-owned and operated businesses. The largest seed corn company, Pioneer Hi-Bred International Co., accounted for 38.7 percent of the 1992 U.S. seed corn market share. The compensation to seed corn contracted-growers is the single largest production expense for U.S. seed corn companies. It is estimated that the seed corn industry injects over $600 million into primarily rural economies, thus, seed corn production becomes an important source of farm income. Given that U.S. corn production accounted for 46.3 percent of world corn production in 1994-1995 and 77.9 percent of world corn exports, the seed corn industry plays an important role in the competitiveness of U.S. agriculture (USDA, cited by Urban, 1995).

3.2.2 Seed Corn Production Management

Seed corn production requires producing seed of the desired purity, quality and quantity by hybrid type. Seed corn production requires specific practices, such as delay-planting, male-row removal, female-row detasseling, and particular pesticide practices (Martin, 1992; Shaw et al., 1989). The production processes are closely supervised by the seed corn processing firm in order to protect the genetic security and purity. More than 99 percent of seed corn is produced by contracting directly with farmer-growers to produce the seed.

Seed corn production is different from commercial corn production in a number of ways. Commercial hybrid corn seed is produced by crossing two parent genetic lines called *inbred varieties*. The process typically entails planting one row of male inbred for every four rows of female inbreds. Because maturity time may differ between male- and female inbred varieties, seed corn inbreds may require planting at two different dates for the same field. After planting, the major field operation in the seed corn field is the detasseling of the female plants. This operation is done prior to silk emergence and pollen shed on the female plants. Male rows are removed after they have tasseled and fertilized the female rows (Martin, 1992; Shaw et al., 1989).

Seed corn growers are required to isolate their seed corn fields from other commercial corn fields in order to prevent fertilization from unwanted genetic lines. Contracted-growers are typically compensated for the reduced yields due to the lower yield capacity of the inbreds and the loss of the male rows.

Because seed corn is a high value crop and the availability of seed corn contracts is restricted, growers are competing with each other in order to obtain seed corn contracts. Contracted-growers are selected by the seed corn company depending on the historical yields, grower cooperativeness, and availability of an isolated seed corn field.

In general, seed corn production requires more labor and pesticides than commercial corn. Except for those noticed above, most of the crop production activities are similar to commercial corn. Pest management is important to seed corn production. Some strict restrictions are imposed on the timing and the use of herbicides, insecticides and fungicides because seed corn is very sensitive to these chemicals. The company sends out a group of scouts and agronomists frequently to examine the seed corn fields and provide contracted-growers with information on how to manage pest problems. Therefore, the company has considerable information about each individual grower's agronomic practices. The company also keeps a complete record of growers' chemical use (Miron, 1995).

Nutrient management is another important element in seed corn production. Growers apply fertilizers, including lime, phosphorus and potash, on the seed corn field. Most seed corn growers apply nitrogen twice on their field: pre-planting and side-dress. Studies have shown that inbred corn requires less nitrogen than hybrids. These differences are due to less biomass and grain yield, detasseling and removing male rows (Balko and Russel, 1980; Martin, 1992; and Peterson and Corak, 1994).

3.3 Geographic Characteristics of St. Joseph County

Most U.S. seed corn production is concentrated in the Midwest. Among these areas, St. Joseph County in Michigan is one of the most important regions. Over ten seed corn companies operate within this region. Many of the companies have similar payment schemes that provide a high premium to encourage contracted-growers to produce high yields. Therefore, this research will mainly focus on the type of contract used by the leading seed corn company in the region.

St. Joseph County is located in the southwestern Michigan. The soils are dominated by sandy loams. A significant proportion of the cropland is irrigated. The groundwater is associated with an unconfined shallow glacial drift aquifer in St. Joseph County (Weight, 1996). These three factors combined to raise the risk that heavy nitrogen application will cause nitrate leaching. Thus, it is not surprising that this county is one of the three areas in Michigan that have high nitrate concentrations in the groundwater (Kittleson, 1987; Weight, 1996). The local public is pressing the growers to reduce nitrate leaching (King, 1989; Martin, 1992). For example, the Environmental Protection Agency (EPA) found that the nitrate level in several wells exceeded the EPA threshold of 10 ppm maximum contaminate level (MCL) -- permitted under the Safe Drinking Water Act (Martin, 1992; Weight, 1996). The EPA required the town of Constantine, in the center of the seed corn production area, to install a $1.2 million de-ionizer in their water system to reduce the nitrate levels below the 10 ppm MCL.

St. Joseph County is a major producer of agricultural products in Michigan, with gross farm receipts of over $65 million. Total cropped acres are 190,000, with 80-85,000 (45 percent) acres of irrigated cropland. Agriculture in St. Joseph County is diversified. The primary crops grown in this area include commercial corn (29 percent of all cropped acreage) and soybeans (21 percent), seed corn (24 percent) and some horticultural crops (11 percent, including tomatoes, cucumbers, carrots and potatoes) (King, 1994). Conventional crops are usually grown as cash crops, while specialty crops such as seed corn and horticultural crops are based mostly on contract production in St. Joseph County.

The production contracts can be classified into two main categories according to management requirements[2]. The first category, representing the majority of contracts,

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[2]Other contract types are also used in this area (Eide, 1997) but rarely.

requires intensive on-farm labor from contracted-growers. To grow seed corn, for example, contracted-growers use their own equipment and do most of the needed field work. All of the seed corn is grown on irrigated land, and it accounts for more than one half of irrigated cropland in this area.

The second category of contracts is closer to a cash-rent agreement. Contracted-growers do part of the tillage at the pre-planting stage and might be required only to run irrigation systems while the contracting company does the remainder of the field work. These contracts include potatoes, snap beans, carrots and tomatoes, are grown under different contract specifications. Among seed corn producers, potatoes are regarded as the second most profitable crop after seed corn. Although potatoes were introduced to this region after 1993, an increasing amount of land was devoted to potatoes during 1993-96 (King, 1994).

3.4 A "Tournament" Seed Corn Contract in St. Joseph County

Seed corn contracts have the characteristics of marketing, production management, and resource-provision base contracts. In addition to general agronomic practices mentioned in section 3.2.2, the seed corn contract also specifies a premium paid to the growers, based on per bushel seed corn yield. This premium provides an incentive mechanism to induce the grower to produce high yields. In one common type of seed corn contract, the seed corn conditioning company offers a "tournament" contract, where the payment is based on the grower's relative performance.

3.4.1 A "Tournament" Seed Corn Contract

The case examined in this research is a contract where a seed corn grower is rewarded by producing yield above the average regional yield, and penalized otherwise. This payment can be expressed in a general form (Shaw et al., 1989):

$$S(y) \quad = \beta[\alpha(y-y_0)+Q]*P*A \tag{3.1}$$

where S denotes total payment from the seed processor to the contracted grower; y, grower yield per acre of seed corn from female inbred rows; y_0, average regional yield per acre; Q, base crop yield (or per acre average regional commercial corn yield); P, price of commercial corn per bushel; A, gross acres of the seed corn variety; α, a coefficient that transforms seed corn yield to commercial corn equivalent; β, a price premium adjustment coefficient. Because the inbred lines have lower yields than commercial hybrids, the value of α is always greater than one. The costs associated with contract production are compensated through a price premium adjustment coefficient, β, which also is greater than one.

The fixed portion, Q multiplied by βPA, ensures the seed corn grower is compensated for the expected opportunity cost of not raising an alternative crop such as commercial corn. The payment above regional yield, $[\alpha(y-y_0)]$ multiplied by βPA, is the premium that rewards (or penalizes) the grower whose seed corn yield is higher (lower) than the average regional yield (y_0). This contract's final payment is conditional on each grower's relative performance which creates competition among contracted-growers.

The advantage of this tournament contract design for the processing firm is the cost-effectiveness. There is a high transaction cost associated with per acre seed corn production, including monitoring and scouting costs. Other costs include seed, pesticides, and detasseling costs. The processor's cost can be reduced, if the contracted grower produces a high level of seed corn yield. A tournament contract is designed for this purpose.

Two factors motivate contracted-growers to achieve high yield goals. First, a high premium (or penalty) is associated with seed corn yield above (or below) the average regional yield. Second, competition exists due to limited contract availability. Because seed corn companies tend to offer contract renewals based on the contracted-growers' historical yield performance, growers perceive a risk of losing the contract associated with low yields. Therefore, contracted-growers interviewed believed that achieving high yields is important for maintaining existing seed corn contracts and obtaining new ones (Dobbins and Swinton, 1995; Batie and Swinton, 1995).

One common way to attempt to achieve high yields is to increase the amount of nitrogen fertilizer applied. Though this can be done at relatively low cost, high nitrogen fertilizer applications can lead to leaching.

3.4.2 Key Environmental Issues: Nitrate Leaching

Seed corn is a high-value crop because the grower net incomes from producing seed under current contract is higher than if they produced commercial corn or other crops. The economic return for one additional bushel of seed corn is high. Though nitrogen is one of the most effective inputs to achieve high yield goals its uptake is constrained by plant capacity and it is influenced by weather conditions (Martin, 1992; Ritchie, 1993). For example, plants are able to take up more nitrogen fertilizer under excellent weather conditions than in normal or poor weather. Because weather conditions are difficult to predict, growers tend to apply high nitrogen rates in order to maximize corn yields in hopes of excellent weather conditions (Babcock, 1992). In normal or poor weather conditions, excessive nitrogen application causes more nitrate leaching to groundwater. In addition, because seed corn is a specialty crop that is not widely grown nationally, research-based optimal nitrogen fertilizer recommendations for seed corn growers are not widely available. There is no restrictions on the amount of nitrogen used within seed corn contracts. Hence, seed corn growers tend to apply nitrogen fertilizer to ensure maximum yield under optimal weather conditions (Wych, 1988).

In addition to nitrogen applications, other agronomic practices can affect nitrate leaching as well. Examples include nitrate carryover from previous crops, tillage practices, and irrigation and fertilization timing (Martin, 1992). In order to design an optimal "green" contract, relationships between nitrogen use, nitrate leaching, profitability and agronomic managements have to be considered.

3.5 Summary

This chapter has reviewed the importance of contractual production in U.S. agriculture. Production contracts are especially important in the seed corn industry in order to ensure genetic purity and protect genetic security. A specific seed corn contract from St. Joseph County, Michigan, is used to illustrate how nitrate leaching could be related to existing contract designs. Nitrate leaching comes from excessive nitrogen application, although it can be affected by other agronomic management practices as well. If a processing firm is concerned the environmental quality, production contracts can be used as a tool to control agricultural NPSP. The principles of contract design to accomplish this goal will be explored in the next chapter.

CHAPTER 4

THEORETICAL FRAMEWORK FOR CONTRACT DESIGNS: A PRINCIPAL-AGENT MODEL

This chapter develops a theoretical principal-agent framework to examine the relationship between a representative agricultural processor (the principal) and a representative contracted-grower (the agent). This model is extended to examine the design of contracts where environmental quality outcomes supplement the agricultural products and services.

4.1 Review on Contract Design Literature

Contract theory is a subfield of information economics that is usually treated in the context of principal-agent problems. A central issue is the information asymmetries between principal (the processor) and agent (the contracted-grower), which makes it impossible or costly for the principal to observe actions taken by the agent. Such situations present the potential for moral hazard--instances in which the agent can benefit through actions that the principal cannot observe, but which may be contrary to the principal's welfare. Thus, if the principal wants the agent to take an action favorable to the principal but costly for the agent, an incentive scheme must be designed to influence the agent's decision rule (Baron, 1987; Demski and Sappington, 1984; Hirshleifer and Riley, 1992; Kreps, 1990; Milgrom and Roberts, 1992;

Sappington, 1991; Varian, 1992).

A general conceptual framework for a principal-agent model is described below. This model can be used to describe the relationship between a seed corn processing firm (the principal), and a contracted-grower (the agent). This framework outlines the key elements that need to be identified in designing an optimal contract. Let A be the set of actions (which includes the levels of nitrogen fertilizer input, labor, etc.) available to the agent. ϵ is assumed to be a state of nature drawn from a probability density function g. The action taken by the contracted-grower (denoted by a, where $a \in A$) and the state of nature jointly determine an observable outcome $y=y(a,\epsilon)$ as well as the monetary payoff $\pi=\pi(a,\epsilon)$ for the principal. y can be a vector, such as yield of seed corn and nitrate-leaching (a by-product), and π is the revenue of the seed corn processor. The utility functions of both the processor and the contracted grower increase with the monetary payoff. The agent receives a payment $s(y)$, based on the observable outcome. The agent also incurs a cost for taking action a, which is denoted $c(a)$. The objective function of the representative contracted-grower (agent) can be written:

$$u(w)=u(s(y)-c(a)) \tag{4.1}$$

That is, the monetary payoff (w) to the contracted-grower is a function of the payment received minus the cost of complying with the contract.

The processor's problem is to design an incentive scheme $s(.)$ that will induce the contracted-grower to take the action that maximizes the processor's objective function, denoted by $v(\pi\text{-}s(y))$, over all states of nature. Through the payment scheme $s(y)$ that transforms outcomes into payments for the agent, the processor can indirectly control the contracted-grower's action. Mirrlees (1974, 1976), Holstrom (1979), and Hart and Holstrom (1987) proposed a method to re-specify parameters of the distribution to solve this problem. Revenue (π) is assumed to be a function of y. They argued, by the choice of a, the agent effectively chooses a distribution over y and π, which can be derived from g via the technology $y(.)$. This derived probability distribution is denoted by $f(y;a)$. The principal's problem therefore becomes:

$$\max_{s,a} \int v(\pi-s(y))f(y;a)dy$$

$$\text{subject to} \quad \int u(s(y)-c(a))f(y;a)dy \geq u^o \tag{4.2}$$

$$\int u(s(y)-c(a))f(y;a)dy \geq \int u(s(y)-c(a^e))f(y;a^e)dy \tag{4.3}$$

where u^o is the agent's reservation utility, and a^e is an agent's alternative action.

This model illustrates the two key components of the principal's problem. The **participation constraint** in equation (4.2) ensures that the agent elects to engage in the principal's enterprise. The intuition behind this constraint is that participation yields utility at least equal to what the agent might obtain from some alternative feasible enterprise. The **incentive compatibility constraint** in equation (4.3) ensures that the optimizing agent will choose those actions preferred by the principal (a) over alternative feasible actions (a^e).

The processor chooses incentive payment s to induce the grower's action a, which satisfies both constraints. The Lagrangian function yields the optimal risk-sharing rule:

$$\frac{v'(y-s(y))}{u'(s(y))} = \upsilon+\varsigma\left(1-\frac{f(y;a^{a})}{f(y;a)}\right) \quad (for\ s) \tag{4.4}$$

where υ and ς are Lagrangian multipliers corresponding to the participation constraint and the incentive compatibility constraint.

If the action preferred by the principal has either a lower cost to the agent than other alternative action, or is easy to monitor, the first-best risk-sharing rule will be satisfied automatically. That is, the principal's marginal utility in terms of the agent's marginal utility is equal to the agent's reservation price of taking this contract (i.e., incentive compatibility constraint is not binding, thus $\varsigma=0$). If the agent's action is impossible, or costly to observe, the incentive compatibility constraint will be binding (i.e. $\varsigma>0$).

Equation (4.4) thus states that penalties or bonuses should be paid in proportion to the ratio $f(y;a^{a})/f(y;a)$, referred to as a likelihood ratio (Holmstrom, 1979). It measures the ratio of the likelihood of observing y given that the agent chooses a^{a} to the likelihood of observing y given that the agent chooses a. A high value of the likelihood ratio is evidence in favor of the view that the agent chose the action a^{a}, while a low value of the likelihood ratio suggests that the agent chose the action a (Milgrom, 1981; Varian, 1992). The *Monotone Likelihood Ratio Property* is a commonly used condition that requires this likelihood ratio $f(y;a^{a})/f(y;a)$ to decrease monotonically in output y. Consequently, the payment $s(y)$ will be a monotonically increasing function of output. That is, the payment increases when the observed output increases.

Contractual production was first examined by Coase in his seminal study, **The Nature of the Firm**. He emphasized that transaction costs of production can be minimized through vertical coordination (Coase, 1937). Such vertical coordination is especially important when risk is very high, information is scarce, or when asset-specificity exists in a production process (Williamson, 1979). Contract production is one form of vertical coordination that can reduce risks, resolve the issue from asymmetric information, and avoid a big investment of the firm.

Three elements affect contract specification: the structure of markets faced by both principal and agent, the risk preferences and production sets of both principal and agent; and the principal's ability to observe the agent's actions (Holmstrom, 1979 and 1982; Krep, 1990; Varian, 1992). The market structure will determine the bargaining power with respect to contract specifications. For instance, when the principal is in a monopsony-type firm while the agent is a competitive firm, the agent can only get its reservation price under a contract. Risk attitudes determine the risk-sharing between the principal and the agent. If the agent's action can be directly observed (the third element mentioned above) without significant cost, a "first best" risk-sharing rule will be reached. Otherwise, there is a trade-off between observability and risk-sharing (Hart and Holmstrom, 1987; Rees, 1987; and Sappington, 1991).

The literature on contract theory provides the theoretical framework to formulate the relationship between the principal and agent; however, empirical work consistent with this framework is rare. Incentive schemes are usually discussed in the literature in terms of taxes or penalties to control nonpoint source pollution; thus, they represent a regulatory perspective. This research will take an empirical approach to contract specification focusing on voluntary pollution control. The principal-agent framework is modified to represent a specific seed corn contract, which has a linear incentive payment. A general form of a linear payment includes a fixed amount and a variable payment proportional to seed corn yield.

4.2 Conceptual Framework for A Seed Corn Contract

The model presented here assumes that the processor (the principal) is a monopsonist, while the contracted-grower is a competitive farmer. The assumption is based on the evidence that farmers compete to obtain seed corn contracts because they provide higher return and lower risks than other contracts or other crops. Therefore, the principal has more negotiation power than do the growers. As indicated in Chapter 3, the current seed corn contract puts a high premium on those yield increments above the average regional yield, creating an incentive for growers to apply nitrogen fertilizer generously.

The relationship between nitrogen use and the incentive payment can be shown in equation 4.5. With the price of seed corn normalized to 1, the per-acre payment to the seed corn grower becomes:

$$\begin{aligned} s(y) &= [\alpha(y-y^0)+Q]\beta P' \\ &= \beta P'(Q-\alpha y^0) + \alpha\beta P'y \\ &= \kappa + by \end{aligned} \tag{4.5}$$

where P' is the price ratio of commercial corn to seed corn. This payment $s(y)$ can be written in a linear form consisting of two parts: a fixed payment ($\kappa = \beta P'(Q - \alpha y^{\rho})$) and a variable payment ($b = \alpha\beta P'$), based on actual seed corn yield. Coefficients κ and b on the fixed and variable payments become the seed corn processing firm's choice variables to design an incentive payment. This linear payment form has two advantages. Not only does it provide a convenient basis for analysis, but more importantly, a linear form has shown to be optimal for the principal to induce desired agent actions (Diamond, 1995).

4.2.1 Objective of the Processor and Contracted-Grower

In order to illustrate the optimal contract design, the objectives for both processor and contracted-grower need be identified. Assume that the processor is risk-neutral[3], and that he (or she) will specify κ, a fixed payment, as well as b, a variable payment, to induce the agent's action to maximize expected profits. In this case, the nitrogen fertilization rate, n, and other inputs, z, are the agent's control variables to grow seed corn. The processor's objective function is to maximize his or her gross margin, calculated by seed corn yield minus the payment made to the grower. That is:

$$Max\ E[y - s(y)] = (1-b)y - \kappa \tag{4.6}$$

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[3]The seed corn processor examined in this model is a large firm. A large firm often has insurance against losses, and has the ability to spread out risks through equity as well as other investments, therefore, it is reasonable to assume risk-neutral behavior (Diamond, 1995).

This research uses a representative seed corn contracted-grower to evaluate the economic impacts from alternative contract designs. Let the grower-agent's risk preferences be characterized by a mean-variance utility function with constant absolute risk aversion (Freund, 1956), where the risk aversion coefficient is denoted λ. (The criteria for selecting the empirical risk model will be discussed in Chapter 7.) The grower's expected utility function per acre from growing seed becomes:

$$\begin{aligned} Eu(w) &= Eu[s(y)-c(n,z)] \\ &= [(Q-\alpha y^o)\beta P'] + \alpha\beta P'y - pn - z - (\lambda/2)(\alpha\beta P')^2\sigma^2 \\ &= \kappa + by - (\lambda/2)b^2\sigma^2 - pn - z \qquad \textbf{(4.7)} \end{aligned}$$

Equation 4.7 states that the grower's expected utility equals the expected profit $(\kappa + by - pn - z)$ minus the variance of income $(b^2\sigma^2)$ weighted by his or her risk preference $(\lambda/2)$. Equation 4.7 assumes that yield is the only random variable faced by the grower, and that nitrogen use and other inputs do not affect the probability distribution of yields.

4.2.2 Seed Corn Production and Leaching Functions

The seed corn production function is assumed to be:

$$\begin{aligned} &y = f(n, z) + \varepsilon, \qquad \textbf{(4.8.a)} \\ &\varepsilon \sim (0, \sigma^2) \end{aligned}$$

where n is the amount of nitrogen fertilizer applied, z is the vector of other inputs, and ε is a random variable. Nitrogen fertilizer is assumed to increase yield at a diminishing rate ($y_n > 0$, $y_{nn} < 0$, where $y_n = \partial y/\partial n$, and $y_{nn} = \partial^2 y/\partial n^2$)[4].

The use of nitrogen generates a by-product--nitrate leaching, ***L***. The leaching function from seed corn production is assumed to be:

$$L = g(n,z,\ y(n)) + \eta \qquad \textbf{(4.8.b)}$$
$$\eta \sim (0, \theta^2),$$

Leaching is affected by nitrogen application and other inputs, such as irrigation. It is also affected by seed corn yield. In a good weather condition, plants might be able to uptake more nitrogen and produce higher yield, resulting in less nitrate leaching, than they would in a normal weather condition. In general, the amount of nitrate leaching increases with respect to nitrogen use (i.e., $L_n > 0$, where $L_n = \partial g/\partial n + (\partial g/\partial y)(\partial y/\partial n)$. In many cases, nitrate leaching is ignored by the grower because of its externality characteristic, that is, the social cost of nitrate leaching is ignored.

For simplicity, the random variables, ε and η, are assumed to be distributed independent of the nitrogen application level. Other inputs, z, might affect nitrate leaching as well. Examples that reduce leaching include planting cover crops in the winter, controlling irrigation properly, and using minimum tillage (Martin, 1992). For analytical convenience, this research will focus on the impacts from nitrogen application control, assuming that other inputs are held constant at z^0 and do not contribute to the level of nitrate leaching.

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[4] This assumption mirrors reality for many but not all circumstances. Evidence exists for instances where yield may plateau or actually decline with supplemental nitrogen (Peterson and Corak, 1994). Plant response depends heavily on existing soil nitrate levels, climate, and biological activity.

Based on the functional form in equation (4.7), the decision rule of nitrogen application for the representative grower becomes:

$$
\begin{aligned}
Max_{\{n\}} EU(w) &= [(Q-\alpha y^{o})\beta P'] + \alpha\beta y - pn - z^{o} - (\lambda/2)(\alpha\beta P')^{2}\sigma^{2} \\
&= \kappa + by - (\lambda/2)b^{2}\sigma^{2} - pn - z^{o}
\end{aligned}
\qquad \textbf{(4.9)}
$$

Equation 4.9 implies that the grower chooses a nitrogen level to maximize his or her profit, which equals the payment received from the processor minus nitrogen costs and the expenses for other inputs.

Since nitrate leaching is incorporated neither in the current contract nor the grower's objective function, a profit-motivated contracted-grower will use nitrogen at the level where $\alpha\beta P'y_n = p$ or $by_n = p$. That is, he or she will use nitrogen according to the marginal benefit (by_n) equal to its margin cost (p). As the variable payment increases, or the price of nitrogen decreases, the application of nitrogen fertilizer will increase. This decision rule implies that the social damage cost (or externality) from nitrate leaching is ignored in the production process. As a result, the grower uses too much nitrogen fertilizer from the social perspective. This result is coincident with the evidence of excessive nitrate concentration in the groundwater for some seed corn production regions (King, 1994).

For purposes of avoiding future regulation or negative public relations, a processor may wish to reduce nitrate leaching on the farms of contracted growers. If the processor cares about the contract's indirect influence on environmental quality, then the processor should design contracts that do not put too much weight on the variable payment due to its tendency to induce high nitrate-leaching[5].

4.2.3 Participation Constraint and Incentive Compatibility Constraint

In order to ensure that the contracted-grower can earn at least up to his or her reservation utility level, the participation constraint should be satisfied. That is:

$$Eu(w) = \kappa + by - (\lambda/2)b^2\sigma^2 - pn - z^o \geq u^o \tag{4.10}$$

where u^o is the opportunity cost for growing seed corn; u^o can represent the return from growing cash crops, or taking other contracts.

The corresponding incentive compatibility constraint for the contracted-grower is denoted by $by_n = p$, where the grower's expected utility is always maximized.

4.2.4 Optimization Without Environmental Constraint

Without considering nitrate leaching, an optimal incentive scheme for the processor is to choose a combination of the fixed payment, κ, and the variable payment, b, to induce the contracted grower to undertake the action, n. That is,

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[3] While reducing fertilizer use can result in "win-win" situations where profitability and environmental quality are both served, the high value of many contracted commodities -- seed corn in particular -- makes a "win-win" outcome less likely than in the instance of lower-value agronomic commodity production.

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$$\begin{aligned}&\underset{\kappa, b, n}{Max}\ (1-b)\ y-\kappa\\&\textit{subject to}\\&\quad \kappa+b\ y-\frac{\gamma}{2}b^2\sigma^2-pn-z^o\geq u^0\\&\quad by_n=p\end{aligned} \tag{4.11}$$

The corresponding non-corner solution will be:

$$\begin{aligned}b^* &= \sqrt{\frac{y_n(y_n-p)}{(-y_{nn})\ \lambda\sigma^2}}\\ \kappa^* &= u^o-b\ y+pn+\frac{\lambda}{2}\ b^2\ \sigma^2\\ &\textit{where}\ \frac{\partial b}{\partial\lambda},\ \frac{\partial b}{\partial\sigma^2},\ \frac{\partial b}{\partial p}<0\end{aligned} \tag{4.12}$$

Equation 4.12 states the optimal variable payment as well as fixed payment. This payment scheme defines an optimal risk-sharing rule. The equation shows that the variable payment (*b*) decreases with increases in the contracted-grower's level of risk aversion (λ), in the level of yield risk (σ^2), and in the price of nitrogen (*p*). These results have implications. Intuitively, equation 4.12 states that the variable payment should be less if the grower is highly risk-averse (λ is high), so that this risk-neutral principal will share more risk in order to meet an optimal risk-sharing rule. If the objective of the grower is characterized by decreasing or increasing absolute risk aversion, the level of wealth might affect the optimal results. Furthermore, if the yield variation is high, the variable payment should be small under this optimal risk-sharing rule.

4.3 Alternative "Green" Contract Designs

Since penalties for nitrate leaching are not incorporated in the current contract, and because leaching possesses the characteristic of a negative externality, a profit-motivated contracted-grower may use higher nitrogen levels than is socially optimal. The processing firm may be concerned with maintaining its "green" reputation as well as fearing potential future government regulations for nitrate leaching caused by seed corn production. The assumption is that the company wants to reduce nitrate leaching from the production of its contracted-grower, providing there is not too large a tradeoff with seed corn production or profits. The research issue to be addressed is how to design a seed corn contract that will encourage contracted-growers to voluntarily reduce nitrate leaching while still maintaining high yields and profitability, i.e., being "green and competitive" (Porter and van der Linde, 1995).

Using a contract for pollution control is discussed by Segerson and Tietenberg (1992), Cabe and Herriges (1992) and Segerson (1994). They recognize that due to the contractual (principal-agent) relationship between the employer and the employee, the buyer and the seller, or the owner and the lender, there is a possibility of cost shifting between the two parties. For example, if the government imposes a liability rule on the processing firm for the environmental damage caused by its contracted-producer, the firm can shift some of the associated costs to its farmer producers through decreases in compensation, or increased monitoring efforts and input prices. The effectiveness of this liability shifting (transfer) will depend on the lags between the time contamination occurs and the time cleanup is required, as well as information about the extent of the contamination. In order to model this relationship, the principal may design an incentive scheme, based on his or her preference with respect to profit and potential liability as well as the agent's constraint, that is, the need to induce the agent to undertake the activity that is preferred by the principal (Segerson, 1994). In order to obtain the optimal incentive payment, the relationship and terms in contract theory need to be explored.

As identified in Chapter 2, a number of contract designs are capable of achieving NPSP control. These strategies can be employed to reduce NPSP, based on outputs, inputs, managements, emissions, ambient levels, and damage liability. These strategies are modified and used to induce contracted-growers to reduce nitrate leaching. Four potential approaches are: 1) restricting nitrate leaching outcomes or agronomic practices within contracts; 2) specifying financial "punishment" within contracts; 3) rearranging the incentive payment schemes; and 4) providing information within contracts.

4.3.1 Imposing a Restriction within Contracts

The most common textbook approach to reduce nitrate leaching is for the contract to restrict outcomes or permissible production practices directly. Such restrictions might include the expected level of nitrate leaching in groundwater[6], or restrict permissible agronomic practices, such as the amount of nitrogen fertilizer

[6]The ambient level can be measured by sampling underground water from the region, or simulated from a crop growth model, such as DSSAT 3.0. However, the enforcement costs need to be considered. Such enforcement issues will be discussed in the Chapter 8.

applied (***n***), timing of nitrogen fertilization and irrigation, choice of crop rotation, or planting of winter crops (Harwood, Ritchie, Vitosh, 1996).

Assume that nitrate leaching has a non-random relationship with nitrogen fertilizers, and it can be easily observed or simulated with high reliability; the processor can impose on the contracted-grower a constraint for the permissible level of nitrogen fertilizer (n^o), where the consequence of failing to comply is loss of the seed corn contract, or some other penalty. The contracted-grower's optimization problem becomes:

$$\begin{aligned} &Max\ Eu(y) = \kappa + by - (\lambda/2)b^2\sigma^2 - pn - z^o \\ &Subject\ to\ n \leq n^o \end{aligned} \tag{4.13}$$

Equation 4.13 states that in order to grow seed corn, the amount of nitrogen applied has to be lower than the permissible level (n^0). Optimization yields the following decision rule:

$$by_n = p + \mu \tag{4.14}$$

where μ (the Lagrangian multiplier on the constraint) takes the value zero if the constraint is not binding, or represents the shadow price of the additional constraint if the constraint is binding. A positive value of μ means that the use of nitrogen fertilizer will decrease due to diminishing margin product of nitrogen. Depending on the value of the seed corn contract to the contracted-grower, this constraint could be a strong incentive to comply with the nitrogen fertilizer standard.

Another form of restriction is to specify a permissible probability on the ambient nitrate level above the water threshold levels (Segerson, 1988). That is, the objective can be designed to meet the following chance restriction if the strategy targets nitrate level from growing seed corn.

$$B(L;\bar{L}) = Prob(L \geq \bar{L}) \leq 1/h^{*} \quad \textbf{(4.15)}$$

where ***B(.)*** is the cumulative distribution function of nitrate leaching above the threshold level $(\bar{L})$; and $1/h^{*}$ is the permissible probability for nitrate leaching (***L***) exceeding the threshold level $(\bar{L})$. In this case, the optimal nitrogen use is:

$$by_n = p + \mu' B_L L_n \quad \textbf{(4.16)}$$

where B_L $(=\partial B/\partial L)$ and L_n are greater than zero, that is, higher nitrate application increases the probability of nitrate leaching above the threshold level. A positive value of $\mu' B_L L_n$ means that the use of nitrogen fertilizer will decrease.

From a contract-design standpoint, much depends on the value of the contract. For a contracted-grower who values the seed corn contract only slightly more than an alternative enterprise, the value of the contract will be close to zero and therefore the incentive to comply with the fertilizer constraint will be small. Nevertheless, to the extent that such marginal contracted-growers fail to comply and lose their contracts, the processor will violate the participation constraint in equation (4.10), so the incentive payment, $s(y) = \kappa + by$, must be enhanced.

Such restrictions can be imposed on other agronomic management practices as well. One example of such a restriction would be to forbid seed corn in rotation with high leaching crops such as potatoes.

4.3.2 Specifying Financial "Punishment" within Contracts

One alternative to a rigid restriction is a financial penalty associated with exceeding a specified threshold level of nitrate leaching. For example, if nitrate leaching from each field can be measured or simulated, a Pigouvian fee can be imposed on the amount exceeding a certain level, perhaps the safe drinking water standard of 10 ppm MCL. A flat-rate penalty on any field exceeding the permissible level would be simpler to apply. Alternatively, such a financial punishment can be imposed on nitrogen fertilizer uses to induce growers to cut nitrogen application, and subsequently reduce nitrate leaching.

For example, if nitrogen applied can be directly observed, the processor might impose a fee (or simply transfer the user charge fee), r, on the contracted-grower for nitrogen use above the permissible nitrogen level, n^0. Moreover, assume that the amount of nitrate leaching is affected by weather and it can only be measured *ex post*. A fixed penalty τ can be imposed on this excessive nitrate leaching outcome. Again, $B(L;\bar{L}) = Prob(L \geq \bar{L})$ represents the cumulated distribution function of nitrate leaching (L) above the threshold level ($\bar{L}$). The optimization for the contracted-grower thus becomes:

$$\max_{n} Eu(y) = \kappa + by - (\lambda/2)\, b^2\sigma^2 - p\,n - z^e - r\,\max(0, n-n^0) - E(T),$$
$$\text{where } E(T) = \tau B(L;L) \tag{4.17}$$

Equation 4.17 outlines two kinds of financial penalties: on nitrogen use or on nitrate leaching. Nitrogen user fee (r) is directly imposed on the amount of nitrogen use. $E(T)$ is the expected penalty when the ambient nitrate leaching level exceeds the threshold L^0. This expected penalty depends on $B(.)$, the cumulative distribution function for nitrate leaching above the threshold level, and τ is a flat rate for this violation. $B(.)$ depends on the specification of threshold level as well as the actual amount of nitrate generated. When the threshold level is high, the possibility of receiving a penalty would be low, i.e., $\partial B/\partial L^0 < 0$. On the other hand, when the amount of nitrate leaching increases, a penalty is more likely, that is, $\partial B/\partial L > 0$. Since the use of nitrogen fertilizer increases the amount of nitrate leaching, it also increases the probability of a penalty, that is, $\partial B/\partial n = B_L L_n > 0$.

Optimization yields the following decision rule:

$$\begin{aligned} by_n &= p + r + \tau B_L L_n && \text{if } n > n^0 \\ by_n &= p + \tau B_L L_n && \text{otherwise} \end{aligned} \qquad \textbf{(4.18)}$$

This result shows that imposing a financial punishment, r or τ, increases the marginal cost of using nitrogen fertilizer. When this penalty is large, or when the use of nitrate increases the probability of incurring the penalty, the amount of nitrogen applied will be reduced compared to the scenario without the penalty. This result is due to its diminishing marginal physical product of nitrogen fertilizer (i.e., $y_{nn} < 0$).

4.3.3 Reducing the Incentive Payment Schemes

If the principal internalizes the social cost of nitrate leaching into the incentive payment, the resulting variable payment will be less than what would result if the negative externality is ignored. One form in which environmental concern could enter the processor's objective function is as a per-unit leaching penalty on nitrate leaching when leaching ($L(n)$) exceeds some threshold (L^o). As equation 4.8 showed, nitrate leaching is assumed to be $L(n)=g(n,z^0)+\eta$, where $\eta\sim(0,\theta^2)$. Such a "penalty" could be interpreted as a weighting placed by the processor firm on the risk of future regulation resulting from perceived groundwater contamination that is tied to the company's activities. If nitrate leaching is linear with respect to nitrogen fertilizer use, then the processor's problem becomes:

$$\begin{aligned}&\underset{\kappa,b,n}{Max}\ (1-b)y-\kappa-t(L-L^0)\\&\textit{subject to}\\&\quad \kappa+by-\frac{\lambda}{2}b^2\sigma^2-pn-z^o \geq u^0\\&\quad by_n=p\end{aligned} \tag{4.19}$$

where the processor's objective is affected by the amount of nitrate leaching. If nitrate leaching exceeds the threshold level, L^o, such that the tax takes effect, the optimal variable payment that solves the processor's problem is

$$b^* = \sqrt{\frac{y_n(y_n-tL_n-p)}{(-y_{nn})\gamma\sigma^2)}};\quad where \frac{\partial b}{\partial t}<0 \tag{4.20}$$

Equation (4.20) suggests several interesting results for design of an optimal variable payment (b). As expected, the variable payment, b, declines with increases in the leaching "penalty", t.

While this contract design avoids the moral hazard (enforceability) problem inherent in the nitrogen use constraint contract, the processor bears all costs of leaching reduction. The reduced incentive payment (**b**) would force the fixed payment (κ) to increase by a corresponding amount in order to respect the participation constraint. In terms of profitability, since expected seed corn yield would decline, the processor would be worse off by the value of the yield decline plus the change in the fixed payment minus the weighted value of the variable payment. The contracted-grower will be no worse off than before.

The above contracts, however, vary in the required measures as well as economic impacts on the principal and the agent. Imposing a restriction or charging a financial fee on nitrate leaching or nitrogen use requires monitoring the amount of nitrate leaching or nitrogen application rate. On the other hand, modifying the incentive payment requires the observation of yield output. An empirical analysis is required to evaluate the economic impacts. Both issues will be examined in the following chapters.

4.3.4 Providing Information within Contracts

The processor-principal could provide information to contracted-growers as a supplement to any contract design. The principal may be well-positioned to support applied research on low-cost methods of reducing nitrate NPSP, and diffusing the results to contracted-growers. Many processing firms either have developed their own research projects, or have joint projects with other researchers such as those within universities. Research is frequently directed at discovering practices which reduce nitrate leaching. The information offered by the processor-principal might include adequate amount of nitrogen, appropriate timing for nitrogen fertilization and irrigation, less leaching crop rotation practices, and winter crop planting. Such information could be delivered through a required grower training program, information packet, or field visits, and could be certified through a stewardship test.

Providing information to growers might avoid setting an unrealistic yield goal from the grower's subjective perception on nitrogen uses (Supalla et al., 1995). Because the information about nitrogen uptake for seed corn is not widely available, such information is more valuable to develop a "win-win" strategy. From personal interviews with several current growers, the results indicated that some growers apply the same amount of nitrogen on seed corn as that on commercial corn (Batie and Swinton; Dobbins and Swinton, 1995). Since some reduction from commercial corn fertilization rates is possible without reducing yields, even in excellent weather, there appears to be considerable potential for an information program.

4.4 Summary

This chapter identifies the structure, and the main components of an optimal seed corn production contract. A principal-agent model is adopted to examine alternative "green" contract designs from the perspective of a risk-neutral seed corn monopsonist and a risk-averse grower. Four categories of alternative contract designs were illustrated: a) restricting outcomes or practices within contracts; b) specifying financial "punishment" within contracts; c) rearranging the incentive payment schemes; and d) providing information within contracts.

These contracts, however, vary in economic impacts on the principal and the agent as well as in enforceability. In order to evaluate the effectiveness of these alternative contracts, an empirical analysis is required. Chapters 5, 6, 7, and 8, will present an empirical method that incorporates the biophysical production and environmental impacts of seed corn production to evaluate and compare the performance of these alternative contract designs. Contract enforceability will be examined as well.

CHAPTER 5

SIMULATION OF ALTERNATIVE CROP MANAGEMENT SCENARIOS

In order to successfully design contracts that can control NPSP, knowledge of the biological and economic dimensions of the pollution generation processes are essential. This research uses a crop growth simulation model --DSSAT 3.0-- to examine the relationships between nitrogen use, yield, and nitrate leaching. These data are subsequently incorporated into whole-farm planning models in Chapters 6, 7 and 8 to calculate the economic impacts on the contracted-grower and the processor from alternative contract designs.

5.1 Review on the Crop Growth Simulation Model -- DSSAT 3.0

The Decision Support System for Agrotechnology Transfer (DSSAT 3.0; Tsuji, Uehara, and Ballas, 1994) that contains a set of crop growth simulation models were used in this research. DSSAT 3.0 is supported by International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT). The CERES models are used to simulate cereal crops, including maize, wheat, sorghum, and rice (Jones and Kiniry, 1986). The CROPGRO models are used for legume crops, including soybeans, peanuts, and dry beans (Wilkerson et al., 1983). Other models are used for rootcrops and other vegetable crops. Three crop growth simulation models will be used in this research; CERES-MAIZE for both commercial corn and seed corn (Jones and Kiniry, 1986; Martin, 1992), SOYGRO for soybeans (Wilkerson et al., 1983), and SUBSTOR for potatoes (Ritchie et al., 1996).

DSSAT 3.0 simulates plant growth and development on a daily basis by integrating the interactions of genetic type, daily weather, soil, and soil nitrogen, as well as management practices. DSSAT 3.0 has two advantages over other crop growth simulation models. First, it provides a more detailed accounting of phenological development and stresses encountered in each phenological stage than other models (Kiniry, 1991; Jones et al., 1991; Krause, 1992). This advantage enables more accurate prediction of variation in crop yields from year to year under different planting dates. Second, DSSAT 3.0 requires only moderate amounts of input data, compared with other simulation models (Krause, 1992). These two advantages have made DSSAT an attractive tool to researchers.

DSSAT has undergone considerable testing and use by researchers (Algoxin et al., 1988; Boggess and Ritchie, 1988; Hodges and Evans, 1990; and Martin, 1992). For instance, Kovacs et al. (1995) showed that CERES-MAIZE accurately projected regional yields in Hungary during a twenty year period test. DSSAT explicitly tracks nitrogen sources and fates, including nitrogen application, grain nitrogen, soil nitrate, and nitrate leaching. Thus, DSSAT is well suited to developing nitrogen fertilizer management alternatives. The amount of yield, and the cumulative nitrate leaching have been validated by several studies in different locations (Jones and Kiniry, 1986; Martin, 1992; Ritchie et al., 1993; Kovacs et al., 1995).

The soybean model within DASSAT 3.0 -- SOYGRO -- was developed and improved by Wilkerson et al. (1983) and Jones et al (1987). Tests were conducted in Gainesville, Florida, to evaluate the accuracy of the model at various locations (Jones and Mishoe, 1991). These tests showed that the model predicted well for different cultivars and locations. The potato model--SUBSTOR--was originally developed by Griffin, Johnson, and Ritchie (1993). The potato growth, development, and yield were tested in Michigan by Ritchie et al. (1996).

Its versatility, wide validity, and limited data demands have led researchers to use the DSSAT models for simulating such different management strategies, as varying the planting populations (Piper and Weiss, 1990), light interception (Hodges and Evans, 1990), irrigation strategies (Algozin et al., 1988; Boggess and Ritchie, 1988; Worman et a., 1988), and tillage systems (Krause, 1992). These ongoing research projects have greatly improved the flexibility of DSSAT model.

5.2 Analytical Methods to Simulate Crop Yield and Nitrate Leaching

Each crop growth simulation model in DSSAT 3.0 shares the same basic structure and input data requirements (Krause, 1992; Martin, 1992; Jones and Kiniry, 1986; and Wilkerson et al., 1983). The basic structure includes:

1. Planting is done on a specific date. Soil characteristics, plant genetic coefficients, nitrogen treatments, irrigation treatments, and climatic data need to be specified.
2. The model simulates the growth process based on daily increments.

3. Temperature, photoperiod, and genetic parameters regulate the phenological development of the plant.

4. Phenological stages determine how biomass production through photosynthesis is partitioned among plant organs.

5. Solar radiation and plant leaf area determine biomass production.

6. Various stresses (including soil moisture, nitrogen or other nutrient deficiencies, temperature, soil bulk density and soil pH), reduce the plant's capacity to produce biomass and partition it for maximum yield.

7. The timing of these stresses relative to the phenological stage has important effects on crop yield.

8. Temperature, photoperiod, and/or genetic parameters determine the maturity date.

9. Grain yield is determined by genetic parameters and by how much biomass has been partitioned to the grain.

10. Soil moisture and nitrogen dynamics are determined by various processes throughout the simulation period (e.g. evaporation, transpiration, drainage, N uptake, mineralization, denitrification, leaching.)

The required input data for each simulation include:

1. Various soil characteristics, such as soil moisture, initial soil nitrogen levels, and soil temperature.

2. Meteorological data, including daily maximum and minimum temeratures, daily solar radiation, and daily precipitation.

3. Dates for the start of the simulation, planting, and irrigation treatments.
4. Planting depth and plant spacing (plant population).
5. Crop-specific genetic parameters.
6. Residue amounts from the previous crop, depth of incorporation, and the carbon to nitrogen ratio for those residues.
7. Dates, amounts, formulations, and depths of nitrogen fertilizer applications.

For the purposes of this study, the location and soil structure are specified to reflect the typical characteristics in St. Joseph County, Michigan. Appendix A lists the key parameters used in the simulation model, including genotypes, soil type, initial soil conditions, planting and harvesting details, irrigation, as well as water management, and fertilization management.

5.2.1 Methods for Crop Growth and Nitrate Leaching Simulation

Forty-two years of yield and nitrate leaching were simulated for common Michigan seed corn, commercial corn, soybean, and potato genotypes using 1951-1992 actual daily weather data. Rainfall, temperature, and precipitation daily data are from the case study area, Three Rivers, Michigan, and solar radiation data are from nearby Ft. Wayne, Indiana (National Weather Service, provided by Andresen, 1996). These locations are the nearest weather stations to the study area with complete records for the study period. Annual average minimum temperature, average maximum temperature, total rainfall, and average solar radiation used in this simulation model are listed in the

Appendix B.

Twenty-one nitrogen treatments were simulated in continuous seed corn production, starting from 0 kg/ha and increasing in 10 kg/ha intervals to 200 kg/ha, in order to estimate the variations of seed corn yield, as well as nitrate leaching with respect to different nitrogen application rates. Seed corn yield represents the productivity and nitrate leaching represents the externalities (by-products) of nitrogen use in this case.

The simulation of seed corn yield and nitrate leaching involves two stages. The genotypes used for male rows and female rows in seed corn production were different, therefore, these two gene types were designed in separate DSSAT 3.0 files. Because one row of male inbred is planted for every four rows of female inbred in seed corn production and since no yield is obtained from the male corn, the simulation data for female-row yield was multiplied by 0.8 to obtain actual per acre yields. In order to estimate total nitrate leaching from seed corn production, female rows and male rows are simulated separately and then adjusted by their acre proportions, where a coefficient on nitrate leaching of 0.8 is used for female rows and 0.2 is used for male rows.

In principle, the amount of nitrate leaching from seed corn production is the summation of leaching from both male and female rows. However, this estimation is subject to bias — that is, some of the nitrate released from the cutting of male rows after pollination will be absorbed by the female rows. Thus, it is difficult to simulate accurately the total amount of nitrate leaching for seed corn production when male- and female-rows are run in separate models. For simplicity, because the proportion of female rows is greater than the proportion of male rows, this study assumed that there was a fixed proportional relationship in nitrate leaching between male rows and female rows across all rotation practices in seed corn production, and this relationship could be estimated from continuous seed corn production (Ritchie, 1996). The estimated total amount of nitrate leaching was obtained from the model in two steps. In the first step, the relationship between nitrate leaching from female rows and from male rows was estimated by a regression, using the amount of nitrate leaching from female rows as the independent variable and nitrate leaching from the male rows as the dependent variable. The regression result is then used to estimate the total amount of nitrate leaching from seed corn production by adjusting simulated leaching from female rows.

Each crop in different rotation patterns is also simulated for the 42 year period. These patterns include continuous seed corn, seed corn in rotation with soybeans or potatoes, continuous commercial corn, and commercial corn in rotation with soybeans and with potatoes. Soybeans do not require any nitrogen application because they fix nitrogen. The nitrogen fertilization for potatoes is set at 265 kg/ha, an average nitrogen fertilization rate for Michigan potato production (Ritchie, 1989).

5.2.2 Adjustment to the Original Model

The previous validations for DSSAT were based on discrete data from one particular year, not from sequential years. Some biases existed in data simulated from the Sequential Analysis program of DSSAT 3.0, therefore, adjustments were made to the original DSSAT 3.0 model.

First, there was only a slight yield response to nitrogen applications from the original model. The output file indicated that the amount of organic matter in the model was decreasing over time, where organic matter was one source of plant-available nitrogen. The released decomposition of organic matter was absorbed by crop plants in the model. As a result, yields were over-estimated, compared with an actual situation. The parameter for organic matter in the soil was adjusted from coefficient 1.00 to coefficient 0.68 within the model. This adjustment keeps the soil organic matter pool at a constant level over time for continuous commercial corn with 120 kg/ha of nitrogen application rate (Ritchie, 1996). The organic matter for the treatments above 120 kg/ha will accumulate over time while those below 120 kg/ha will decline over time.

Second, several studies have indicated that the decay rate of fresh organic matter specified in DSSAT 3.0 was over-estimated by 10 times (Gabrielle and Kengni, 1996; Vigil et al., 1991). Therefore, the decay rate is adjusted to the correct level, that is, 10 times less than the original level.

The third bias occurs as an estimation error. Some of the yield data in one given treatment appear to be 10 percent higher than the yield from the treatment with 10 kg/ha more, and 10 kg/ha less nitrogen fertilizer in the same year. In this case, adjustment is made by taking the average of yield data from the treatments with 10 kg/ha more and 10 kg/ha less nitrogen fertilizer (Ritchie, 1996).

The DSSAT 3.0 model assumes perfect conditions for crop growth except weather and other user specified agronomic practices. Other risk sources, such as pest problems and mechanic failures, are not included. As a result, the yield data simulated from DSSAT 3.0 tended to over-estimate compared to actual field conditions, especially for continuous corn and seed corn (Ritchie, 1996). It was estimated that a 5-8 percent yield reduction in continuous corn and seed corn due to rootworm damage could occur in actual conditions (Vitosh, 1996; Miron, 1996; Stute and Posner, 1993). In potato and corn/seed-corn rotation, a 2-3 percent yield reduction might be expected because of some constraints on post-emergence herbicide use. However, because these data have considerable variation across farms, as well as across states of nature and because these are relatively small reductions, this research assumes that seed corn growers are able to control these risks by using pesticides so that any yield reduction is ignored in this study.

5.3 Simulation Yield and Nitrate Leaching Data from DSSAT 3.0

The average yield and nitrate leaching data simulated from DSSAT 3.0 under different nitrogen applications for continuous seed corn are listed in Table 5.1. Split applications were specified in the simulation model, where 30 kg/ha was applied as the starter. In order to be consistent with conventional U.S. farm data, these numbers were converted to Imperial units: acres (ac), pounds (lb), and bushels (bu). The moisture level of seed corn yield in Table 5.1 is at 15.5 percent, a standard moisture content for corn grain.

Table 5.1: Average simulated seed corn yield and nitrate leaching from DSSAT 3.0 for St. Joseph County, Michigan, 1951-92

No.	Nitrogen Fertilizer		Average Seed Corn Yield		Average Nitrate Leaching	
	(A) (kg/ha)	(B) (lb/ac)	(C) (kg/ha)	(D) adjust.(bu/ac)	(E) (kg/ha)	(F) adjust. (lb/ac)
1	0	0.0	750	9.56	13.6	19.5
2	10	8.9	1189	15.17	13.6	19.5
3	20	17.9	1705	21.75	14.5	20.4
4	30	26.8	2294	29.27	15.5	21.5
5	40	35.7	3063	39.07	15.9	21.9
6	50	44.6	3690	47.07	16.5	22.5
7	60	53.6	4168	53.17	17.1	23.2
8	70	62.5	4630	59.06	18.0	24.1
9	80	71.4	5101	65.07	18.8	24.9
10	90	80.4	5541	70.69	19.5	25.7
11	100	89.3	5805	74.05	20.2	26.5
12	110	98.2	6001	76.55	21.4	27.7
13	120	107.1	6047	77.14	23.2	29.6
14	130	116.1	6100	77.82	25.9	32.4
15	140	125.0	6119	78.05	29.4	36.1
16	150	133.9	6129	78.19	34.3	41.2
17	160	142.9	6133	78.24	41.1	48.3
18	170	151.8	6135	78.26	48.6	56.2
19	180	160.7	6136	78.28	56.7	64.8
20	190	169.6	6137	78.28	65.1	73.6
21	200	178.6	6137	78.28	74.4	83.3

Column ***A*** indicates the amount of nitrogen application in terms of kilograms per hectare, and it is divided by coefficient 1.12 to convert to pounds per acre (column ***B***). Column ***C*** lists the average seed corn yield in terms of kilogram per hectare, which are directly obtained from the female rows in DSSAT 3.0. These yield data were adjusted by multiplying by a coefficient of 0.8 to convert the simulated yield of the inbred female variety to the grower's actual seed corn yield. Yield data in kg/ha were then divided by 62.71 to convert them into bushels per acre (or bu/ac) units. The adjusted yield data are listed in column ***D***. Columns ***E*** and ***F*** list the average amount of nitrate leaching of female-rows simulated from DSSAT 3.0 and adjusted average total nitrate leaching from seed corn production, respectively. Column ***F*** combines the amount of nitrate leaching from female rows and male rows from seed corn production. Twenty-one nitrogen treatments using forty-two years of weather data (882 observations) were used to estimate the nitrate leaching relationship between female rows and male rows. The result from the regression is shown below.

$$L_m = 29.12 + 1.87\,L_f \tag{5.1}$$

(t-statisitic) ***(24.29) (60.79)***

Adjusted $R^2 = 0.77$

where L_m is per acre nitrate leaching from the male row and L_f is per acre nitrate leaching from the female row. Using the result from equation 5.1, the total amount of nitrate leaching from seed corn production in terms of pounds per acre is calculated by:

$$\text{Total nitrate leaching (lb/ac)} = (0.8^* L_f + 0.2^* L_m)/1.12 = 5.20 + 1.05\,L_f \tag{5.2}$$

where 1/1.12 is the coefficient that converts kg/ha to lb/ac.

Two observations can be made from Table 5.1. First, seed corn yield increases at a diminishing rate with nitrogen fertilization. However, the nitrate leaching increases at an increasing rate as nitrogen application increases. Therefore, when the grower intends to increase yield by increasing nitrogen fertilization rate, more nitrate leaching will be expected. That is, there is a tradeoff relationship between yield and the reduction of nitrate leaching.

5.3.1 Nitrogen Application and Seed Corn Yield

Figure 5.1 describes the average seed corn yield response with respect to the amount of nitrogen application from the simulation model.

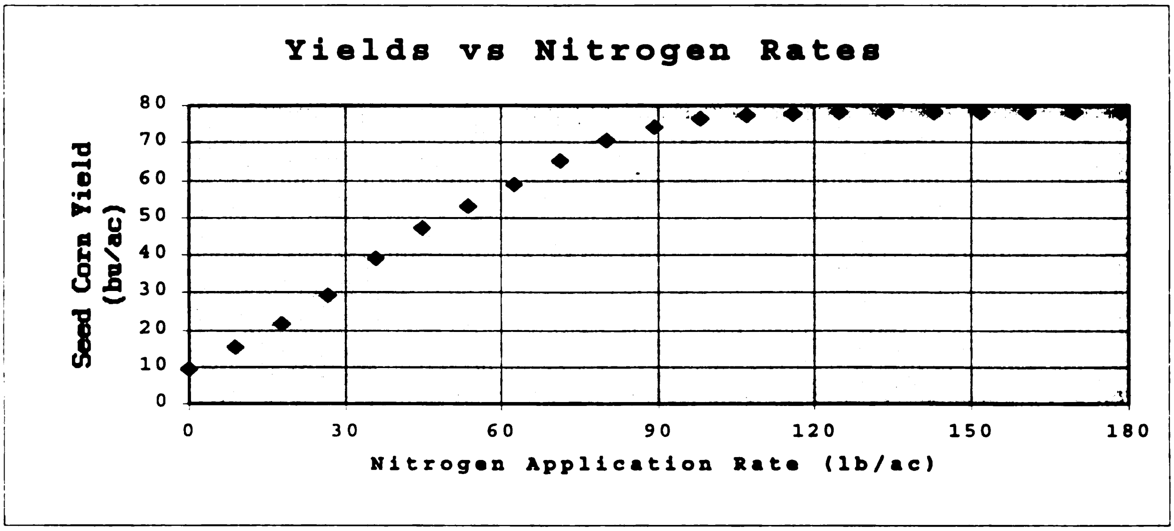

Figure 5.1: Seed corn yield under various nitrogen application rates

This yield curve shows a von Liebig (i.e., plateau) production function (Peterson and Corak, 1994). This curve displays three stages of seed corn production. When nitrogen use is less than 80 lb/ac, seed corn yield increases linearly with the amount of nitrogen use; when nitrogen use is between 80 lb/ac to 120 lb/ac, there is only a slight increase in seed corn yield; and there is no yield response when nitrogen application is more than 120 lb/ac. The optimal nitrogen application rate will depend upon the marginal benefit and marginal cost of nitrogen fertilizer, which are discussed in Chapter 6.

5.3.2 Nitrogen Application and Nitrate Leaching

In order to control nitrate leaching, its relationship with nitrogen use needs to be explored. Figure 5.2 graphs the average amount of nitrate leaching with respect to nitrogen applications (Table 5.1, column F), based on the simulation result from DSSAT 3.0.

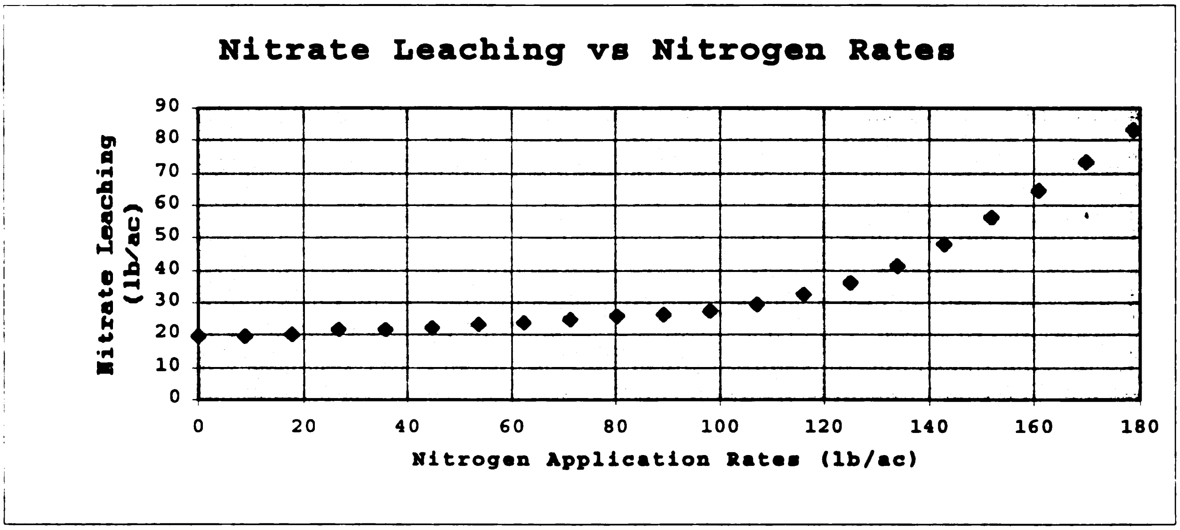

Figure 5.2: Nitrate leaching from seed corn production under various nitrogen treatments

The amount of nitrate leaching increases slightly with the nitrogen application rate when nitrogen application rate is less then 100 lb/ac. However, beyond 100 lb/ac, the nitrate leaching increases geometrically.

5.3.3 Relationship between Seed corn Yield and Nitrate Leaching

In order to design a "green" contract, the relationship between seed corn yield and nitrate leaching must first be identified. Figure 5.3 shows this relationship based on simulation of continuous seed corn production from DSSAT 3.0.

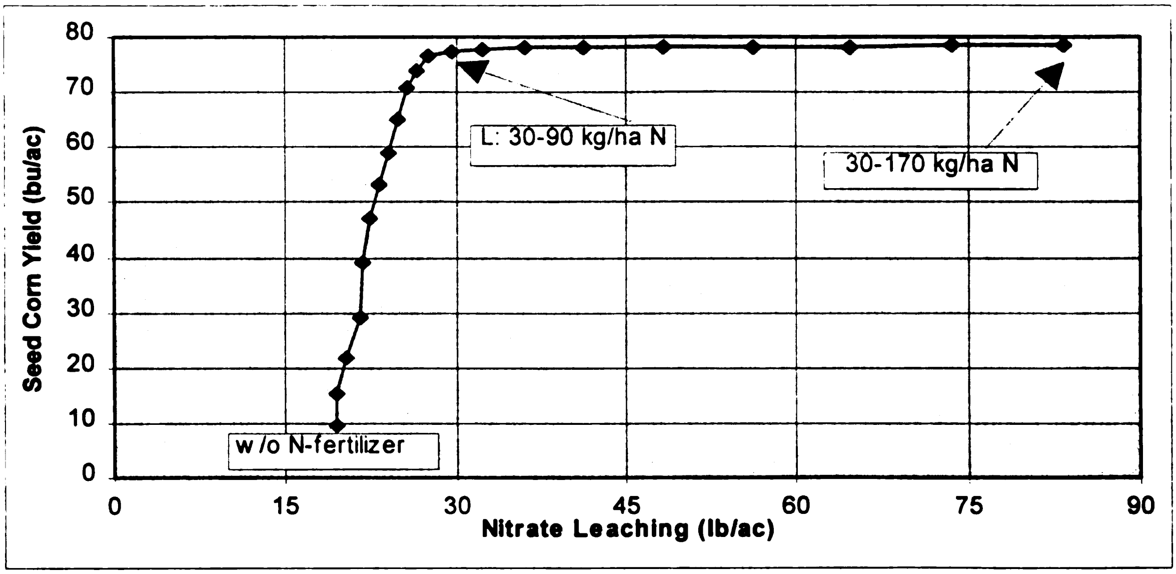

Figure 5.3: Relationship between mean nitrate leaching and seed corn yield under various nitrogen treatments

The graph shows that as yield increases, so does the amount of nitrate leaching. However, the rate of increase in nitrate leaching is slow before point L (with 30-90 kg/ha, or 27-80 lb/ac, N-application rate, where 30 kg/ha (27 lb/ac) and 90 kg/ha (80 lb/ac) were applied as starter and sidedress fertilizers, respectively). After this point, the amount of nitrate leaching increases geometrically, but seed corn yield does not significantly increase. Therefore, the opportunity cost for the processor should be small to reduce the nitrate leaching level to 30 lb/ac in continuous seed corn. This conclusion, however, ignores rotational practices that might increase nitrate leaching.

In conclusion, there is a positive relationship between seed corn yield and nitrogen application rate when the amount of nitrogen applied is less than 107 lbs per acre (or 120kg/ha). Beyond this level, there is only a slight yield response to additional nitrogen applied. Secondly, nitrate leaching increases with nitrogen fertilizer application rate, and the trend increases geometrically about 30-90 kg/ha (27-80 bu/ac) of N-application.

Field interviews in southwest Michigan indicated that some farmers applied nitrogen fertilizer up to 180 lb/acre (Dobbins and Swinton, 1995; Batie and Swinton, 1995). Two factors might explain this result: lack of information and/or aversion to risk. Because seed corn is a specialty crop, and a relatively new crop to many growers, growers may lack sufficient information about nitrogen application. Furthermore, farmers apply nitrogen use as an ex-ante decision, which is based on their expectation of weather conditions. As Chapter 3 indicated, some farmers apply more nitrogen fertilizer than average plant uptake capacity in order to avoid any nitrogen shortage in good weather years (Babcock, 1992). This explanation is also related to the third explanation, the grower's risk attitude. The growers might be concerned with yield distribution as well as its variation. Since this research assumes full information, only the third explanation was examined.

In order to understand how yield distributions (or variations) under different nitrogen treatments affect the grower's decision-making, the relationship between nitrogen application rates and the grower's profitability needs to be explored. The choice of nitrogen application is assumed to be a discrete choice because the data simulated from DSSAT 3.0 is also discrete. For simplicity, only three nitrogen treatments for seed corn production are selected and incorporated into a whole-farm programming model. The medium level (***M*** with 107 lb/ac nitrogen use) shows the optimal fertilization rate for the programming model to be presented in Chapter 6; high level (denoted by ***H*** with nitrogen rate 116 lb/ac) and low level (***L*** with 98 lb/ac nitrogen use) indicates 10 kg/ha increase and decrease, respectively, from the medium level. These three levels illustrate a tradeoff relationship between yield and nitrate leaching reduction. They are closely clustered because the whole-farm model in Chapter 6 shows profit-maximizing results to be closely linked to yield response in this range.

5.3.4 Yield and Nitrate Leaching Distributions under Three Nitrogen Treatments

If the processor's objectives are to ensure stable seed corn production, and to minimize the possibility of exceeding nitrate leaching thresholds over time, the distributions (or the variation) of yield and resulting nitrate leaching under different nitrogen fertilizer rates are important in any contract design. The yield distributions of three different nitrogen treatments are shown in Figure 5.4.

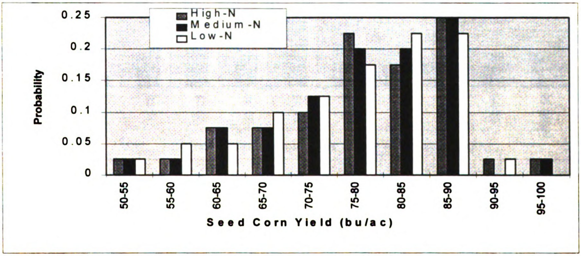

Figure 5.4: Probability distribution of seed corn yield under three nitrogen treatments

From Figure 5.4, high nitrogen treatments tend to have distributions more skewed toward higher yield than do low nitrogen treatments. The mean yield of the low nitrogen treatment is 77.2 bu/ac, and it is 77.9 bu/ac in the high nitrogen treatment. The probability of obtaining at least 75 bu/ac of seed corn yield (or, the cumulative probability of yield above 75 bu/ac) is 62.5 percent from the low nitrogen treatment, 67.5 percent from the medium nitrogen treatment, and 70 percent from the high nitrogen treatment. If the goal is set at 85 bu/ac of seed corn yield, the probability to achieve this goal is 25 percent with low nitrogen, 27.5 percent with medium nitrogen, and 30 percent with high nitrogen treatment.

The corresponding nitrate leaching levels from the three nitrogen treatment are shown in Figure 5.5.

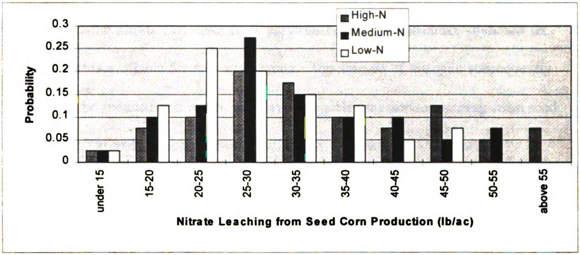

Figure 5.5: Probability distribution of Nitrate Leaching under Three Nitrogen Treatments

From Figure 5.5, the distributions between high nitrogen treatment and low nitrogen treatment are quite different. The low nitrogen treatment has a mean of 30 lb/ac while the high nitrogen treatment has a mean of 36 lb/ac. If the threshold of nitrate leaching is set at 50 lb/ac, the probability of exceeding such a threshold under low, medium, and high nitrogen treatments are 7.5 percent, 10 percent, and 27.5 percent. If the threshold for nitrate leaching is set at 40 lb/ac, the probability of exceeding such a threshold under low, medium, and high nitrogen treatments are 27.5 percent, 45 percent, and 60 percent. Thus, at a 40 lb/ac nitrate leaching threshold, the high level of nitrogen application is more than twice as likely to exceed the threshold as the low nitrogen application level.

5.4 Yield and Nitrate Leaching Data for All Enterprises

Rotation is another element that affects the amount of nitrate leaching from both seed corn production, and the whole-farm. Nitrogen applications need to be adjusted by incorporating nitrate carryover from previous crops. For instance, soybeans fix nitrogen that is available for following crops. The amount of nitrogen subsequently applied can be reduced as a result. The average yield and nitrate leaching from seed corn production under three rotation practices are illustrated in Figure 5.6.

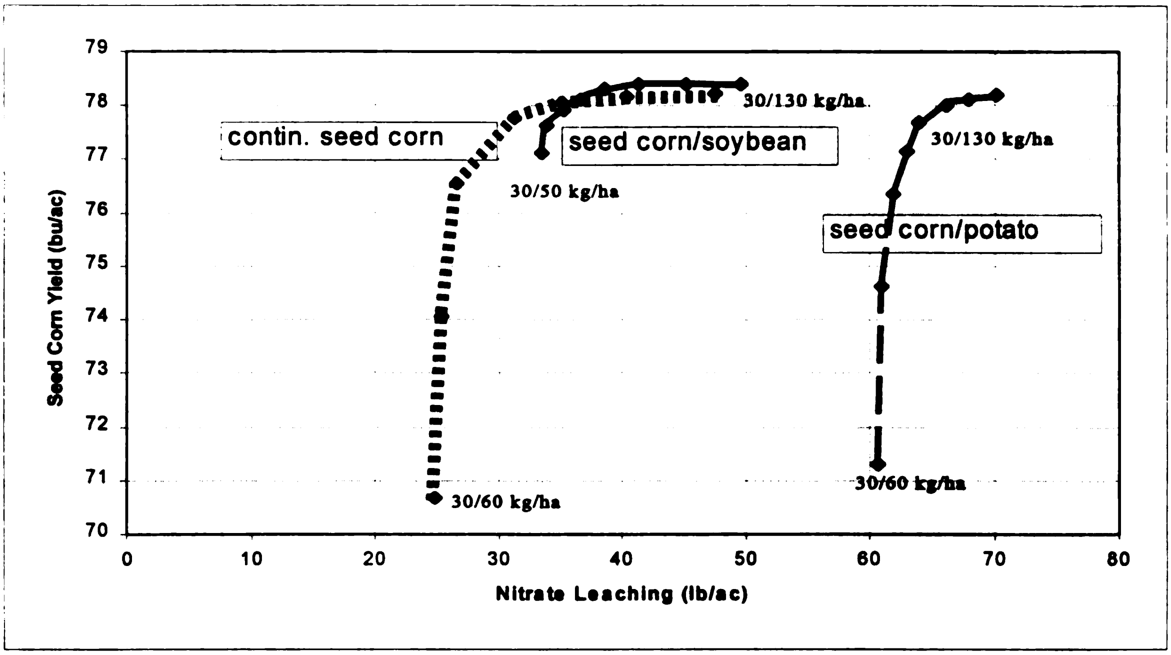

Figure 5.6: Relationship between nitrate leaching and seed corn yield under different rotation practices

Figure 5.6 shows three rotation practices for seed corn production: continuous seed corn, seed corn/potato, and seed corn/soybean. Each rotation practice has eight nitrogen treatments, ranging from 90 kg/ha to 160 kg/ha with a 10 kg/ha increment in both the continuous seed corn and seed corn/potato rotations, and from 80 kg/ha to 150 kg/ha in the seed corn/soybean rotation. Among these three rotation practices, the data from continuous seed corn show the lowest average nitrate leaching. These nitrate leaching data are likely to be underestimated because DSSAT 3.0 does not account for pest damages which cause yield reductions and subsequently increase in nitrate leaching. Nitrate leaching from rotations of seed corn after potatoes has the highest leaching rate; large amounts of nitrate carryover occurs from potato production which receives 237 lb/ac of nitrogen fertilizer. The seed corn/soybean rotation has the highest seed corn yield potential among these three rotation practices. The seed corn/potato rotation and continuous seed corn have similar yield responses under the same nitrogen treatment.

Four crops -- corn, seed corn, soybeans, and potatoes -- are considered in this study. The mean yield and nitrate leaching data 3.0 during 1951-1992 simulated from DSSAT with respect to different crops, rotations, crop enterprise names used in a programming model, and nitrogen application rates are shown in Table 5.2 and Table 5.3, respectively.

Because seed corn has a higher unit value than commercial corn, the tradeoff between nitrate leaching reduction and profitability might be greater with seed corn than with commercial corn. Therefore, the interval between each nitrogen treatment is set at 10 kg/ha for seed corn production and 20 kg/ha for commercial corn to indicate the incremental changes in yield and nitrate leaching with respect to nitrogen application rates.

Several conclusions can be drawn from Table 5.2. First, there is a critical point where seed corn or commercial corn becomes less responsive to nitrogen fertilizer. This point occurs when the nitrogen application rate is 120 kg/ha for continuous seed corn or seed corn after potatoes; it occurs at 90 kg/ha for seed corn after soybeans. It is 170 kg/ha in both continuous corn and commercial corn after potatoes, and 130 kg/ha in commercial corn after soybeans. Second, there is not much difference in soybean mean yield between seed corn/soybean and commercial corn/soybean rotation from the simulation. The yield is about 46.6 bu/ac in the model.

Table 5.2: Mean simulated yields of four crops from DSSAT 3.0 for St. Joseph County, Michigan, 1951-92

N-rate		Seed corn (bu/ac)			Corn (bu/ac)			Soybeans (bu/ac)		Potatoes (lb/ac)	
kg/ha	lb/ac	cont.	after soybeans	after potatoes	cont.	after soybeans	after potatoes	after seed corn	after corn	after seed corn	after corn
0	0	-	-	-	-	-	-	46.59	46.70	-	-
80	71	-	77.13	-	-	-	-	-	-	-	-
90	80	70.69	77.64	71.30	-	-	-	-	-	-	-
100	89	74.05	77.93	74.63	-	-	-	-	-	-	-
110	98	76.55	78.12	76.36	-	186.54	-	-	-	-	-
120	107	77.14	78.32	77.15	-	-	-	-	-	-	-
130	116	77.79	78.39	77.70	178.94	188.37	180.28	-	-	-	-
140	125	78.05	78.40	78.00	-	-	-	-	-	-	-
150	134	78.19	78.41	78.13	185.32	189.02	185.11	-	-	-	-
160	143	78.24	-	78.21	-	-	-	-	-	-	-
170	152	-	-	-	187.79	189.25	187.86	-	-	-	-
190	161	-	-	-	188.87	189.31	188.47	-	-	-	-
210	170	-	-	-	189.26	-	189.03	-	-	-	-
265	237	-	-	-	-	-	-	-	-	5875	5660

Table 5.3: Mean simulated nitrate leaching of four crops from DSSAT 3.0 for St. Joseph County, Michigan, 1951-92

N-rate		Seed corn (lb/ac)			Corn (lb/ac)			Soybeans (lb/ac)		Potatoes (lb/ac)	
kg/ha	lb/ac	cont.	after soybeans	after potatoes	cont.	after soybeans	after potatoes	after seed	after corn	after seed	after corn
0	0	-	-	-	-	-	-	23.17	22.01	-	-
80	71	-	33.50	-	-	-	-	-	-	-	-
90	80	24.78	34.00	60.75	-	-	-	-	-	-	-
100	89	25.36	35.26	61.03	-	-	-	-	-	-	-
110	98	26.62	36.62	61.90	-	22.30	-	-	-	-	-
120	107	28.56	38.56	63.00	-	-	-	-	-	-	-
130	116	31.37	41.37	63.97	15.65	23.01	46.67	-	-	-	-
140	125	35.13	45.26	66.15	-	-	-	-	-	-	-
150	134	40.35	49.72	67.96	16.85	24.17	47.21	-	-	-	-
160	143	47.59	-	70.17	-	-	-	-	-	-	-
170	152	-	-	-	19.00	25.65	49.17	-	-	-	-
190	161	-	-	-	21.23	27.46	51.32	-	-	-	-
210	170	-	-	-	23.48	-	53.35	-	-	-	-
265	237	-	-	-	-	-	-	-	-	121.12	120.58

One similarity is shown in the amount of nitrate leaching among crops under various rotation practices. There is a point where the amount of nitrate leaching with respect to nitrogen applications increases substantially for both seed corn and commercial corn. This point occurs at 110 kg/ha nitrogen application rate in seed corn production, and at 150 kg/ha in corn production.

As Table 5.3 has shown, the seed corn crop, which is susceptible to contract design manipulation, is not the crop responsible for most nitrate leaching. Potatoes cause more leaching than seed corn, as do commercial corn and soybeans under some scenarios. The results also show that there is little yield response with nitrogen application beyond the medium level in seed corn production across all rotation practices.

Within seed corn or corn production, rotation practices also have a different impact on the amount of nitrate leaching. When seed corn or corn is grown in rotation with potatoes, the average level of nitrate leaching generated is about 20-30 pounds per acre higher, compared with continuous seed corn or seed corn in rotation with soybeans.

In general, seed corn production generates more nitrate leaching than corn production. Among all corn rotation practices, growing commercial corn after corn tends to have the lowest mean nitrate leaching than of the practices simulated. Both seed corn and corn generate higher nitrate leaching when they are grown after potato crops. This results because of substantial nitrate carryover from potato production within the simulation model DSSAT 3.0.

5.5 Summary

The data simulated from crop simulation model -- DSSAT 3.0 -- provide information on the relationship between yield, nitrogen application rate, and nitrate leaching. These data show that there is a three-stage relationship between yield and nitrate leaching. In the first stage, where nitrogen application rates are low, an increase in yield does not cause much increase in the amount of nitrate leaching. In the second stage, a tradeoff exists between yield and nitrate leaching. However, the amount of nitrate leaching increases rapidly after the yield reaches the capacity of the crop in the third stage.

The yield and nitrate leaching variations under three nitrogen treatments were also examined in this chapter. The result shows a slight difference in yield distributions but with a large variation in the nitrate leaching distribution across these three nitrogen treatments. This chapter also compares the amount of nitrate leaching from seed corn, commercial corn, soybeans, and potatoes by incorporating various rotation practices. The data show that seed corn is not the crop with the highest nitrate leaching potential. Potatoes incur more leaching. Thus, seed corn production will have more nitrate leaching when in rotation with potatoes. The data from DSSAT 3.0 provides information on physical dimensions of NPSP, but not abatement cost and economic opportunity cost of NPSP abatement.

CHAPTER 6

AN EMPIRICAL PRINCIPAL-AGENT MODEL

Chapter 4 showed that, theoretically, various alternative contract designs are able to reduce nitrate leaching. Such "green" contract specifications, however, might unacceptably impose higher product costs on the contracted grower or reduce the processor's profit due to yield reduction. In order to examine how alternative contract designs affect the processor and the contracted-grower, this chapter presents an empirical principal-agent framework based on a mathematical programming model of the agent's behavior. Using this framework, the tradeoff between nitrate leaching and profitability under various nitrogen treatments for both processor and contractor-grower can be predicted under different contract specifications.

Various alternative contract designs that can reduce nitrate leaching are identified in the case of seed corn contracts. In order to rank these alternative contract designs, this chapter outlines the criteria that can elicit preferable contractual designs from both processor's and seed corn grower's perspectives.

6.1 Mathematical Programming Model for Optimal Contract Designs

A mathematical programming (MP) model is a common tool to obtain optimization solutions. In an ideal empirical principal-agent model, the agent's optimization problem needs to be nested inside the principal's optimization problem. Both participation and incentive compatibility constraints are identified in the principal's decision-making process. On the other hand, the agent's optimization is affected by the incentive scheme, given technology and resource availability constraints.

The general structure of a principal-agent model adapted to the seed corn processor-grower context can be outlined as follows (Candler and Townley, 1982):

$$\max_{s} E\{G[y-s(y)]\},$$

subject to

$$E\{U[s(y),n]\} \geq U^0 \quad (6.1)$$

$$n \in \underset{n,\, n' \in N}{\operatorname{argmax}}\, E\{U[s(y), n']\} \quad (6.2)$$

where the processor chooses an incentive payment, $s(y)$, based on observable seed corn yield, y, which induces the grower to choose a nitrogen application rate, n, conditioned on two constraints: participation (equation 6.1) and incentive compatibility (equation 6.2). The participation constraint states that participation must yield utility at least equal to what the agent might obtain from some alternative feasible enterprise, that is, reaching his or her reservation utility level, U^0. The incentive compatibility constraint guarantees that the agent will choose those actions preferred by the principal over alternative feasible nitrogen use, n'. The processor's and the agent's objective functions are $G(.)$ and $U(.)$, respectively.

In theory, a principal-agent model can be solved empirically using two-level mathematical programming (Bard and Moore, 1990; Candler et al., 1981; Candler and

Townley, 1982; Kornai and Liptak, 1965). However, two practical barriers impede all but the simplest attempts to use two-level mathematical programming. First, due to the model's inherent non-convexity, convergence to the global optimum is not guaranteed (Candler, et al., 1981; Bard and Moore, 1990). Second, due to the complexity of stating interdependent objective functions, applications must be limited to small matrices.

To overcome these barriers, this study decomposes the general principal-agent model into two steps. Because any constrained optimization must first satisfy its constraints, the first step begins by modeling the behavior of the representative seed corn contracted-grower. A representative whole-farm model verifies whether the principal's incentive-compatibility and participation constraints are met when the grower's objective function is maximized. In the second step, this research evaluates the impacts of different contract specifications for both processor-principal and grower-agent. This paper then identifies the preferred contract designs for each party, including which of these might be potentially acceptable to both parties.

6.2 Welfare Measurement for the Seed Corn Contract

The first stage in structuring a principal-agent model is to characterize the objective functions for both the processor and the representative grower. These objective functions will dictate the decision-making processes and welfare measurements for each party. The choice of a particular objective function is based on an analysis of previous literature.

In this research, the processor is assumed to be risk-neutral. This assumption is justifiable for a large company that has insurance against losses and has the ability to spread risks through equity investments. Many studies have provided evidence that supports the assumption of decreasing absolute risk aversion as wealth increases (Chavas and Holt, 1990; Lins et al., 1981; Saha et al., 1994). A large firm tends toward risk-neutral behavior when its income is high (Diamond, 1995).

In order to estimate the impacts of different contract specifications on the processor, the welfare change for the processor will be measured by ***gross margins***, the difference between gross income and total variable costs. An enterprise's gross margin is its contribution to fixed investments and profit after specified variable costs have been paid.

The processor's gross margin per acre over specified production and marketing costs is constructed by subtracting the grower payment from marginal revenue,

$$\textit{Processor Gross Margin} = (1 - \frac{SCMC}{TR}(y)) * P_w - s(y) \tag{6.3}$$

where P_w is the wholesale price of corn seed per 80,000-kernels bag (weighing 47 pounds[7], or 0.84 bushel); $\frac{SCMC}{TR}(y)$ is the proportion of seed conditioning plus marketing costs (*SCMC*) to total seed corn operating income (*TR*); and $s(y)$ is the payment to the grower.

The base scenario is the case where the wholesale price of conditioned seed corn

[7]The price of corn seed varies by the number of seeds. Weights for each bag varies, depending on the size of corn seed. The number, 47 pounds per bag, is the average weight for medium size seed.

is $71.50 per bag, a typical wholesaler price for one bag of medium-quality hybrid corn seed in 1996. The conditioning and marketing costs are assumed to be 40 percent of the total value (Brinkman, 1996). Therefore, the gross margin for the processor is $51 per bushel.

A representative whole farm model is used to predict the grower's behavior under different seed corn production contract specifications, including outcomes for nitrate leaching and gross margins. The use of a representative farm assumes that growers are somewhat homogeneous in objective functions, production practices, and resource constraints. This assumption is based on the observation that the growers typically use similar operational practices in seed corn production. The representative farm approach provides insights into the relationships among factors affecting the predicted responses to alternative technologies, policies, or pricing mechanisms (such as contracts). Although not constructed on a statistically representative basis, this model was developed based on interviews and expert opinion of conditions typical of full-time seed corn farms in Southwest Michigan (Batie and Swinton; Dobbins and Swinton; King, 1995).

In order to examine the impacts of alternative contract designs on a representative grower, a whole-farm planning model will be used. Whole-farm planning is widely used to determine the optimal size and enterprise mix of the farm operation (Harsh et al., 1981). One commonly used analytical technique is mathematical programming, which maximizes or minimizes an objective function subject to technology and resource constraints. The whole farm programming model can analyze how a grower's objective function (gross margin or expected utility), yield, and nitrate leaching differ between the current contract and alternative contract designs. Using the results on nitrate leaching and yield from a whole-farm model, the principal then can choose the preferable contract designs that have higher profitability and/or lower nitrate leaching.

6.3 A Linear Programming Model

The first case to be examined is optimization by a risk-neutral contracted-grower. A linear programming (LP) model can be used to model the behavior of a risk-neutral grower, where the grower is assumed to maximize expected profit from the whole farm operation. In this research, the grower's profit is calculated using gross margins (GM), that is, cash income minus all variable costs. Therefore, the grower's gross margin represents the return to fixed investment and unpaid family labor and management.

The mathematical programming structure of a whole-farm linear model is:

$$\begin{aligned} &\textbf{\textit{Max}} \sum_j \bar{c}_j x_j \\ &\textbf{\textit{subject to}} \sum_j a_{mj} x_j \le b_m \\ &\mathbf{x_j} \ge \mathbf{0} \ \forall j \end{aligned} \tag{6.4}$$

where

x_j: the level of j^{th} farm activity (e.g. crop enterprises and inputs); j indicates the number of activities;

c_j: expected net return of one unit of the j^{th} activity, e.g., price for each crop or marketed input as well as the payment received from seed corn contract production;

a_{ij}: the technological coefficient, i.e., the amount of the m^{th} resource required to produce one unit of the j^{th} activity; and

b_i: the amount of the m^{th} resource available, including available stocks of owned land, rental land, family labor, seed corn contract land, and timeliness restrictions on attainable yield; m indicates the number of resource, as well as institutional constraints, such as contract restrictions on nitrogen use.

The grower's objective is to find the farm plan which generates the largest net return subject to the resources and institutional constraints.

6.3.1 Assumptions of a Linear Programming Model

Linear programming (LP) is based on several assumptions (Hazell and Norton, 1986):

1. Linearity: both the objective function and the constraints are linear;
2. Optimization: the objective function is either maximized or minimized;
3. Finiteness: only a finite number of activities and constraints are considered in order to ensure that an optimal solution is obtainable;
4. Fixedness: At least one constraint has a non-zero right-hand side coefficient;
5. Continuity: resources can be used and activities produced in quantities that are fractional units;

6. The coefficients of the objective function, those of the constraints, and the right hand sides are non-random;
7. Additivity: activities are additive, i.e., the total result of two or more activities is the sum of their individual results.
8. Homogeneity: all units of the same resource or activity are identical; and
9. Proportionality: the net return and resource requirements per unit of activity are constant regardless of the level of activity used. This assumption implies a perfectly elastic demand curve for the product, perfectly elastic supplies of variable inputs, and a Leontief production function.

The assumption of linearity implies that the aggregate whole farm production function exhibits constant returns to scale. One advantage of linear programming is that it allows users to test a wide range of alternative adjustments, and to analyze their impacts with minimum effort (Beneke and Winterboer, 1973). In this study, LP makes it possible to evaluate both the profitability and the nitrate leaching reduction associated with different seed corn contract designs in St. Joseph County, Michigan.

The marginal productivity value of the limiting resources (or shadow prices) indicate how much the net revenue would be changed through relaxing the resource constraint by one unit. A comparison of the shadow price with the cost of acquiring one additional unit of the resource will show whether such an adjustment in resource use is profitable. LP also lists the inventory of surplus resources which are not completely used in the model. This inventory can be used as a guide, together with the binding constraints, in planning for long-run adjustments within the farm.

6.3.2 Purdue Crop/Livestock Linear Programming

The primary analytical tool used here for risk-neutral whole-farm modeling is the PC-LP computer software package (Purdue Crop/Livestock Linear Programming, Dobbins et al., 1994), a whole-farm planning model developed in the early 1990s by agricultural economists at Purdue University. PC-LP assists farmers in achieving more efficient farm management, including planning cropping patterns, machinery acquisitions, or other farm decisions.

PC-LP examines a farm plan by maximizing the expected profit (or gross margin) from farm operation during one year. PC-LP includes crop alternatives (rotation, governmental programs, and types of cultural practices), crop activities (land preparation, planting and post-planting activities, harvesting activities, labor hiring activities, and drying and storage activities), and constraints (acreage, machinery timing, labor time, field-accessible time, storage availability, and sequencing constraints). PC-LP can be designed to incorporate specifically yield penalties and machinery, and field time constraints under different management practices. Using PC-LP, the key whole-farm constraints, such as the time of year that labor or equipment are most constraining, can be identified as well. These features make PC-LP a convenient tool to analyze the impact of alternative contract designs.

6.4 Description of the Seed Corn Farm Based Model

The representative farm is assumed to own 1200 tillable acres with irrigation and to have the option to rent up to 500 additional acres. It is operated by one full-time adult with a typical machinery complement and has the option to hire supplementary labor. This farm represents a typical seed corn grower in St. Joseph County as identified by the county's Cooperative Extension Director Rod King (1995). The details of resources, crop enterprises, tillage practices, prices, and other miscellaneous data are listed as follows.

6.4.1 Resource Constraints

The resources used in the whole-farm programming model include land, machinery, labor, and seed corn contract availability.

A. Land

The soil type of this representative farm is sandy loam, which is well suited to center, pivot irrigation but has a high propensity for leaching when large amounts of nitrogen fertilizer are applied. This contracted-grower may rent up to 500 additional irrigated acres at $165/acre, the typical rental price for irrigated land in this area in 1997 (King, 1997).

B. Machinery

Within the model, the grower is assumed to own two tractors and various tillage equipment. The tillage machinery used on this farm can be divided into five categories according to different purposes: field preparation, pre-tillage, planting, post-tillage, and harvesting. The various equipment used, the working hours per day, labor required, tractor working rate (acres per hour), and cost per acre are listed in Appendix C (Lazarus, 1996).

Machinery operations require both labor and tractor time. Fertilizer application is assumed to be done by the grower with rented equipment. Therefore, the cost is based on custom-hired rates without labor cost. Both equipment for insecticide and herbicide spraying are also based on custom work (Schwab and Siles, 1994). Within this model, the seed corn grower is assumed to hire labor to remove the male row after pollination has finished. This task is done as piece work at a cost of $5 per acre. It is assumed that the representative farm does not have drying, processing, or storage facilities.

C. Labor

The labor force includes one full-time worker (1 person), and two part-time (or hired) workers in this case study. The wage rate is assumed to be $7.50 per hour. No off-farm income is included in the model.

For labor constraints, labor activities are divided into 23 periods according to different tasks and weather conditions. The number of suitable days for field work depends on both soil and weather conditions. Estimates of the suitable days for field work are mainly based on previous publications (Rosenberg et al., 1982; Doster et al., 1994). The details are listed in Appendix C.

D. Seed Corn Contract Availability

Due to high competition in obtaining seed corn contracts among farmers, the maximum seed corn contract available to this representative grower is restricted to 500 acres in the study.

6.4.2 Crop Enterprises

Crop enterprises include seed corn, commercial corn, soybeans, and potatoes. The crop alternatives, nitrogen use, and their respective mean yield and nitrate leaching levels are listed in Table 6.1. Three nitrogen treatments--high (***H***), medium (***M***), and low (***L***)-- are examined in seed corn and commercial corn production.

In the crop enterprise names, the first letter indicates previous crops, where ***S*** is seed corn; ***C***, corn; ***B***, soybeans; and ***P***, potatoes. The rest of these names stand for crops planted this year, where ***SEED*** is seed corn; ***CORN***, corn; ***BEAN***, soybeans; and ***POTATO***, potatoes. In terms of nitrogen application, **H** indicates high levels of nitrogen use; **M**, medium level; and, **L**, low level. The median level of nitrate leaching from seed corn production is 35 pounds per acre, and 23 pounds per acre from corn production.

Table 6.1: Mean yield and nitrate leaching under enterprises included in the whole-farm programming model

Crops and rotation	Enterprise Name	Nitrogen kg/ha	Nitrogen lb/ac	Yield bu/ac	Leaching lb/ac
Commercial corn					
continuous corn	CCORN(H)	190	170	189	21
	CCORN(M)	170	152	188	19
	CCORN(L)	150	134	185	17
corn after soybeans	BCORN(H)	150	134	189	24
	BCORN(M)	130	116	188	23
	BCORN(L)	110	98	187	22
corn after potatoes	PCORN(H)	190	170	189	51
	PCORN(M)	170	152	188	49
	PCORN(L)	150	134	185	47
Seed Corn					
continuous seed corn	SSEED(H)	140	125	78.1	35
	SSEED(M)	130	116	77.8	32
	SSEED(L)	120	107	77.1	29
seed corn after	BSEED(H)	100	89	77.9	36
soybeans	BSEED(M)	90	80	77.6	34
	BSEED(L)	80	71	77.1	34
	PSEED(H)	140	125	78.0	58
seed corn after potatoes	PSEED(M)	130	116	77.7	56
	PSEED(L)	120	107	77.2	55
Soybeans					
after seed corn	SBEAN	0	0	47	23
after comm. corn	CBEAN	0	0	47	22
Potatoes					
after seed corn	SPOTATO	265	237	NA	136
after comm. corn	CPOTATO	265	237	NA	121

Source: DSSAT 3.0 simulation.

As Table 6.1 shows, growing seed corn following potatoes incurs a substantial amount of nitrate leaching, compared to other rotation practices. This result reflects that there is a high level of nitrate carryover from potato production. In reality, the profit-maximizing grower would reduce nitrogen application rates to account for such nitrate carryover in the soil. However, the data simulated from DSSAT 3.0 do not reflect such a nitrate carryover advantage. As shown in Chapter 5, seed corn yield responses to nitrogen use is the same as continuous seed corn. This result implies that nitrogen use in the model from simulation model DSSAT 3.0 might be overestimated.

Both corn and soybeans are cash crops. Seed corn is grown by contracting with a seed corn processing company and paid according to the relative performance of yield (i.e., grower's yield relative to the regional average). Potato production is based on cash rent agreements, where potato growers pay a lump-sum rent per acre and require lime application, spring chisel plowing and periodic irrigations during the summer season. Although potato production is not undertaken on a large scale in this area, it serves to represent other specialty crops, such as carrots, cucumbers, and tomatoes.

Commercial corn and seed corn are grown either continuously, or in rotation with soybeans or potatoes. Due to serious pest problems in continuous cropping, soybeans and potatoes are only allowed to be grown in two-year rotations. In general, corn or seed corn in rotation with other crops has several advantages (Harwood, King, Ritchie, and Vitosh, 1995):

1. Corn or seed corn in rotation with soybeans can increase yields and save costs. Corn crops can obtain a nitrogen credit of up to 30 lb/ac from soybean crops and can reduce insecticide use by about $10.75/ac for seed corn production and $13.05/ac for corn production due to reduced probability of incurring rootworm problems with rotations.
2. Corn or seed corn in rotation with potatoes can increase yields and save costs. When corn crops are in rotation with potatoes, potash application can be reduced by $7.80/ac for commercial corn and by $7.34/ac for seed corn

production due to high potash residuals when corn is planted after potatoes. Insecticide use can be reduced by $10.75/ac for seed corn production and $13.05/ac for corn production due to less pest problems when seed corn or corn rotates with potatoes.

These two advantages make crop rotation more attractive in terms of cost savings. However, the whole-farm planning also depends on other elements, such as labor availability, resource constraints, and economic incentives, including prices and price premiums.

6.4.3 Yield Adjustment and Moisture Content

Within the model, crop yields and moisture contents vary by planting dates and harvesting dates (Appendix C).

A. Timeliness and Yield Adjustments

Planting and harvest dates affect crop yields for several reasons. First of all, the longer the growing season, the higher the probable yield. Second, due to the possible damages from fall-frost in Michigan, the yield levels of corn and soybeans are likely to decline when harvesting occurs after late October. Early planting, therefore, can ensure early harvest, and thus avoids such damage. Although early planting has this advantage, it also means that during late April and May many activities must be completed; thus, the farmer might need to sacrifice some yield by late planting due to labor and machine constraints.

In general, the highest commercial corn yields are obtained for planting during April 26 - May 2, and harvesting during October 11 - October 31 (King, and Black, 1995). Planting or harvesting in other periods tend to lead to yield reductions of varying magnitude.

By contrast, seed corn suffers little yield loss under different planting and harvesting periods because its growing season is shorter, and because both planting and harvesting are controlled by the processing company. Planting occurs during late April and May, and harvest during late August and early October.

Late planting reduces yields in soybean production. However, late planting of soybeans impacts yield less than it does in corn production. Both potato planting and harvesting are controlled by the renters of the land, so potato yield variation due to planting and harvesting dates is not examined in this research.

B. Moisture Content

Delaying corn harvest tends to reduce grain moisture content, which saves drying costs. The standard moisture level required for corn storage is 15.5 percent. In this study, the grower is assumed to send his or her crop to an elevator for drying and storage. The cost to dry one percent of moisture is assumed to be 2.5 cents per bushel.

The moisture content for storing soybeans is 13 percent. It is assumed that no drying is required in soybean production. Seed corn can be harvested at a relatively high moisture level of 40 percent. The processing company dries the corn seed to 15.5 percent, so the grower does not need to pay for the drying expense.

6.4.4 Tillage Practices

Tillage practices used within the model are based on practices identified through interviews with several experts, including agricultural economists (Harsh and Schwab), agronomists (Harwood, Miron, Lupkes, Ritchie, and Vitosh, 1995), and extension agents (King, Kennedy, and Wamhoff, 1995). The tillage practices incorporated within the model can be divided into five categories: field preparation, pre-planting tillage, planting, post-planting tillage and harvesting (Appendix C). Field preparation is usually done in the fall to save time in spring. It includes plowing and spreading phosphate (P_2O_5), and potash (K_2O) fertilizers. A V-ripper is used to loosen the soil after potato harvest.

During December to March, there are no field activities, but the grower repairs and maintains machinery. In the spring, the grower has to cultivate the field before planting. When the soil is hard, a tandem disk is often used to break up the soil. For a typical grower, tandem disking is done every other year.

Planting commercial corn during the end of April and middle of May, and planting soybeans and potatoes during mid-late May, generates high yield outcomes. However, due to the tight time schedule, a grower might need to allocate his or her time among different crops by delaying some of the planting. All planting, except potatoes, are done by the grower[8]. No planting is required in potato contracts.

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[8]Different seed corn varieties require different planting practices. Single or double delay planting, flaming, and male cutting might be required for some varieties in order to get better pollen production. The variety used in this model covered the highest percentage of seed corn acreage planted in St. Joseph County in 1995. It requires single delay planting. Male rows are planted one week after female rows are planted. The grower is compensated by the company for any delay planting requirement.

Standard post-planting tillage includes rotary hoe, field cultivation, insecticide and herbicide spraying, irrigation, and the side-dressing of nitrogen fertilizers. In the case of seed corn, the contracted-grower is responsible for weed control while the processing company will take care of insect and fungus problems. In the case of continuous corn or seed corn, the farmer will apply insecticides for rootworm at a cost of approximately $16.30 per acre.

6.4.5 Commodity Prices and Input Costs

Commodity prices tend to fluctuate every year. The price ratio of corn to soybeans is approximately 1:2.5 (Krause, 1992). During the last several years, the price for corn was about $2.40/bu. Therefore, the price of soybeans is set at $6.00/bu in the model. Inputs are based on several studies, where nitrogen fertilizer costs 25 cents per pound (Nott et al. 1995; King, 1993 and 1996). The prices of commodities and all input expenses except nitrogen fertilizer are listed in Table 6.2.

Table 6.2: Crop prices and cash production expenses (excluding nitrogen cost) of each crop

Crops	Seed Corn		Corn		Soybeans		Potatoes	
Commodity Price	Fix: $150/ac[1] Var:$5.28/bu		$2.40/bu		$6.00/bu		$235/ac	
Expenses (excluding nitrogen cost)								
	(item)	Total	(item)	Total	(item)	Total	(item)	Total
Seeds		$20.00		$26.88		$13.20		-
Fertilizer (total)		29.04		33.10		16.50		$10.00
Phosphate(P_2O_5)@25¢/lb	$ 4.50		$ 7.50		-		-	
Potash (K_2O)@13¢/lb	14.69		15.60		$ 5.50		-	
Limestone @$20/ton	10.00		10.00		10.00		$10.00	
Insecticide		10.75[2]		16.30[2]		-		-
Herbicide		20.35		20.35		26.63		-
Irrigation		24.00		24.00		-		28.00
Machinery operating costs		32.42		39.49		26.16		4.32
Total Cash Expenses		$136.56		$160.12		$82.49		$42.32

Note:

[1] The payment of seed corn contract is converted for the following calculation:

$$\text{Payment per acre} = ((y-\bar{y})\alpha+Q)\beta P$$

where y is the grower's seed corn yield; $\bar{y}$ is the grower's and average regional seed corn yield (assumed to be 66.56 bu/acre); Q is the average regional commercial corn (assumed to be 190 bu/acre); and P is the price of commercial corn. α is assumed to be 2 and β is 1.1 in the model.

[2] This cost is based on continuous corn production. In rotation with soybeans or potatoes, this cost will be $3.25 for commercial corn and zero for seed corn.

6.5 Optimization of the Representative Risk-Neutral Whole-Farm Model

In order to estimate the impact of alternative contract designs, this analysis first examines a base scenario: maximization of expected net revenue for a representative whole-farm model under no environmental restriction in his or her production process. Using the data listed above, the optimal solution for the profit-maximizing representative grower is summarized in Table 6.3.

Table 6.3: Summary of optimization results for a representative grower in the base scenario model

Category		Results
1. Net revenue (or Gross margin)		$357,830/yr
2. Average seed corn yield (bu/ac)		77.7 (bu/ac)
3. Nitrate leaching from the whole-farm (lb/ac)		80.2 (lb/ac)
4. Nitrate leaching from seed corn field (lb/ac)		63.9 (lb/ac)
5. Shadow prices: ($/acre)		
Land		$199.18/ac
Seed corn contracts		$193.41/ac
6. Crop mix: (acre)	Total acres	Individual acres
a. Seed corn	500	
SSEED (acre)		0
BSEED (acre)		0
PSEED(M) (acre)		500
b. Commercial corn	350	
CCORN (acre)		0
BCORN (L) (acre)		104
PCORN(M) (acre)		246
c. Soybean	104	
SBEAN (acre)		0
CBEAN (acre)		104
d. Potato	746	
SPOTATO (acre)		500
CPOTATO (acre)		246

The expected net revenue for the grower is $357,830 per year under the base scenario. This return represents the gross margin after paying variable costs, therefore, it is the return to fixed costs and family labor. The total amount of nitrate leaching from the whole farm is 136,250 pounds (80.2 lb/ac on average).

Should a seed corn processing firm care about leaching when the analysis shows that potatoes contribute the majority of leaching from the whole farm? Since potatoes have been introduced into this area only for a few years and before that, nitrate leaching was a major concern in this area, the seed corn processing firm then needs to consider this environmental impact from seed corn production.

In the base scenario, the total cropped acreage is 1,700 acres, including 500 acres of rented land. Seed corn covers the full 500 acres available under contract. These 500 acres are in rotation with potatoes with medium nitrogen application rate. For commercial corn, 246 acres (14 percent of total are grown in rotation with potatoes, and the remaining 104 acres in rotation with soybeans in the base scenario. Figure 6.1 shows the percentage of each crop under a profit-maximizing whole-farm plan. Potatoes, accounting for 44 percent of 1,700 acres, have the highest percentage of acres among all crops. Seed corn production is 30 percent of the whole-farm acreage. Soybeans are only 6 percent of the whole-farm operation.

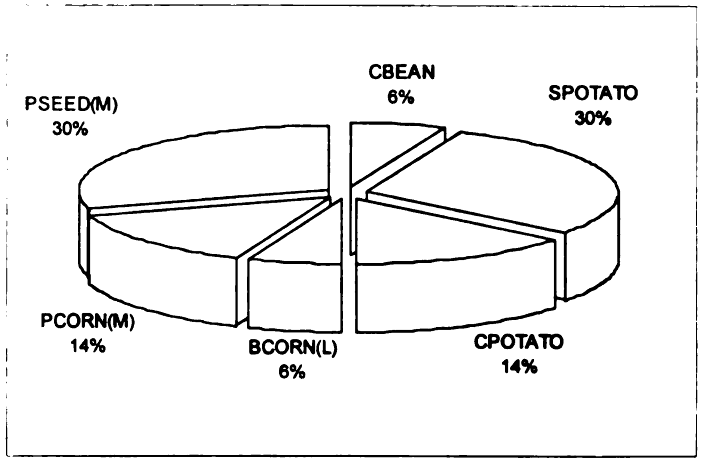

Figure 6.1: Crop mix in the base scenario

Comparing these optimization results with crop acreage distribution in St. Joseph County, the acreage of potatoes seems much higher than the actual potato acreage. Recall that potato crops are used as a representative for all specialty crops, which accounts for 11 percent of all cropped acreage in this area. The whole-farm model examined here does not impose a restriction on the availability of potato contracts. Another reason to explain this difference is the constraint from governmental policies. Before 1996, farmers were required to keep a corn base in order to receive deficit payment from government. As a result, little acreage is used in two-year rotations.

In terms of its contribution to nitrate leaching, seed corn production generates relatively less nitrate leaching than the whole farm average. The mean nitrate leaching level from seed corn production (63.9 lb/ac) is below the average nitrate leaching level from the whole farm (80.2 lb/ac). More nitrate leaching occurs from potato production (120 lb/ac on average). Within seed corn production, the seed corn/potato rotation generates more nitrate leaching (64 lb/ac on average) than the seed corn/soybean rotation (34 lb/ac on average).

6.5.1 Shadow Prices

A shadow price indicates the increased net return obtained by relaxing the constraint by one unit of the relevant resource. The two most restricted resources in the base scenario are land and contract availability. The shadow price of land is \$199.18/ac. The shadow price implies that if the grower could have one more acre of land, his or her expected return would increase by \$199.18. Given that the rental rate for one acre of land is \$165/ac, if the grower could rent more land, the profit could be increased by \$34.18 per acre (i.e., \$199.18-\$165), which is also the shadow price on the land rental constraint. The 500-acre limit on land contract for seed corn production generates the shadow price \$193.41, so if the grower could increase seed corn contracted acreage by one acre, the expected returns would increase by \$193.41.

6.5.2 Sensitivity Tests

Sensitivity tests examine how optimal behavior responds to changes in key parameters (including prices, costs, technical coefficients, available resources, etc). For the purpose of this study, sensitivity tests will focus on how changes in nitrogen prices and contractual arrangements affect optimal nitrogen application and resulting nitrate leaching.

A. Nitrogen cost

The optimal solution is sensitive to nitrogen costs. Nitrogen prices in 1996 were 25 cents per pound, which was about 30 percent above prices in 1995. When the nitrogen price is 19 cents per pound, the representative profit-maximizing grower will not change the nitrogen application rate in seed corn production, but will switch 103 acres of commercial corn from rotation with soybeans using 98 lb/ac nitrogen to rotation with potatoes with 152 lb/ac nitrogen application rate. The mean nitrate leaching from the whole farm will increase from 80.2 lb/ac (base scenario) to 87.8 lb/ac. This result is because the grower uses higher nitrogen fertilizer and more nitrate carryover in a potato/corn rotation than in a soybean/potato rotation. The mean nitrate leaching from seed corn average does not change. In terms of the profit from whole-farm operation, the gross margin increases to $364,370, an increase of $6,540 per year.

On the other hand, if the price of nitrogen increases from 25¢/lb to 35¢/lb, the amount of nitrate leaching will reduce dramatically from 80.2 lb/ac to 54 lb/ac in the whole farm, and from 63.9 lb/ac to 56.7 lb/ac in seed corn production by increasing the acreage in rotation with soybeans. This result is because planting corn after soybeans requires less nitrogen fertilizers, and then has less leaching. The gross margin also declines from the whole farm operation, from $357,830 to $348,880 per year.

Interestingly, the result shows that both nitrogen application and nitrate leaching are very sensitive to an increase in nitrogen cost. This result contradicts the literature which indicates that nitrogen use on commercial corn is insensitive to an increase in nitrogen cost (House et al., 1996; Carriker, 1993). The difference lies on the substitutability of other crops. In this case, the benefit from soybean rotations is similar to that from potato rotation, while the former requires much less nitrogen application. Thus, a slight increase in nitrogen cost will result in a switch from potato rotations to soybean rotations, resulting in a reduction in nitrate leaching.

This result implies both nitrogen application and the grower's gross margin can be sensitive to nitrogen cost. When nitrogen fertilizer is cheap, the profit-maximizing grower will increase the rate of nitrogen fertilizer in order to increase gross margins, which results in higher nitrate leaching levels. Therefore, an increase in nitrogen cost could potentially be used as a means to reduce nitrate leaching.

B. Contract availability

Seed corn contract availability indicates the seed corn acreage available to the representative grower. In the case where no constraint is imposed on contract availability, the optimal seed corn acreage for the profit-maximizing grower will be 727 acres. All of this seed corn acreage would be in rotation with potatoes. Although the mean nitrate leaching from seed corn production remains the same as the base scenario, nitrate leaching from the whole farm operation slightly decreases, from 80.2 lb/ac to 80 lb/ac. The decrease of the amount of nitrate leaching results from the additional commercial corn acreage being planted in rotation with soybeans (from 104 acres to 123 acres), which generates lower nitrate leaching than the base scenario. This switch is due to the equipment constraint during planting seasons. The increase in seed corn availability would increase the contracted-grower's gross margin from $357,830 to $400,080 per year.

C. Relative performance

The incentive scheme within the current contract includes 4 parameters: average regional yield (y_0), base crop yield (Q), a coefficient that transforms seed corn yield to commercial corn equivalent (α), and a price premium adjustment coefficient (β) (Shaw et al., 1989). In the LP model of this research, the per acre incentive payment is:

$$s(y)=(\alpha(y-y^0)+Q)\beta P \tag{6.5}$$

The change either in average regional yield, or in base crop yield only alters the fixed payment of the incentive structure. Therefore, any reduction in either parameter does not affect the grower's decision on nitrogen application rate, but only reduces net revenue and the shadow price of the seed corn contract.

On the other hand, any change in the coefficient α or β might affect the amount of variable payment. For instance, if the coefficient that transforms seed corn yield to commercial corn equivalent (α) changes from 2 (used in the current contract) to 1, the variable payment becomes $2.64 /bu. This change results in a reduction of nitrogen use, from a medium level (116 lb/ac), to a low level (107 lb/ac) in potato/seed corn. As a result, nitrate leaching subsequently declines by 1 lb/ac from seed corn production, for a 0.3 lb/ac reduction from the whole-farm operation. The gross margin of the grower declines to $343,520.

Reducing the price premium adjustment coefficient (β) from 1.1 to 1, however, does not change the optimal solution. It is difficult to use the price premium β individually to change the contracted-grower's behavior because a change in β will greatly affect the revenue received by both processor and contracted-grower. Thus, it is more likely to be unacceptable to either party.

The minimum total payment for a profit-maximizing grower to grow seed corn is $365/ac. Below this payment, the optimal seed corn acreage in the solution is less than 500 acres. This level can be interpreted as the participation constraint for seed corn contracts.

6.5.3 Other Commodity Price Scenarios

Different commodity prices were used in the model in order to compare how changes in relative prices affect crop mix as well as the amount of nitrate leaching. For instance, assume the price of conventional corn is $2.40/bu, soybeans are $5.70/bu and a potato contract is $235 per acre (1995 commodity prices). If the cost of nitrogen fertilizer is 25 cents per pound, then the grower will grow commercial corn and seed corn in rotation with potatoes with a medium nitrogen application rate. The average amount of nitrate leaching is 88.67 lb/acre from the whole farm, and 63.56 lb/acre from seed corn average. Compared to the base scenario, the mean nitrate leaching from the whole farm increases because of the switch from a corn/soybean rotation to corn/potato rotation. In this case, the contracted-grower's gross margin is reduced, from $357,830/year to $357,700/year.

If the price of corn is $2.70/bu, soybeans are $6.75/bu, potato contracts are $235 per acre, and nitrogen is priced at 25 cents per pound (1996 commodity prices), the grower would cultivate commercial corn in rotation with soybeans (579 acres), continuous seed corn (457 acres), and 43 acres of seed corn in rotation with soybeans. All corn and seed corn production use medium nitrogen application rates in this case. Because potatoes are not in the solution, the amount of nitrate leaching is 24.9 lb/acre from the whole farm, and 31.6 lb/acre from seed corn average. This result implies that the relatively high prices of less-nitrate-leaching crops create incentives for the profit-maximizing contracted-grower to reduce nitrate leaching through selection of these crops. In this case, the grower's gross margin increases to $438,780 ($357,830 in the base scenario).

From the sensitivity tests, as well as different price scenarios, the amount of nitrate leaching is sensitive to price changes and other resource constraints. Therefore, in order to reduce nitrate leaching, these elements should be considered.

6.6 Analysis of Alternative Contract Designs

As shown in Chapter 2 and 4, several strategies can be employed to reduce nitrate leaching. Three categories of alternative contract designs are evaluated in the PC-LP model[9]. They are: A) imposing restrictions on the amount of permissible nitrate leaching, nitrogen use, or other agronomic practices, B) charging a fee on the amount of nitrate leaching or nitrogen use that is above a specified level, and C) reducing incentive payments. The details are outlined in Table 6.4.

Table 6.4: Alternative seed corn contract designs

A.	**Imposing restrictions on agronomic practices**
a.1	Restrictions on ambient level of nitrate leaching (NL) to 45 lb/acre[1] a.1.1 Restrict NL to 35 lb/ac on the whole farm a.1.2 Restrict NL to 35 lbs/ac on each seed corn field
a.2	Restrict maximum nitrogen fertilizer to 107 lb/ac
a.3	No rotation with potatoes
B.	**Charging "fees" on agronomic practices**
b.1	Charge a 30 ¢/lb effluent fee on nitrate leaching above 30 lb/ac
b.2	Charge an input fee of 15 ¢/lb on nitrogen fertilizer above 90 lb/ac
C.	**Adjusting incentive payment structure**
c.1	$253/ac fixed payment with $ 3.96/bu variable payment
c.2	$230/ac fixed payment with $ 3.96/bu variable payment

[9] The model assumes that the representative grower has full information, so that a fourth alternative contract design specified in Chapter 4, providing information within contracts, will not be discussed here.

6.6.1 Justifications of Alternative Contract Designs

The first category (A) imposes restrictions on permissible nitrate leaching, nitrogen use, or agronomic practices. Under strategy ***a.1***, the maximum permissible nitrate *leaching* level in a seed corn field is set at 35 lb/ac per growing season. This rate is the medium nitrate leaching level of those modeled for seed corn production. The restriction on permissible nitrogen *use* on seed corn field (***a.2***) is set at a mean of 107 lb/ac, the lowest nitrogen treatment for continuous seed corn in the model. Below this level, seed corn yield begins to decline on a larger scale, which is unlikely to be acceptable to both processor and grower. Because potatoes result in leaching in seed corn production via nitrate carryover, forbidding seed corn/potato rotations (***a.3***) becomes an instrument to reduce nitrate leaching.

Charging a fee on the amount of nitrate leaching above 30 lb/ac, or for nitrogen fertilizer above 90 lb/ac (category ***B***), raises the marginal cost of nitrogen use for most crop enterprises. Charging 10 cents per pound on nitrate leaching above the 30 lb/ac level will cause the grower to begin to lower nitrogen rates, resulting in reduced nitrate leaching compared to the base scenario. The 15 cents per pound fee on nitrogen applications over 90 lb/acre is the minimum fee required to induce substitution of the base model seed corn enterprise with one that uses less nitrogen.

The third category (category ***C***) of incentive schemes decreases the variable payment paid to the grower by the processor. The base scenario incentive payment includes a fixed payment of $150 /ac plus a variable payment of $5.28 /bu for seed corn yield. One alternative (***c.1***) increases the fixed payment to $397/ac and lowers the variable payment to $3.96/bu, 75 percent of the original variable payment. This redesigned contract is intended to induce a risk-neutral grower to lower the nitrogen rate, while retaining the same income level he/she earns in the base scenario. This variable payment is the level that a grower will switch nitrogen application rates from a medium level to a low level. When the variable payment is between $0 and $3.96/bu, the decision of the contracted-grower is the same as the decision when the variable payment is $3.96/bu in this model. Therefore, the model will use the variable payment $3.96/bu in the model to represent the change in the payment scheme.

The second alternative (***c.2***) retains the variable payment at $3.96/bu, while reducing the fixed payment to $230/ac, the fixed payment that will keep the gross margin of the processing firm the same as the base scenario. The design of alternative contracts ***c.1*** and ***c.2*** shows that the incidence of who bears the costs of leaching reduction has a linear relationship. The amount of cost borne by each party can be adjusted simply by changing the fixed payment.

The strategy of imposing a leaching restriction on the whole farm (***a.1.1***) is used as a method to identify growers with low whole farm nitrate leaching. This strategy requires measures of nitrate leaching from the whole farm. Those growers who fail to reduce whole-farm leaching to this 35 lb/ac threshold level will lose seed corn contracts. Imposing a leaching restriction on the average seed corn field (strategy ***a.1.2***) allows some flexibility in adjusting different nitrate leaching on seed corn fields. That is, if a grower uses higher nitrate leaching practices on some acres, and low nitrate leaching practices on other acres, the average nitrate leaching for all seed corn production can be maintained at the restricted level. Imposing a restriction on nitrogen fertilizer rates (***a.2***) is based on evidence that nitrogen fertilizer use is the most important and direct element affecting the amount of nitrate leaching (Ritchie, 1996). Imposing a restriction on rotation with potatoes (***a.3***) is also a method to reduce nitrate leaching, since this rotation incurs more nitrate leaching than does other rotation practice.

Imposing a restriction and charging a fee on the amount of nitrogen or nitrate leaching will potentially increase the marginal cost of nitrogen use, making the grower bear an additional cost from using nitrogen fertilizer. Reducing variable payments, on the other hand, will reduce the value of the marginal product for nitrogen use and subsequently reduce nitrate leaching as well.

6.6.2 Impacts on Nitrate Leaching Reduction from Alternative Contract Designs

The changes in seed corn yield, average whole-farm nitrate leaching, and average seed corn field nitrate leaching from various contract designs are listed in Table 6.5. The corresponding crop mixes are listed in Appendix D.

Table 6.5: Mean yield and nitrate leaching for a profit-maximizing grower under different contract designs

	Alternative Contract Designs	Mean seed corn yield (bu/acre)	Mean leaching from seed corn (lb/ac)	Mean whole-farm leaching (lb/ac)
Unrestricted base scenario		77.71	63.92	80.15
a.1.1	Restrict ANL to 35 lb/ac (whole-farm)	77.66	41.51	35.00
a.1.2	Restrict ASNL to 35 lb/ac (seed field)	77.64	35.00	52.99
a.2	Restrict N fert. to 107 lb/ac	77.15	62.95	79.86
a.3	No rotation with potatoes	77.64	33.97	51.76
b.1	Charge 10 ¢/lb on ASNL > 30 lb/ac	77.65	36.56	54.87
b.2	Charge 15 ¢/lb on N fert. > 80 lb/ac	77.60	36.47	54.84
c.1	varpay:$3.96/bu; fixpay:$253/ac	77.15	62.95	79.86
c.2	varpay:$3.96/bu; fixpay:$230/ac	77.15	62.95	79.86

Note: ANL: average nitrate leaching from the whole farm;
ASNL: average nitrate leaching from seed corn production
Fixpay: fixed components of seed corn contract payment ($/acre);
Varpay: variable components of seed corn contract payment ($/bushel).

From Table 6.5, the alternative contract designs reduce seed corn yield. Under these contract designs, the contracted grower will switch either from medium to low nitrogen applications, or from seed corn/potato rotation over to a seed corn/soybean rotation, which results in lower seed corn yield and lower nitrate leaching than in the base scenario. This result implies a trade-off relationship between yield and nitrate leaching abatement. There are two ways to capture the cost of leaching reduction on the processor. One is to calculate the opportunity cost forgone under alternative contract designs. This opportunity cost reflects on the gross margin reduction from the same seed corn acreage.

Another way to calculate the cost is to calculate the cost to achieve the same yield goal. As mentioned in Chapter 3, one of the main purposes of contracting production is to maintain a stable supply. The principal's objective could be to maintain the same yield level as in the base scenario. Therefore, the principal might need to increase the seed corn acreage. An increase in the seed corn acreage will increase the processor's cost, including higher cost for more seed for additional acres, monitoring cost, detasseling cost, and pesticide cost.

This analysis uses the first approach, that is, seed corn acreage changes are not considered due to several reasons. First, the yield difference between alternative contract designs and the base scenario is not significant, ranging 0.07 bu/ac to 0.56 bu/ac. Second, all alternative contract designs have lower nitrate leaching per unit of seed corn yield. Therefore, an increase in the seed corn acreage in order to maintain yield the same as the base scenario still has less nitrate leaching than the base scenario. The third reason is that it is difficult to formulate a stable yield supply as the objective function because yield is not a choice variable, but instead it is a random variable. The fourth reason is due to the difficulty in obtaining the additional costs that a processor incur from alternative contract designs.

The average amount of nitrate leaching from seed corn acreage (*ASNL*) as well as from the whole farm (*ANL*) is described in figure 6.2.

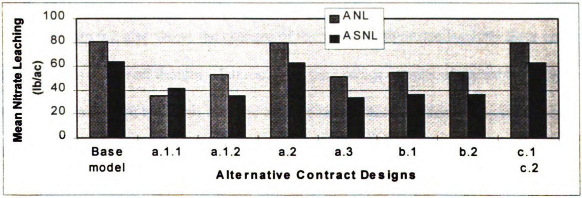

Figure 6.2: Mean nitrate leaching from seed corn production (ASNL) and from the whole farm (ANL) under alternative contract designs

The contract design that forbids seed corn/potato rotation (***a.3***) will result in the lowest nitrate leaching level from seed corn production among all alternative contract designs. This contract design reduces nitrate leaching by 30 lb/ac per growing season by substituting a seed corn/soybean rotation with medium nitrogen application. The next most effective nitrate leaching reduction contract designs are restricting nitrate leaching from seed corn production to 35 lb/ac (***a.1.2***), charging a fee of 15 ¢/lb on nitrogen fertilizer above 90 lb/ac (***b.2***), and charging a fee of 10 ¢/lb on nitrate leaching above 30 lb/ac (***b.1***). These three strategies induce the contracted-grower to switch most of the 500 acres from seed corn/potato rotation to seed corn/soybean rotation, which reduces nitrate leaching by 29-27.5 lb/ac per season. A contract design that restricts the nitrate leaching level from the whole farm (***a.1.1***) is able to reduce nitrate leaching by 23 lb/ac per season by switching 374 of the seed corn acres from a rotation with potatoes to a rotation with soybeans. Restricting nitrogen fertilizer (***a.2***), and adjusting contract payment schemes by reducing the variable payment to $3.96 /bu (***c.1 and c.2***), reduce nitrate leaching by only 1 lb/ac via reducing nitrogen application to low levels in a seed corn/potato rotation. Both strategies have only small impacts in terms of reducing nitrate leaching from seed corn production.

Figure 6.2 also shows the changes of the whole-farm nitrate leaching level under the alternative contract designs. Interestingly, the average amount of nitrate leaching from the whole farm is greater than the average nitrate leaching from seed corn fields, except in the case that restricts the average whole farm nitrate leaching (***a.1.1***). The major source of the whole-farm nitrate leaching is potato production. Seed corn production is not the major nitrate leaching source if the farm is operated on a profit-maximizing basis.

All of the alternative contract designs are able to reduce whole-farm nitrate leaching from the base scenario level. If the company can identify growers who generate low nitrate leaching from the whole farm (***a.1.1***), then the grower needs to reduce nitrate leaching to show his or her environmental stewardship in order to obtain seed corn contracts. As a result, the average amount of nitrate leaching from the whole farm will be substantially reduced (35 lb/ac per growing season). Other contract designs that restrict nitrate leaching from growing seed corn (***a.1.2***), forbid seed corn/potato rotation (***a.3***), or charge a fee on either nitrate leaching (***b.1***) or nitrogen use (***b.2***), can reduce nitrate leaching levels by 25 to 30 lb/ac per growing season. Such nitrate leaching reduction comes from the switch from seed corn/potato rotations to seed corn/soybean rotations. Contract designs that restrict nitrogen application to 107 lb/ac (***a.2***), or reduce the variable payment (***c.1 & c.2***) only reduce the whole farm nitrate leaching by 0.3 lb/ac.

6.6.3 Impacts on Gross Margin from Alternative Contract Designs

Increased financial returns represent the other objective of the contracting parties, apart from reduced nitrate leaching. These returns are represented in Table 6.6 as the whole-farm gross margin (GM) over variable costs. For the contracted grower, this gross margin represents the optimal solution to the LP problem. For the seed corn processor, GM is calculated as the value of seed corn yield minus payments made to growers plus revenues from fees charged to growers (e.g., for excessive nitrate leaching or nitrogen fertilizer application).

Table 6.6: Nitrate leaching, principal's and agent's gross margins under various contracts

Alternative Contract Designs		TSNL* (lbs)	ASNL* (lb/ac)	Grower's GM ($/year)	Firm's GM ($/year)
Unrestricted base model		31960	63.92	357830	1386600
a.1.1	Restrict whole-farm NL to 35 lb/ac	20754	41.51	355790	1385700
a.1.2	Restrict seed corn NL to 35 lb/ac	17500	35.00	357140	1385400
a.2	Restrict N fert. to107 lb/ac	31474	62.95	357500	1376100
a.3	No rotation with potato	16985	33.97	357030	1385400
b.1	Charge 10¢/lb on NL>30 lb/ac	18278	36.56	356960	1385800
b.2	Charge 15¢/lb on N fert.>90 lb/ac	18236	36.47	357150	1384700
c.1	Fixpay*:$253/ac; varpay*:$3.96/bu	31474	62.95	357830	1375790
c.2	Fixpay*:$230/ac; varpay*:$3.96/bu	31474	62.95	347020	1386600

Note: TSNL: the total nitrate leaching from seed corn production;
ASNL: the average nitrate leaching from seed corn production;
GM: gross margin;
Fixpay: fixed components of seed corn contract payment ($/acre);
Varpay: variable components of seed corn contract payment ($/bushel).

From the grower's viewpoint, decreasing the variable payment to 75 percent of the original payment ($3.96/bu) and increasing the fixed payment ($253/ac) to maintain the same revenue as the base scenario (*c.1*), gives the grower the same gross margin as the base scenario, which is the highest grower's margin among all alternative contracts. Other contract designs decrease the grower's gross margin from as little as $330 (restricting nitrogen application to 107 lb/ac, ***a.2***) to as much as $10,810 per growing season (decreasing the variable payment to $3.96/bu with the fix payment $230/ac, ***c.2***).

From the processing firm's viewpoint, all alternative contract designs, except decreasing the variable payment to $3.96/bu with the fixed payment $230/ac (*c.2*), decrease the processing firm's gross margin. Contract design ***c.2*** maintains the processor's gross margin at the level of the base scenario. Charging a fee on nitrate leaching above 30 lb/ac (***b.1***) costs the least to the processing firm ($800 per growing season in total) among the contract designs. Restricting the permissible whole farm nitrate leaching level to 35 lb/ac (***a.1.1***) reduces the processing firm's gross margin by $900; and restricting the permissible nitrate leaching level from seed corn production to 35 lb/ac (***a.1.2***), or forbidding the seed corn/potato rotation (***a.3***) reduces the processing firm's gross margin by $1,200. Charging a fee on nitrogen fertilizer use above 90 lb/ac costs the processing firm $1,900; and restricting nitrogen use to 107 lb/ac costs the processing firm $10,500. The contract design that involves decreasing the variable payment to $3.96/bu plus the fixed payment of $253/ac (***c.1***) maintains the same gross margin of the grower, but it is the most costly contract design to the processing firm. It reduces the processing firm's gross margin by $10,810 per year.

A contract design that charges a fee of 15 ¢/lb on nitrogen application above 90 lb/ac can achieve similar leaching reduction as a contract that charges a fee of 10 ¢/lb on nitrate leaching above 30 lb/ac, given that the costs to the grower are similar ($356,960 versus $357,150). However, the former costs the processor $1,100 more than the latter. Under both contract designs, the grower will grow 457 acres of seed corn in rotation with soybeans with medium levels of nitrogen application. The other 43 acres is in rotation with potatoes. Charging a fee on nitrate leaching will induce the grower to use medium levels of nitrogen application, while charging a fee on nitrogen application will result in low levels of nitrogen application. This result is because charging a fee on nitrogen will induce the grower to reduce nitrogen application rates, based on the tradeoff between nitrogen cost and reduced profit from yield reduction, although it might not significantly reduce nitrate leaching. Charging a fee on leaching will induce the grower to undertake the practice that incurs less nitrate leaching, based on the tradeoff between leaching cost and reduced profit from yield reduction. In this case, the nitrogen cost is greater than the benefit from medium nitrogen fertilization levels. Therefore, the grower will use low nitrogen application rates to grow seed corn in rotation with potatoes. On the other hand, the leaching cost is less than the benefit from medium nitrogen fertilization levels. The grower will use medium nitrogen application rates to grow seed corn in rotation with potatoes. As a result, the yield and the processor's gross margin are reduced under a contract charging a fee on nitrogen more than they are under a contract charging a fee on leaching.

In order to identify contract designs which are preferable to both the processor and contracted grower, two criteria can be used. The first criterion requires that the contract design should be acceptable to both parties. The second criterion is that the contract design should be cost-effective. Based on these two criteria, two definitions of dominance analysis will be introduced to evaluate contract designs from both grower's and processor's perspectives. They are *acceptability to each contracting party* and *efficiency at achieving reduction in nitrate leaching*.

6.6.4 Contract Acceptability Dominance

Profitability and environmental quality are the most important elements in designing a "green" contract from the processor's perspective. A contract with higher profitability and lower environmental damage is assumed to be preferred from the processor's viewpoint. The contract design also needs to be acceptable to the grower, that is, it must satisfy the grower's participation constraint. In this case, an acceptable contract design for the grower is defined as the contract that will reduce the grower's gross margin by less than a certain level. A dominant contract is one that is acceptable to both processor and grower[10].

Based on these assumed preferences, we define *contract acceptability dominance* in terms of mean nitrate leaching (lower levels preferred) versus mean gross margins (higher levels preferred) from the processing firm's viewpoint. It is defined such that strategy ***A*** dominates strategy ***B***, if and only if, either $(ASNL_A < ASNL_B \text{ and } GM_A \geq GM_B)$ or $(ASNL_A \leq ASNL_B \text{ and } GM_A > GM_B)$, where ***ASNL*** is the average amount of nitrate leaching from seed corn production and ***GM*** is the gross margin. The above definition is based on the assumption that the processing firm desires both profitability and environmental quality (the latter based on the firm's "green" image or avoiding future regulation). The contract is assumed to be acceptable to the grower if it reduces expected net return by less than 1 percent.

All contract designs satisfy acceptability dominance from the grower's

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[10] Other circumstances might extend to examine the case where the grower also desires environmental quality from the whole-farm operation. For instance, if the grower relies on groundwater from his or her farm for drinking water, the grower will have the incentive to produce less nitrate leaching. In this situation, game theory can be used to include the cooperative or non-cooperative behavior in the negotiation process between processor and contracted growers. For simplicity, this research only examines the case where only the processor desires nitrate leaching reduction.

perspective, except reducing the variable payment to $3.96/bu and increasing the fixed payment to $230/ac (*c.2*). From the processor's viewpoint, some contract designs are dominated by others. For instance, charging 10 ¢/lb on nitrate leaching above 30 lb/ac (***b.1***) generates a higher gross margin and lower nitrate leaching than strategy ***a.1.1***, which restricts the permissible nitrate leaching from the whole farm, ***a.2***, which restricts nitrogen use below 107 lb/ac, or ***c.2***, which reduces the variable payment to $3.96 with a fixed payment of $230/ac. Therefore, strategy ***b.1*** is the dominant contract design. In another example, strategies ***a.2, c.1,*** and ***c.2*** all result in the same amount of nitrate leaching from seed corn production, however, reducing the variable payment to $3.96/bu, and increasing the fixed payment (*c.2*), has the highest gross margin to the processing firm. Based on this information, ***a.3, b.1,*** and ***c.2*** are efficient in terms of contract acceptability dominance from the processor's perspective.

By the definition of contract acceptability dominance, the efficient strategies that are undominated from the processor's (principal's) and the grower's (agent's) perspective are contracts which forbid seed corn/potato rotation practices (***a.3***), or charge 10 cents per pound on nitrate leaching above 30 lb/ac (***b.1***).

In additional to aggregate efficiency, the cost of reaching the environmental quality objective of reduced leaching should be considered. In order to account for the cost for nitrate leaching reduction, another criterion should be used to evaluate contract alternatives.

6.6.4 Cost Efficiency Dominance

One way to measure the cost per pound of reducing nitrate leaching from seed corn production is to measure the reduction in gross margins, as shown in the last two columns of Table 6.7.

Table 6.7: Nitrate leaching, principal's and agent's gross margins, and unit cost of leaching reduction from seed corn production under various contracts

Alternative Contract Designs		TSNL (lbs)	ASNL (lb/ac)	Grower's GM	Principal's GM	ΔGM(G) $/lb	ΔGM(P) $/lb
Unrestricted base model		31960	63.92	357830	1386600	NA	NA
a.1.1	Restrict whole-farm NL to 35 lb/ac	20754	41.51	355790	1385700	0.18	0.08
a.1.2	Restrict seed corn NL to 35 lb/ac	17500	35.00	357140	1385400	0.05	0.08
a.2	Restrict N fert. to 107 lb/ac	31474	62.95	357500	1376100	0.68	21.60
a.3	No rotation with potatoes	16985	33.97	357030	1385400	0.05	0.08
b.1	Charge 10¢/lb on NL>30 lb/ac	18278	36.56	356960	1385800	0.06	0.06
b.2	Charge 15¢/lb on N fert. > 90 lb/ac	18236	36.47	357150	1384700	0.05	0.14
c.1	Fixpay*:$253/ac; varpay*:$3.96/bu	31474	62.95	357830	1375790	0.00	22.24
c.2	Fixpay*:$230/ac; varpay*:$3.96/bu	31474	62.95	347020	1386600	22.24	000

Note: TSNLand ASNL: the total and the mean nitrate leaching from seed corn production;
ΔGM(G): reduction in the grower's gross margin (GM) for per unit leaching reduction;
ΔGM(P): reduction in the processor's gross margin (GM) for per unit leaching reduction;
Fixpay: fixed components of seed corn contract payment ($/acre);
Varpay: variable components of seed corn contract payment ($/bushel).

The *ΔGM* and *ΔTSNL* figures are calculated as the differences in gross margins and total nitrate leaching from seed corn production between the base model levels and those in each alternative scenario. The *ΔGM/ΔTSNL* ratios can also be evaluated by dominance analysis. In this instance, strategy A dominates strategy B if it reduces leaching at lower unit cost for the grower without increasing unit costs for the processor or vice-versa. Algebraically, strategy A dominates strategy B if and only if $[(\Delta GM/\Delta ASNL)^P_A \geq (\Delta GM/\Delta ASNL)^P_B$ *and* $(\Delta GM/\Delta ASNL)^G_A > (\Delta GM/\Delta ASNL)^G_B]$ or $[(\Delta GM/\Delta ASNL)^P_A > (\Delta GM/\Delta ASNL)^P_B$ *and* $(\Delta GM/\Delta ASNL)^G_A \geq (\Delta GM/\Delta ASNL)^G_B]$, where superscripts ***G*** and ***P*** indicate the grower and the processor, respectively. This concept is illustrated in figure 6.3.

In figure 6.3, ***A, B, C, D, D'*** and ***D"*** are different strategies. ***A, B*** and ***C*** are cost-efficiency dominant strategies over all strategies labeled by ***D, D',*** and ***D"***. For instance, strategy ***A*** has a lower cost than strategies ***D'*** per one unit of nitrate leaching, therefore, strategy ***A*** is cost efficient compared to ***D'***. Compared with strategies ***A*** and ***B***, however, one cannot decide which one is more cost efficient because strategy ***A*** has a lower per unit cost for the processor while it has a higher per unit cost for the grower under strategy ***B***. Therefore, strategies ***A*** and ***B*** are not dominated by each other. Although this analysis cannot rank all of the alternative contracts, it does rule out the contract designs with higher costs to both parties.

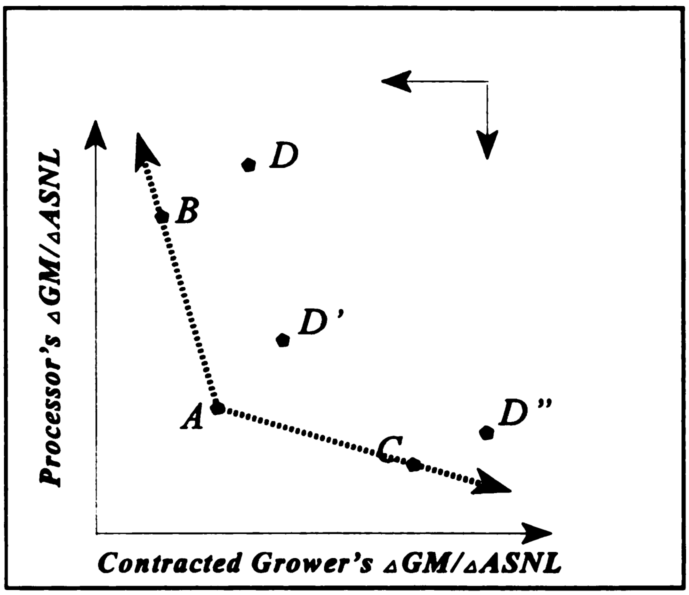

Figure 6.3: Cost efficiency dominance analysis

By this definition, the cost-efficiency dominance criterion eliminates four inefficient contract designs, ***a.1.1***, ***a.2***, and ***b.2***. The contract designs that fall into efficient set are the contracts restricting nitrate leaching from seed corn production (***a.1.2***), restricting rotation (***a.3***), and charging for nitrate leaching above 40 lb/ac (***b.1***). This result is also shown in Figure 6.4.

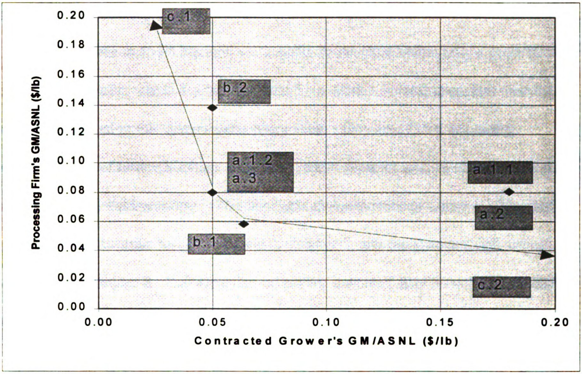

Figure 6.4: Cost efficiency dominance analysis of the processing firm's and contracted grower's cost for per pound of leaching reduction

In Figure 6.4, the line indicates a cost efficiency frontier. Every strategy on this line cannot be dominated by another strategy. In terms of the overall cost (combining the grower's and the processing firm's cost) for per unit nitrate leaching reduction, the strategy that charges 10 cents per pound for nitrate leaching above 30 lb/ac has the lowest unit cost, 12 ¢/lb in total. Strategies ***a.1.2*** and ***a.3*** cost 13 cents per pound of nitrate leaching reduction.

There are two contracts-- restricting seed corn/potato rotation (***a.3***), and charging 10 cents per pound on nitrate leaching above 30 lb/ac (***b.1***)--that satisfy both contract acceptability dominance and cost efficiency dominance. These contract designs can be interpreted as the "first-best" policy when the grower is risk-neutral. Under the situation where they are observable or measurable, these two contract designs can achieve both efficiency criteria.

The above analysis has outlined a means to structure empirically a processor-grower relationship within a principal-agent framework. Several important elements are not discussed in this deterministic framework. They are: 1) the stochastic characteristics of nitrate leaching, 2) grower risk of contract loss, 3) the grower's risk attitude, and 4) enforceability. The stochastic characteristics of nitrate leaching and grower risk of contract loss is discussed in Chapter 7, and the grower's risk-attitude is examined in Chapter 8. Enforceability is another important issue in contract designs, in addition to *contract acceptability dominance* and *cost efficiency dominance* criteria. The enforcement issues will be discussed in the following chapters.

6.7 Summary

This chapter has outlined an empirical framework to solve the principal-agent model. Although two-level mathematical programming methods have been proposed in the literature, none have proved implementable because of practical complexities. As an alternative, this research decomposed the principal-agent problem into two stages. In the first stage, whole-farm mathematical programming is applied to model optimizing behavior of the representative grower-agent. The impacts on the processing firm (principal) are calculated in the second stage.

The results from the base scenario show that the shadow price of the seed corn contract ($193/ac) is relatively high. From sensitivity tests, higher nitrogen costs, a lower variable contract payment, and relatively higher soybean prices can all potentially reduce nitrate leaching.

The results also show that the mean nitrate leaching from the whole farm is greater than that from growing seed corn. This result indicates that seed corn is not necessarily the major crop responsible for nitrate leaching, particularly if potato rotations are included. However, even though seed corn production generates relatively low nitrate leaching, this analysis shows that the nitrate leaching both from the whole farm and from seed corn production can be reduced through various alternative seed corn contract designs.

Three categories of contract specifications have been examined: imposing a restriction (on the permissible nitrate leaching, nitrogen application, or agronomic practice), charging a fee (on the permissible nitrate leaching, nitrogen application), and adjusting the contract payment formula (by reducing the variable payment). The model results show that nitrate leaching from growing seed corn can be effectively reduced by contract designs that impose a restriction on nitrate leaching, forbid rotation with potatoes, or charge a fee on nitrate leaching or nitrogen use. These contract designs can reduce nitrate leaching from the whole farm as well.

Two dominance criteria are introduced and used to rank these alternative contract designs: contract acceptability dominance and cost efficiency dominance. Based on this analysis, contracts forbidding rotations with potatoes (***a.3***) and contracts charging 10 ¢/lb for nitrate leaching above 30 lbs (***b.1***) are the only two contract designs undominated under either criterion.

CHAPTER 7

CHANCE CONSTRAINTS IN DESIGNING SEED CORN CONTRACTS TO REDUCE NITRATE LEACHING

Chapter 6 outlined a basic framework that can empirically model the contractual relationship, and that can evaluate the impacts on the processor as well as the grower under various alternative contract designs. Two additional concerns need to be considered in designing a seed contract to reduce nitrate leaching. One is the grower's concern over risk of seed corn contract loss, as mentioned in Chapter 4. This concern has been cited as a major reason for over-fertilization. The other concern is the stochastic nature of nitrate leaching and its abatement due to unpredictable weather and water influences. This is problematic, since the damage caused by NPSP is often related to exceeding a specified threshold level.

The objective of this chapter is to incorporate these two concerns into the model of the grower's decision-making process. The impacts on nitrate leaching as well as the grower's and the processor's gross margins are estimated in an empirical principal-agent model. This chapter first clarifies the probabilistic nature of contract loss risk and nitrate leaching abatement. The second section subsequently reviews the literature on how to model these two issues. How these two concerns affect the representative grower's decisions as well as the processor's welfare within a contract are examined.

Then implications for alternative contract designs are discussed.

7.1 Issues in Designing Seed Corn Contracts to Reduce Nitrate Leaching

Seed corn contract loss risk and the probabilistic nature of a nitrate leaching reduction strategy influence the grower's response to various seed corn contract designs. Additional analysis is required to evaluate their impacts.

7.1.1 Risk of Seed Corn Contract Loss

Although several risks are associated with growing seed corn, the primary risk involves losing the seed corn contract[11] (Batie, 1994). In some instances, a company may allocate grower allotments by calculating a grower evaluation index, based on objective criteria known to the growers such as isolation block requirements and yield history, and subjective criteria unknown to the grower such as grower cooperativeness (Doering, 1996). Growers risk losing their contracts if their performance is poor over time. Some growers believe that such an evaluation index puts heavy weight on yield history (Dobbins and Swinton; Batie and Swinton, 1995).

Because the availability of seed corn contracts is limited and the profitability of growing seed corn is high, the seed corn grower has an incentive to maintain or to increase his or her seed corn acreage (Dobbins and Swinton, 1995). Growers perceive that they are likely to lose their seed corn contracts if their seed corn yields fall below

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[11]This is a subset of the broader category of unpredictable policies by the processing company, such as reducing grower acreage, changing to new varieties, or requiring more costly management practices.

the average regional yield too frequently, such as, say, two out of five years (or 40 percent). The concern over risk of seed corn contract loss accentuates the importance of achieving high yields that is already inherent in the tournament contract payment scheme.

Preckel et al. (1997) used dynamic programming to model this contract loss risk. By examining the impacts from the grower's perspective in a continuous seed corn cropping, their analysis demonstrated that the contracted-grower will use a relatively high nitrogen application rate when he or she is concerned with the risk of contract loss. High fertilization, however, results in excessive nitrate leaching. Their model, however, considered neither the participation constraint (the opportunity of growing other crops) nor the impacts on the processor.

Because experimentation with new practices to reduce nitrate leaching might imperil high yields, the concern over contract loss could become an obstacle to grower adoption of such practices. This research examines the impacts of contract loss risk within a principal-agent framework, by incorporating other crop enterprises in the whole-farm model to represent the opportunity cost from growing seed corn. The impacts on the contracted-grower and the processor are examined as well.

7.1.2 A Probabilistic Nitrate Leaching Reduction Strategy

The health risks associated with nitrates in drinking water are linked to nitrate concentrations. As noted in Chapter 2, EPA has established 10 ppm of nitrate as the maximum contaminant level (MCL) for nitrates in water judged safe for drinking.

Exceeding this threshold could pose health risks to a farm household, or pose regulatory liability or reputation risks to a processing firm contracting for the agricultural product responsible for the contamination.

Nitrate leaching control is subject to a considerable randomness, stemming from natural variability of weather, soils and plants, imperfect monitoring and measurement; and time-lags between nitrogen applications and actual leaching. Each abatement strategy generates a probability distribution of outcomes instead of one single outcome. In order to manage the risk of exceeding a NPSP threshold, a leaching control strategy should be designed to take probabilities into account, rather than realization of abatement efforts. A method to implement probabilistic risk management is proposed by Lichtenberg and Zilberman (1988), Braden et al. (1991), and Teague et al. (1995). They suggested a NPSP abatement strategy to prevent bad outcomes by setting a threshold standard as to ambient environmental quality that includes a safety margin. Specifying an acceptable frequency (or probability) of achieving the environmental standard is more practical than specifying a mean nitrate leaching level (Lichtenberg and Zilberman, 1988; Braden et al., 1991). After all, it is difficult to ensure that a nitrate leaching standard is always met at different time periods and different locations. The probabilistic approach is to require the grower to meet the safe drinking water standard with a minimum probability, for example, in a two out of every five years.

Both the concerns of seed corn contract loss and exceeding a nitrate leaching threshold are based on the probability of achieving a target level. This can be modeled using safety-first decision rules.

7.2 Safety-First Rule: A Probabilistic Chance Constraint

Both contract loss risk and risk of exceeding an NPSP threshold are cases where serious, nonmarginal losses ensue from a bad outcome. This characteristic makes them amenable to modeling with "safety-first" rules. The safety-first rule is a model in which the decision maker is concerned with the probability of failing to achieve his or her goals. It is often used when the consequence of catastrophe is large (such as bankruptcy), or when the decision-maker's decision is subject to a threshold level. Below this threshold level, there is a discontinuous drop in welfare. In a typical safety-first framework, over-achievement of the goal might not necessarily increase total utility, but an infinite disutility is associated with under-achievement (Roy, 1952; Pyle and Turnovsky, 1970; Telser, 1955; and Kataoka, 1963; and Robison and Barry, 1987). Safety-first decision rules can be adopted in this research where the grower is concerned about the risk of losing contracts, while the processor is concerned about the risks of nitrate leaching exceeding a threshold level.

7.2.1 Modeling Contract Loss Risk Avoidance

In order to avoid losing the contract, the grower is assumed to avoid the probability that his or her own annual seed corn yields fall below the average regional yield (y^0), exceeding some acceptable probability level, $1/g^*$. This concern can be expressed mathematically as follows:

$$Prob(y \leq y^0) \leq 1/g^* \tag{7.1}$$

In order to model the contract loss assumption in a whole-farm model and for simplicity, this research uses a one period analysis. Several techniques can be used to formulate the equation 7.1 probabilistic constraint in a mathematical programming framework. One technique is to use the Chebychev inequality that uses mean and standard deviation to form a boundary for equation 7.1 (Telser, 1955; Anderson et al., 1977). The second alternative is to use a lower partial moment method where negative deviations from a specified goal are used to formulate a condition sufficient to meet this probabilistic constraint (Atwood, 1985; Atwood et al., 1988). When income is normally distributed, the definition in equation 7.1 can be modified and analyzed within a mean-variance model (Pyle and Turnovsky, 1970; Hazell and Norton, 1986). Among these techniques, the lower partial moment approach has a relatively wide range of applications because it does not require a parametric distribution (Atwood et al., 1988).

The lower partial moment technique, suggested by Fishburn (1977) and Atwood (1985), is employed to derive an equivalent condition for a chance constraint. It measures the deviations below a specific target level, weighted by the corresponding probability level and the inverse of a permissible safe margin (equation 7.2), that is,

$$t - g^{*} \sum_{y_i \le t} (t - y_i)\, q_i \ge y_0 \tag{7.2}$$

where t is an endogenously selected target level; $1/g^*$ is the permissible probability level; y_i is seed corn yield in state i; q_i is the probability associated with state i; and y_0 is the average regional seed corn yield. The yields below the target level (t - y_i) is the main concern in equation 7.2. This equation is sufficient to guarantee that the chance constraint of avoiding contract loss (equation 7.1) is met. The proof is shown in Appendix E.

7.2.2 Modeling a Probabilistic Leaching Control

The same chance constraint approach can be applied to the risk that measurable NPSP exceeds some benchmark. In this instance, the chance constraint would be imposed to comply with the processor's interest in avoiding significant nitrate leaching. If the grower is required to ensure that the probability of nitrate leaching (***L***) surpassing a threshold level ($\bar{L}$) may not exceed some permissible probability level $1/h^*$, that is:

$$Prob(L \geq \bar{L}) \leq 1/h^* \tag{7.3}$$

The sufficient condition to ensure equation 7.3 becomes (Atwood et al., 1988; proof shown in Appendix E) :

$$L^t - h^* \sum_{L_i \geq \bar{L}} (L_i - \bar{L}) p_i \geq 0 \tag{7.4}$$

where L^t is the reference level of target nitrate leaching; L_i and p_i, the level of nitrate leaching and its corresponding probability in state i; $\bar{L}$, the target level of nitrate leaching (per acre) and $L^t \geq \bar{L}$; and, $1/h^*$, allowed probability for nitrate leaching exceeding $\bar{L}$.

The specification in equation 7.4 accounts for leaching exceeding the threshold level (L_i - $\bar{L}$), weighted by corresponding probability and the inverse of the permissible probability level. This lower partial moment approach can ensure the leaching chance constraint in equation 7.3 is met. The main objective is to restrict the occurrence of undesirable outcomes. Any deviation from the threshold level is undesirable to the processor.

7.2.3 Modeling the Whole-Farm Decision Rule

In this research, the objective of the contracted-grower is assumed to be the maximization of the gross margin from the whole-farm operation, and that he or she will avoid the risk of contract loss if and only if the contract is profitable. Mathematically, the whole-farm framework of the grower can be expressed as:

$$\begin{aligned} Max_{x_j} \quad E(M) &= \textstyle\sum_j (\bar{c}_j x_j) \qquad (7.5) \\ \textit{subject to} \quad & \textstyle\sum_j (a_{mj}\, x_j) \leq b_m, \\ & t - g^* \sum_{y_i \leq t} (t - y_i) q_i \geq y^0 \\ & L^t - h^* \sum_{L_i \geq \bar{L}} (L_i - \bar{L}) p_i \geq 0 \\ & x_j \geq 0 \;\; \forall j \end{aligned}$$

where M: the expected income;

$\bar{c}_j$: expected income (=price*expected yield);

x_j: farm activity j, such as crop acreage and input use;

q_i : probability of yield below the target level in state i;

p_i : probability of nitrate leaching exceeding the threshold level in state i;

$\sum_j (a_{mj}\, x_j) \leq b_m$: resource availability constraints (including contract acreage); where a_{mj} is the technical coefficient, representing the amount of resource m needed in producing x_j, b_m is the availability of resource m.

y_i : the seed corn yield in state i;

y^0 : the average regional seed corn yield (per acre);

t : reference target seed corn yield, where $t \geq y^0$ (per acre);

$1/g^*$: maximum allowed probability for seed corn yield falling below y^0.

L_i : level of nitrate leaching in state i;

$\bar{L}$: nitrate leaching threshold;

L^t: reference level of target nitrate leaching, where $L^t \geq \bar{L}$;

$1/h^*$: allowed probability for nitrate leaching exceeding $\bar{L}$.

This whole-farm programming model, as represented in equation 7.5, includes several components: (1) the states of nature, (2) the possible outcomes, (3) the probabilities of outcomes, (4) the set of alternative choices, and (5) the decision rule for ordering choices (Boisvert and McCarl, 1990; Hirshleifer and Riley, 1992; Robison and Barry, 1987). The decision rule of the representative grower is assumed to allow choice of various farm activities to maximize the expected gross margin, subject to several constraints: resource availability (or technology feasibility), a leaching chance constraint, the risk of contract loss, and non-negativity constraints.

For illustration purposes, ten states of nature were constructed for the mathematical programming model in order to represent the probability distribution of crop yields and nitrate leaching outcomes. Each state of nature is assumed to have equal 0.1 probability. The alternative choices include crop enterprises (seed corn, corn, soybeans, and potatoes), nitrogen fertilization rates in growing seed corn and corn, and production practices (such as planting date and harvesting date).

Yield and nitrate leaching data are simulated from DSSAT 3.0 using 1951-1992 weather input data (as discussed in Chapter 5). The data from the first two years were truncated to remove starting point carryover bias, where yield and nitrate leaching are highly affected by initial soil conditions in the model. The remaining 40 years of data were sorted according to the yield of continuous seed corn with 116 lb/ac (or 130 kg/ha; medium level) nitrogen fertilization. The sorted data were then divided into ten sets of four years each in order to represent "good" states of nature versus "poor" states of nature. Finally, each four-year set of data was averaged to construct ten "states of nature".

In order to include the chance constraints into a whole-farm model, PC-LP is simplified and translated into a GAMS (General Algebraic Modeling System; Brooke et al., 1988) formulation (Dobbins et al., 1996). This translation is necessary because PC-LP cannot model risk programming. The optimization results from the GAMS version of PC-LP have been tested and shown to be almost identical to the original PC-LP model (Etyang, 1994).

Because the contract loss risk is based on the grower's relative performance in the region, data on the long-term grower's yield and regional yields are required in order to calculate yield variability. The average regional yield data are affected by the variations of soil structure, agronomic techniques, and pest control. Because the range of these variations is large across the region, and because DSSAT 3.0 is a deterministic simulation model, it is difficult to account for yield variability for one particular year. DSSAT 3.0 assumes perfect conditions for yield growth--no pests and machinery failures--so the simulated yield data tend to out-perform the real situation. The only source of yield variation in DSSAT 3.0 comes from different weather conditions, given nutrient, water treatments, and certain tillage practices. Because of the lack of data on regional yield variations, the empirical analysis of this study chooses four yield levels to represent the levels of average regional yield. From these four levels, this research discusses how the chance constraint of avoiding yield falling below the average regional level affects the grower's nitrogen application rate and resulting nitrate leaching.

Leaching data from different states of nature are required to construct the nitrate leaching chance constraint. In principle, the selection of the threshold level and permissible probability level should be related to the processor's objective. It might be related to how the processor values his or her "green image" as well as potential future penalties, resulting from nitrate leaching damages. Contamination data requirements to estimate the potential degree of damage caused by nitrate leaching under seed corn include the bio-physical fate and transport of fertilizer nitrogen, such as the amount of nitrogen application, nitrogen uptake by the plant, water table indicators, leaching potential, nitrate concentration, and environmental susceptibility. Nitrate leaching is used to represent the environmental quality in this research because that is the environmental outcome that DSSAT 3.0 can simulate. The specifications of the threshold level, as well as the permissible probability of exceeding this level of nitrate leaching are crucial in designing a leaching chance constraint. This research employs two leaching threshold levels, each with five permissible probability levels, in order to examine how different specifications of these two parameters affect nitrate leaching as well as how they affect the processor's and the grower's gross margins. It does so by examining two leaching threshold levels, each with five permissible levels.

The results of whole-farm optimization with these two sets of chance constraints will be presented separately in order to consider the impacts from each model specification. The two issues examined are: 1) how the concern of the seed corn contract loss affects nitrate leaching; and, 2) how a probabilistic nitrate leaching chance constraint can be used in reducing nitrate leaching. These results will be discussed subsequently.

7.3 Whole-Farm Optimization with a Chance Constraint on Contract Loss

The whole-farm model from Chapter 6 was adjusted to incorporate the chance constraint (equation 7.1), where the grower avoids the risk that seed corn yield (y) falls below the average regional yield (y^0) more than $1/g^*$ proportion of the time, in order to manage the risk of contract loss.

This section examines optimal grower choices under four different average regional yield levels (y^0): 60 bu/ac, 65 bu/ac, 70 bu/ac, and 75 bu/ac and four chance constraint levels. These four average regional yield levels represent the lowest four yield levels from ten states of nature. These levels are chosen for the consideration of avoiding bad yield outcomes. The results from the whole-farm planning are summarized in Table 7.1- 7.3. There is a particular probability associated with each average regional yield level that will motivate the grower to use more nitrogen fertilization. For convenience, the results are shown using four intervals.

Table 7.1: Seed corn mean yield and nitrate leaching from growing seed corn (*ASNL*) and from the whole farm (*ANL*) under different regional yield and permissible probability levels of a contract loss chance constraint

Chance Constraint: $Prob(y \leq y^o) \leq 1/g^*$	Mean Nitrate Leaching and Seed Corn Yield from $Prob(y \leq y^o) \leq 1/g^*$			
Average Regional Yield: y^o bu/ac	interval 0%-20%	interval 20%-40%	interval 40%-60%	interval 60%-80%
y^o = 60 bu/ac	ASNL 65.23 lb/ac ANL 80.54 lb/ac Yield 77.89 bu/ac (11.5%)	ASNL 63.92 lb/ac ANL 80.15 lb/ac Yield 77.71 bu/ac	ASNL 63.92 lb/ac ANL 80.15 lb/ac Yield 77.71 bu/ac	ASNL 63.92 lb/ac ANL 80.15 lb/ac Yield 77.71 bu/ac
y^o = 65 bu/ac	ANL 51.17 lb/ac	ASNL 65.08 lb/ac ANL 80.49 lb/ac Yield 77.86 bu/ac (26%)	ASNL 63.92 lb/ac ANL 80.15 lb/ac Yield 77.71 bu/ac	ASNL 63.92 lb/ac ANL 80.15 lb/ac Yield 77.71 bu/ac
y^o = 70 bu/ac	ANL 51.17 lb/ac	ANL 51.17 lb/ac	ASNL 65.85 lb/ac ANL 80.72 lb/ac Yield 77.97 bu/ac (48%)	ASNL 63.92 lb/ac ANL 80.15 lb/ac Yield 77.71 bu/ac
y^o = 75 bu/ac	ANL 51.17 lb/ac	ANL 51.17 lb/ac	ANL 51.17 lb/ac	ASNL 64.65 lb/ac ANL 80.36 lb/ac Yield 77.81 bu/ac (80%)

Note: (.) indicates the point estimation of actual probability level used for the acreage shown. These acreage in fact vary over the range of $1/g^*$ values indicated in the column label.

Table 7.2: Gross margins of the grower and the processor under different regional yield and permissible probability levels of a contract loss chance constraint

Chance Constraint: $Prob(y \leq y^o) \leq 1/g^*$	Gross Margin of the Grower (GM(G)) and the Processor (GM(P)) from $Prob(y \leq y^o) \leq 1/g^*$			
Average Regional Yield: y^o bu/ac	interval 0%-20%	interval 20%-40%	interval 40%-60%	interval 60%-80%
y^o = 60 bu/ac	GM(G) 357620 GM(P) 1389900 (11.5%)	GM(G) 357830 GM(P) 1386600	GM(G) 357830 GM(P) 1386600	GM(G) 357830 GM(P) 1386600
y^o = 65 bu/ac	GM(G) 255330	GM(G) 357650 GM(P) 1389500 (26%)	GM(G) 357830 GM(P) 1386600	GM(G) 357830 GM(P) 1386600
y^o = 70 bu/ac	GM(G) 255330	GM(G) 255330	GM(G) 357520 GM(P) 1391500 (48%)	GM(G) 357830 GM(P) 1386600
y^o = 75 bu/ac	GM(G) 255330	GM(G) 255330	GM(G) 255330	GM(G) 357710 GM(P) 1388500 (80%)

Note: (.) indicates the point estimation of actual probability level used for the acreage shown. These acreage in fact vary over the range of $1/g^*$ values indicated in the column label.

Table 7.3: Acreage of seed corn enterprise under different regional yield and permissible probability levels of a contract loss chance constraint

Chance Constraint: $Prob(y \leq y^o) \leq 1/g^*$	Seed Corn Acreage Under Probability: $1/g^*$ (acres)			
Average Regional Yield: y^o bu/ac	interval 0%-20%	interval 20%-40%	interval 40%-60%	interval 60%-80%
y^o *= 60 bu/ac*	PSEED(M) 198 PSEED(H) 302 (11.5%)	PSEED(M) 500	PSEED(M) 500	PSEED(M) 500
y^o *= 65 bu/ac*	0	PSEED(M) 234 PSEED(H) 266 (26%)	PSEED(M) 500	PSEED(M) 500
y^o *= 70 bu/ac*	0	0	PSEED(M) 56 PSEED(H) 444 (48%)	PSEED(M) 500
y^o *= 75 bu/ac*	0	0	0	PSEED(M) 331 PSEED(H) 169 (80%)

Note: (.) indicates the point estimation of actual probability level used for the acreage shown. These acreage in fact vary over the range of $1/g^*$ values indicated in the column label.

As these three tables show, for each hypothesized average regional yield level, there is a probability[12] (diagonal part of the tables) that will make the profit-maximizing grower use high nitrogen applications on part of his or her seed corn acreage. Beyond this probability level (upper part of the tables), the optimizing grower would use a medium nitrogen application rate, the same rate as estimated in the base scenario. On the other hand, if the yield level falls below this probability level (lower part of the tables), the grower perceives that he or she will lose the seed corn contract. That is, the seed corn acreage is either nil when the constraint is not met, or 500 acres in rotation with potatoes when the constraint is not binding.

For example, if the grower expects that the average regional yield is 65 bu/ac,

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[12]This permissible probability level of each specified average regional yield level is obtained by a trial-and-error process. This process shows that the range of the permissible level that can alter the optimal solution is small, 1 or 2 percent in general.

and the permissible probability of falling below this level is 26 percent, the optimal solution is for seed corn in rotation with potatoes using a high nitrogen fertilization rate in 266 acres and a medium level in the other 234 acres (Table 7.3). In order to satisfy this constraint, the mean yield increases from 77.71 bu/ac to 77.86 bu/ac. Meanwhile, this increase in nitrogen use also causes more leaching from both seed corn production (from 63.9 lb/ac to 65.1 lb/ac) and the whole farm (from 80.2 lb/ac to 80.5 lb/ac) (Table 7.1). By doing this, the grower's gross margin slightly decreases ($180/year, from $357,830 to $357,650), but the grower perceives that he or she is ensured to have the contract for next year. If the grower fails to achieve this constraint, he or she perceives that there is a dramatic income loss (from $357,830 to $255,330 per year) by losing seed corn contracts. When the permissible probability is above 26 percent, the grower will use the same nitrogen level as the base scenario. On the other hand, when the permissible probability is below 26 percent, the chance constraint of contract loss is too restricted. As a result, the grower will no longer "qualify" to grow seed corn, if the processor indeed uses this criterion to allocate seed corn contracts.

This result implies that concern over risk of losing a seed contract may foster high nitrogen application rates. However, this concern of losing the contract does not cause a total switch from medium to high nitrogen fertilization use, because the yield distributions between these two nitrogen application levels do not different from each other very much (Table 7.4).

As Table 7.4 shows, all practices except seed corn following soybeans with low nitrogen fertilization have the same probability of achieving the target yields 60, 65, 70, and 75 bu/ac.

Table 7.4: Summary of seed corn yields from DSSAT 3.0 using different agronomic practices under 10 states of nature

States	Seed Corn Yields Under Different Agronomic Practices (bu/ac)								
	Continuous Seed Corn			Seed Corn after Soybeans			Seed Corn after Potatoes		
	H	*M*	*L*	*H*	*M*	*L*	*H*	*M*	*L*
1	58.9	58.8	58.4	58.7	58.9	58.4	59.0	58.9	58.4
2	67.1	66.7	66.0	67.0	66.7	66.2	67.0	66.6	66.0
3	72.5	72.0	70.3	72.3	71.8	71.3	72.3	71.8	70.3
4	75.8	75.5	74.3	75.6	75.2	74.3	76.0	75.6	75.1
5	77.4	77.3	76.9	77.3	77.1	76.8	77.3	77.1	76.8
6	80.8	80.5	79.9	80.9	80.5	80.0	80.9	80.5	80.0
7	83.5	83.3	83.0	83.3	83.1	82.9	83.3	83.2	82.9
8	86.0	85.7	85.2	85.7	85.3	84.7	85.7	85.4	84.9
9	87.3	87.2	86.7	87.1	86.9	86.4	87.1	86.8	86.2
10	91.4	91.1	90.6	91.3	91.0	90.5	91.3	91.1	90.7

Note: *H* represents high nitrogen fertilization; *M*, high nitrogen fertilization; and *L*, low nitrogen fertilization. Ten states of nature are presented in the order from poor-yield to good-yield states.

There are some potential limitations of this approach. First, the simulated yield distributions may not be the same as the grower's expectation before harvest. As shown in Chapter 2, the grower tends to use nitrogen fertilizer based on expectations of a good-yield year. As a result, excessive nitrogen may be used if normal or poor weather occurs. One implication is that the provision of accurate information on yield or weather distribution may be one strategy to prevent excessive nitrogen applications.

If the actual yield distributions of the medium and high nitrogen treatments are different, and if the grower because there is a risk of losing contracts for low yield outcomes, he or she may be motivated to use more nitrogen. Therefore, one direct strategy to reduce nitrate leaching is to "decouple" the relationship between relative yield performance and seed corn contract assignment, that is, to have less or no penalty for a poor relative yield performance.

7.4 Specification of a Chance Constraint on Nitrate Leaching

Because leaching outcomes are influenced by natural variability, perfect monitoring is impractical, and damage from leaching tends to be associated with a threshold level ($_L$), an alternative strategy for leaching reduction is to impose a leaching chance constraint on this specified threshold level. Adapting equation 7.3,

$$\boldsymbol{Prob(SNL_i \geq {}_L) \leq 1/h^*} \qquad \textbf{(7.3a)}$$

Equation 7.3a requires that the probability of the nitrate leaching from growing seed corn (SNL_i) in state i exceeds the threshold level must be less than the permissible probability level ($1/h^*$). This strategy involves the specifications of two terms: the threshold level on nitrate leaching, $_L$, and the permissible probability, $1/h^*$.

In order to estimate the impacts from the specification of a threshold as well as a permissible probability level, different scenarios are examined in this study. Two nitrate leaching threshold levels are selected as the processor's objective: 35 lb/ac and 40 lb/ac per growing season. The level of 35 lb/ac per growing season is the medium level of nitrate leaching from seed corn production in the model. Another threshold level, 40 lb/ac per growing season, was chosen as an alternative scenario because it will generate results that are similar to a contract that imposes a deterministic nitrate leaching level on 35 lb/ac. Five permissible probabilities for each threshold level are specified. All of these scenarios are modeled and compared in order to examine how parameter specifications affect the effectiveness as well as the cost of leaching reduction.

7.4.1 Probabilistic Chance Constraint on Nitrate Leaching Threshold 35 lb/ac

Table 7.5 and 7.6 summarize the main results for a profit-maximizing grower under a leaching chance constraint with different permissible probability levels for nitrate leaching from seed corn production exceeding 35 lb/ac per growing season. For convenience, this constraint can be written as: $Prob(SNL \geq 35) \leq 1/h^*$.

Table 7.5: Summary of nitrate leaching, profits, and unit cost of leaching reduction under a probabilistic constraint $Prob(SNL \geq 35) \leq 1/h^*$

Chance Constraint: $Prob(SNL \geq 35) \leq 1/h^*$	(1) ASNL (lb/ac)	(2) ANL (lb/ac)	(3) GM(G) ($/year)	(4) GM(P) ($/year)	(5) MGM(G) ($/lb)	(6) MGM(P) ($/lb)
Unrestricted base scenario	63.92	80.15	357830	1386600	na	na
a.1.2 Restrict ASNL=35 lb/ac	35.00	52.99	357140	1385400	0.05	0.08
Restrict Prob(SNL≥35)≤ 1/2	32.34	55.45	356010	1375900	0.12	0.68
Restrict Prob(SNL≥35)≤ 1/3	31.48	58.37	355070	1375900	0.17	0.66
Restrict Prob(SNL≥35)≤ 1/4	31.08	58.63	354480	1375900	0.20	0.65
Restrict Prob(SNL≥35)≤ 1/5	30.88	58.33	354150	1375900	0.22	0.65
Restrict Prob(SNL≥35)≤ 1/10	30.52	58.21	353190	1375900	0.28	0.64

where ASNL, ANL: average nitrate leaching from seed corn production and from the whole farm
SNL: nitrate leaching from seed corn production in different states of nature
GM(G), GM(P): grower's and processor's gross margin
MGM(G), MGM(P): grower's and processor's gross margin change for per unit leaching reduction

Table 7.6: Shadow prices of land and contracts, and crop enterprise mix from the grower's profit optimization under a probabilistic constraint *Prob(SNL≥35)≤ 1/h**

Results:	*a.1.2* Restrict ASNL=35	Probability level: *1/h** for *Prob(SNL≥35)≤ 1/h** 1 / 2	1/3	1/4	1/5	1/10
A. Shadow price ($/ac)						
Land	198.42	198.42	193.07	192.61	192.61	192.61
Contract	186.04	187.15	194.18	192.65	192.00	190.87
B. Total seed corn yield	38822	38569	38569	38570	38570	38570
C. Crop enterprise (acres)						
PCORN(M)	350	407.5	451	457	454	454
BCORN(L)	0	0	0	14	28	46
SSEED(L)	0	115	202	242	263	299
BSEED(M)	483	0	0	0	0	0
BSEED(L)	0	385	298	258	237	201
PSEED(M)	17	0	0	0	0	0
SBEAN	483	385	298	258	237	201
CBEAN	0	0	0	14	28	46
SPOTATO	17	0	0	0	0	0
CPOTATO	350	407.5	451	457	454	454

A. Nitrate Leaching from Seed Corn Production and the Whole Farm

From Table 7.5, the mean nitrate leaching from seed corn production (*ASNL*) declines as the permissible probability (*1/h**) of nitrate leaching exceeding 35 lb/ac becomes more restricted (that is, smaller). When this permissible probability equals 1/10, the mean nitrate level from seed corn production falls to the lowest level, 30.5 lb/ac (compared with 64 lb/ac in the base scenario). This change on the mean nitrate leaching from seed corn production (*ASNL*) under each permissible probability level is shown in Figure 7.1.

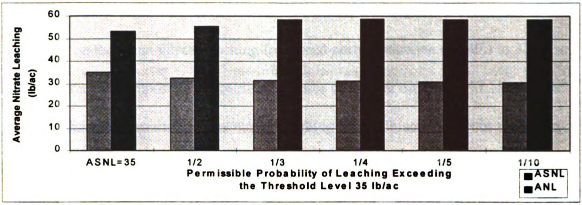

Figure 7.1: Average nitrate leaching from seed corn production (ASNL) and from whole farm (ANL) under different permissible probability of exceeding 35 lb/ac

Imposing a probability constraint, $\boldsymbol{Prob(SNL \geq 35) \leq 1/h^*}$, on seed corn nitrate leaching (*SNL*) above 35 lb/ac results in a reduction of nitrate leaching from seed corn production (*ASNL*) by 32-33 lb/ac, compared to 64 lb/ac in the base scenario. This leaching reduction is mainly from switching from a seed/corn potato rotation with a medium nitrogen treatment to a seed corn/soybean rotation and continuous seed corn with low nitrogen use. Nitrate leaching from seed corn reaches the lowest level modeled in continuous seed corn production. Therefore, the contracted-grower will grow seed corn continuously with low nitrogen fertilization rate under a strict restriction on nitrate leaching levels.

Figure 7.1 also shows the changes in mean nitrate leaching from the whole farm (*ANL*). On average, mean whole-farm nitrate leaching is reduced by 22-25 lb/ac from 80 lb/ac in the base scenario. In contrast to the nitrate leaching results from seed corn (*ASNL*), imposing a very strict chance constraint (e.g., 1/10) does not necessarily reduce whole-farm nitrate leaching (*ANL*), because more potato acreage will be grown in rotation with commercial corn. This result implies that a contract which targets only one leaching source will not necessarily reduce the ambient leaching level.

There are some differences between a contract that imposes a deterministic restriction on the mean nitrate leaching from seed corn production (*ASNL*) to 35 lb/ac, and a contract that imposes a probabilistic chance constraint on ***Prob(SNL≥35)***. The leaching chance constraint reduces nitrate leaching by 3-5 lb/ac more from seed corn production (Table 7.5). This result implies that if the processor is concerned about the deviation from a threshold (35 lb/ac in this case), only targeting mean leaching levels is not enough. A relatively conservative mean target level needs to be specified. Another difference is that mean nitrate leaching from the whole farm (*ANL*) is higher when imposing a probabilistic chance constraint on ***Prob(SNL≥35)*** than when imposing a deterministic restriction on the mean nitrate leaching on 35 lb/ac.

B. Cost of Leaching Reduction

The economic cost of leaching reduction is calculated by the reduction in the gross margins from the grower and the processor. Table 7.5 shows that the probability level ($1/h^*$) in the chance constraint affects these two parties differently. The grower's gross margin decreases when the permissible probability becomes smaller. On the other hand, the processor's gross margin is insensitive to the various levels of permissible probabilities applied within a probabilistic chance constraint, although the resulting gross margin is less than in the base scenario. The reason for this outcome is that the yield difference is small between seed corn in rotation with soybeans and continuous seed corn practices, thus resulting a similar revenue level for the processor.

The cost borne by the grower and the processor per unit nitrate leaching reduction is listed in Column (5) and (6) in Table 7.5 is shown in Figure 7.2 .

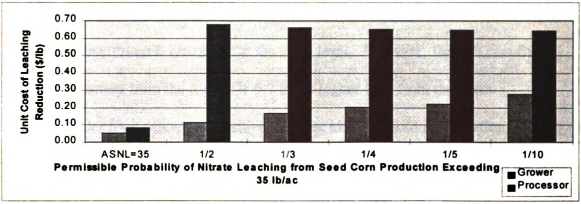

Figure 7.2: Unit cost of leaching reduction under different permissible probability of mean leaching from seed corn (ASNL) exceeding the threshold level 35 lb/ac

As the permissible probability of *ASNL* exceeding 35 lb/ac becomes smaller, the cost per pound of nitrate leaching reduction increases for the grower, but slightly decreases for the processor (Figure 7.2). The chance constraints under different permissible probability levels cost the grower \$0.12-\$0.28, and cost the processor \$0.64-\$0.68 for per pound of leaching reduction.

The combined cost per pound of nitrate leaching increases from \$0.80/lb to \$0.92/lb as the permissible probability of exceeding the 35 lb/ac leaching threshold decreases from ½ to 1/10 (Figure 7.2). This overall unit cost of leaching reduction from imposing a leaching chance constraint is much higher than the cost of imposing a deterministic restriction on seed corn nitrate leaching to 35 lb/ac per growing season. Indeed, it is about 6-7 times higher (\$0.13/lb versus \$0.80-0.92/lb). The result is because of large reductions in seed corn yields due to the switch from medium to low nitrogen application levels when a leaching chance constraint is imposed using 35 lb/ac per growing season as a threshold level.

In summary, a chance constraint of 35 lb/ac on seed corn leaching reduces nitrate leaching from growing seed corn production (*ASNL*) by 3-5 lb/ac more than imposing a deterministic restriction at the same level. However, the unit cost for leaching reduction from the former is 6-7 times higher than from the latter.

In order to examine the sensitivity of cost to a threshold specification, a threshold specification of 40 lb/ac was examined as an alternative scenario to the 35 lb/ac.

7.4.2 Probabilistic Chance Constraint on Nitrate Leaching Threshold 40 lb/ac

Given a leaching chance constraint with a threshold level of 40 lb/ac, the optimal solutions from the five different permissible probability levels show sharply different results than those at the 35 lb/ac threshold (Table 7.7 and 7.8).

Table 7.7: Summary of nitrate leaching, profits, and unit cost of leaching reduction under a probabilistic constraint ***Prob(SNL≥40)≤ 1/h****

Chance Constraint: Prob(SNL≥40)≤ 1/h*	(1) ASNL (lb/ac)	(2) ANL (lb/ac)	(3) GM(G) ($/year)	(4) GM(P) ($/year)	(5) MGM(G) ($/lb)	(6) MGM(P) ($/lb)
Unrestricted base scenario	63.92	80.15	357830	1386600	na	na
a.1.2 Restrict ASNL=35 lb/ac	35.00	52.99	357140	1385400	0.05	0.08
Restrict Prob(SNL≥40)≤ 1/2	36.61	54.93	357290	1385500	0.04	0.08
Restrict Prob(SNL≥40)≤ 1/3	36.12	54.34	357250	1385400	0.04	0.09
Restrict Prob(SNL≥40)≤ 1/4	35.90	54.07	357230	1385400	0.04	0.09
Restrict Prob(SNL≥40)≤ 1/5	35.79	53.94	357210	1385400	0.04	0.09
Restrict Prob(SNL≥40)≤ 1/10	35.51	53.61	357190	1385400	0.05	0.08

where ASNL, ANL: average nitrate leaching from seed corn production and from the whole farm
SNL: nitrate leaching from seed corn production in different states of nature
GM(G): grower's and processor's gross margin
MGM(G), MGM(P): grower's and processor's marginal gross margin for per unit leaching reduction

Table 7.8: Shadow prices of land and contracts, and crop enterprises for a profit-maximizing grower under a probabilistic constraint *Prob(SNL≥40)≤ 1/h***

Results:	*a.1.2* Restrict ASNL=35	Probability level: 1/h* for Prob(SNL≥40)≤ 1/h*				
		1 / 2	1/3	1/4	1/5	1/10
<u>A. Shadow price ($/ac)</u>						
Land	198.42	198.42	198.42	198.42	198.42	198.42
Contract	186.04	189.73	186.27	186.22	186.20	186.15
<u>B. Total yield</u>	38822	38824	38823	38823	38823	38823
<u>C. Crop enterprise (acres)</u>						
PCORN(M)	350	350	350	350	350	350
SSEED(L)	0	0	0	0	0	0
BSEED(M)	483	456	464	468	470	474
PSEED(M)	17	44	36	32	30	26
SBEAN	483	456	464	468	470	474
SPOTATO	17	44	36	32	30	26
CPOTATO	350	350	350	350	350	350

A. Nitrate Leaching from Seed Corn Production and the Whole Farm

Columns (1) and (2) in Table 7.7 list the mean nitrate leaching from seed corn production (*ASNL*) and from the whole farm (*ANL*), when the nitrate threshold level of a leaching chance constraint is 40 lb/ac per growing season. The differences between these two nitrate leaching levels under different permissible probabilities are shown in Figure 7.3.

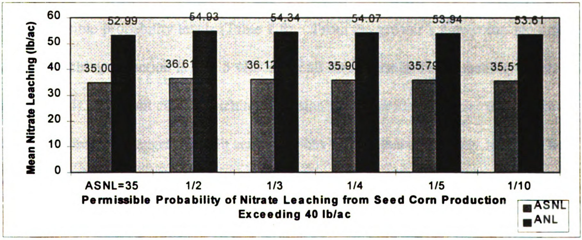

Figure 7.3: Mean nitrate leaching from seed corn production (ASNL) and the whole-farm (ANL) under various permissible probability levels

As Figure 7.3 illustrates, the smaller the permissible probability of nitrate leaching exceeding 40 lb/ac per growing season, the lower the nitrate leaching from both seed corn production and whole-farm operation. This result is because the acreage planted in seed corn/potato rotations declines as the probability level decreases.

B. Cost of Leaching Reduction

At the 40 lb/ac leaching threshold, the probability constraint affects the grower's gross margin but only has a small impact on the processor's gross margin. The smaller the permissible probability ($1/h^*$), the lower the grower's gross margin, although the decline is slight (Table 7.7). The grower's gross margin reduction comes from a decrease of seed corn/potato rotation acreage, although it is accompanied by an equal acreage increase in seed corn/soybean rotation. However, the yield difference between these two rotation practices are not significantly different from each other. The processor's gross margin, therefore, remains at the same level.

The unit cost of seed corn leaching reduction does not vary substantially across all permissible probability levels (Table 7.8). From the grower's viewpoint, the unit cost of leaching reduction is 4 or 5 ¢/lb under all these permissible probability levels (Figure 7.4). The unit cost of leaching reduction for the processor under the chance leaching constraint ranges 8-9 ¢/lb across various permissible probability levels. The overall cost from both parties is 12-13 ¢/lb.

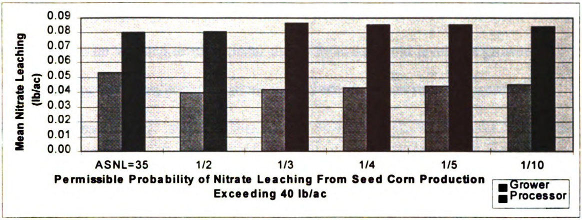

Figure 7.4: Changes in the gross margins under different permissible probability of nitrate leaching from seed corn production exceeding 40 lb/ac

In general, a contract imposing a chance constraint on a 40 lb/ac leaching threshold level results in similar mean nitrate leaching and unit cost of leaching reduction to a contract imposing a deterministic restriction on a 35 lb/ac leaching level.

7.4.3 Comparisons Between Nitrate Threshold at 35 lb/ac and 40 lb/ac within a Leaching Chance Constraint

There are some differences between the two contracts with different leaching threshold specifications. In terms of controlling nitrate leaching from seed corn production, a chance constraint with a 35 lb/ac leaching threshold generates 5 lb/ac less leaching than a chance constraint with a 40 lb/ac leaching threshold. However, the threshold level 35 lb/ac does not necessarily reduce more nitrate leaching from the whole farm (*ANL*) than the threshold level 40 lb/ac. This result implies that a strict threshold only on seed corn production does not necessarily improve overall water quality, which is correlated with whole-farm nitrate leaching. Other crop enterprises are also important in determining nitrate leaching from the whole farm. In order to meet the low (35 lb/ac) threshold nitrate leaching level, more seed corn acreage is grown continuously, resulting in an increase in potato/commercial corn rotation acreage with high nitrate leaching levels. Under the 40 lb/ac threshold level, the grower switches from seed corn/potato rotations to seed corn/soybean rotations, resulting in less nitrate leaching.

The result also indicates that there is a large difference in the unit cost of reducing leaching using these two nitrate leaching threshold specifications. When the leaching threshold level is set at 35 lb/ac, the overall cost from both grower and processing firm for one pound of nitrate reduction ranges between 80-92 ¢/lb, while it is 12-13 ¢/lb when the leaching threshold level is set at 40 lb/ac. This result implies that the cost of reducing leaching is strongly affected by the choice of the nitrate leaching threshold level and the crop enterprises that can feasiblely comply. If a leaching reduction contract is to be voluntarily adopted, it is important to choose a threshold level that is not costly to both parties under alternative contract designs.

In order to examine the efficiency of the contract with a leaching chance constraint, Chapter 8 evaluates this contract design with other alternative contract designs specified in Chapter 6 by serval criteria. Furthermore, the analysis is extended to examine cases where the contracted-growers have different risk preference levels.

7.5 Summary

This chapter used lower partial moment approaches to include the risks of seed corn contract loss and unacceptable nitrate leaching chance into the whole-farm programming model. One result showed that grower concern over contract loss risk may foster a higher nitrogen application rate, depending on the average regional yield, the target probability level specified, and the yield distributions of different nitrogen treatments. Random assignment of seed contracts can remove this incentive. Also, if there is a perception gap between actual and expected yield distributions, providing accurate information on yield distributions and weather conditions can reduce nitrogen application rates.

This analysis also demonstrates that a leaching chance constraint can be employed as an alternative contract design when the strategic objective is to avoid exceeding a threshold level. This strategy is designed to account only for the deviations exceeding the specified threshold level. A low threshold level (L) or permissible probability (***1/h****) will reduce nitrate leaching from growing seed corn (***ASNL***), but it does not necessarily reduce nitrate leaching from the whole farm (***ANL***), compared with other strategies. If the objective is to improve the overall water quality, targeting nitrate leaching from growing seed corn is not enough. The impact on leaching from other product and input substitutions needs to be considered as well.

The magnitude and incidence of abatement costs are crucial elements in designing a "green" contract to induce voluntary leaching reduction. Within a leaching chance constraint, the permissible probability level (***1/h****) and the threshold level (L) are important in determining the magnitude as well as the incidence of leaching abatement costs. In this representative farm model, the overall cost from the processor and the grower at the threshold level 35 lb/ac was 7 times higher than that at the threshold level 40 lb/ac. Both the grower and the processor would bear much higher leaching reduction cost in the 35 lb/ac threshold level than the 40 lb/ac threshold level.

CHAPTER 8

AN EMPIRICAL PRINCIPAL-AGENT MODEL WITH RISK AVERSION

Risk is an important consideration in designing agricultural contracts to control nonpoint source pollution (NPSP). Contract outcomes are highly influenced by unobservable stochastic influences. As shown in Chapter 4, risk preferences will determine an optimal contractual risk-sharing rule between principal and agent. Therefore, risk preferences may affect the effectiveness of using contract designs to reduce NPSP. The objective of this chapter is to explore contract designs that can induce growers who are averse to production risk to reduce nitrate leaching. Three levels of risk preferences are used within a whole-farm risk programming model in order to identify how risk aversion affects the grower's decision as well as the processor's welfare. The level of nitrate leaching as well as the profit of the processor and the grower under alternative contract designs are evaluated in a principal-agent framework.

8.1 Sources of Ordinary Business Risk

Agricultural production processes are influenced by stochastic factors such as weather, machinery failure, pest populations, and input prices. Two major classes of ordinary business risks are production risk and marketing risk. Production risk includes yield loss due to poor weather, and other sources of yield damage, such as uncontrolled pest problems or machinery failure. Marketing risk is related to price fluctuations in commodity markets. These ordinary business risks can affect a grower's decisions on enterprise combinations and input uses (Sandmo, 1971).

The grower's risk preference influences not only farm-level decision-making processes, but also plays a role in determining the level of associated NPSP. Some studies have empirically demonstrated that farmers typically behave in risk-averse ways (e.g. Binswanger, 1980; Dillon and Scandizzo, 1978). The purpose of this chapter is to examine optimal "green" contract designs for growers with different levels of risk aversion. This research thus focuses only on production risk because reduction of nitrate leaching by reducing nitrogen use or changing rotation will affect the probability distribution (e.g., mean and variance) of seed corn yield levels, affecting the associated production risk. Commodity prices are assumed to be known, deterministic, and exogenously determined by the market.

This research is designed to examine the potential behavior of representative growers exhibiting different levels of risk preference under alternative contract designs. Both yield and nitrate leaching outcomes are random variables, greatly influenced by weather conditions, but also affected by grower choices of crops, nitrogen levels, and crop rotation. The next section discusses a particular expected utility function as the grower's objective function.

8.2 Mean-Variance Objective Function

Mean-variance (EV) analysis has been widely used and empirically tested. In general, EV models have several advantages over other risk models (Robison and Hanson, 1996). EV models are theoretically consistent with the Expected Utility Method (EUM) under conditions such as those discussed below. EV models have produced theoretical results that correspond with our intuition in many cases (Robison and Barry, 1987). The results derived from EV analysis can be described in two dimensional space for analytical convenience. EV produces more tractable analytical results than the EUM in the case of multiple sources of risk because of its computational convenience (Duncan, 1994).

EV analysis assumes that the utility function is expressed over two dimensions -- mean and variance (Freund, 1956; Meyer, 1987; Robison and Barry, 1987). It is consistent with expected utility theory when one of the following conditions is met: 1) the utility function is quadratic (Tobin, 1958); 2) the risky income variable has a normal distribution (Freund, 1956); or, 3) the location and scale condition is satisfied (Sinn, 1983; Meyer, 1987). The location and scale condition requires that the expected return is linearly related to the random variables. For instance, if expected return is a function of price (deterministic variable) times quantity (random variable) [scale shifter] plus some fixed payment [location shifter], the location and scale condition is satisfied.

In the case of seed corn production, the linear payment scheme commonly used in contracts satisfies the location and scale condition. When an individual's utility can be represented by the exponential function $U(M)=1-e^{-\lambda M}$ and income has a normal distribution, the maximization of expected utility function is equivalent to a quadratic form (Freund, 1956):

$$\textbf{Max EU(M)} = E(M) - (\tfrac{1}{2})\lambda\, V(M) \tag{8.1}$$

$$= \sum_j (\bar{c}_j x_j) - (\tfrac{1}{2})\, \lambda \sum_j \sum_k x_j x_k \sigma_{jk}$$

$$\textbf{subject to} \quad \sum_j a_{mj}\, x_j \le b_m \; (m = 1, \ldots, \bar{m})$$

$$x_j \ge 0 \;\; \forall j$$

where E(M) is the expected income; V(M) is variance-covariance matrix of income; and the parameter λ is the coefficient of absolute risk aversion, representing an individual's risk attitude.

The risk-aversion coefficient λ can be obtained by several methods. This first approach is to assume that the expected utility has an exponential functional form, and to estimate λ from empirical data. Pratt (1964) showed that the risk coefficient λ could be approximated by a second-order Taylor expansion. In addition to a linear EV expression, Robison and Barry (1987) and Meyer and Robison (1988) developed a nonlinear EV model. Their studies allow EV models to characterize decreasing absolute risk aversion (DARA) and increasing absolute risk aversion (IARA) coefficients, where income has impacts on risk-attitude, thus enhancing the flexibility concerning different risk attitude specifications.

The EV objective function requires data on income and income variance, which can be calculated from commodity prices, yields, and input costs. Using this framework, the effect of grower risk aversion in reducing nitrate leaching and the cost incidence under alternative contract designs can be examined.

8.3 Growers Optimization under Different Levels of Risk Preference

Three levels of risk preferences, characterized by the coefficient of absolute risk aversion λ, are examined here. They are 0 (risk-neutral), 10^5 (mildly risk-averse), and 10^{-4} (highly risk-averse). The optimal solutions under these three risk preferences are summarized in Table 8.1. These results include the grower's expected utility and expected profits, the processor's gross margin, nitrate leaching from the whole farm and from growing seed corn, and the shadow prices of contracts and land. The acreage from expected utility maximization under these three scenarios is listed in Table 8.2. These results are illustrated graphically and discussed in the following subsections.

Table 8.1: Summary of the grower's expected-utility maximization results under three risk preference levels

Risk Preference	Grower's Expected		Processor's Gross Margin ($/yr)	Nitrate Leaching (lb/ac)		Shadow Price ($/ac)	
	Utility	Net revenue ($)		Whole-farm (*ANL*)	Seed corn (*ASNL*)	Contract	Land
$\lambda = 0$	357,830	357,830	1,386,600	80.15	63.92	193.41	199.18
$\lambda = 10^{-5}$	346,480	357,700	1,386,600	87.79	63.92	199.71	185.09
$\lambda = 10^{-4}$	289,600	340,040	1,386,600	88.85	63.92	210.86	110.53

Table 8.2: Optimal crop enterprise mix under three risk preference levels

Acres under Various Risk Preferences (acres)					
$\lambda=0$		$\lambda=10^{-5}$		$\lambda=10^{-4}$	
BCORN(L)	103	PCORN(M)	350	PCORN(L)	100
PSEED(M)	500	PSEED(M)	500	PSEED(M)	500
PCORN(M)	246	POTATO	850	POTATO	600
SOYBEAN	103				
POTATO	746				

A. Grower's Expected Utility and Processor's Gross Margin

From Table 8.1, the scenarios for risk-averse growers have lower expected utility as well as lower expected profits than for the risk-neutral grower. The difference between expected utility and expected profit is the insurance premium, which measures the grower's willingness to pay in order to ensure a certain income level. The grower's expected utility and expected profit of these three risk preferences are graphed in Figure 8.1. As shown in equation 8.1, the expected utility for a risk-averse grower as estimated from an EV model weights the variance from income negatively. Therefore, the risk-averse grower might select an enterprise that has less mean income if it has less income variation.

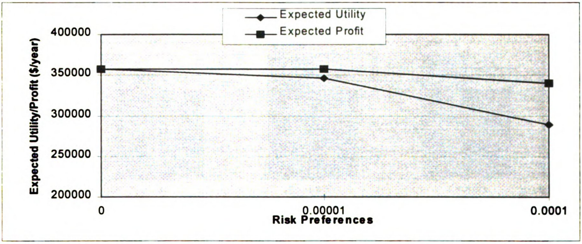

Figure 8.1: Growers' expected utility and profit under various risk preferences

In this model, as the level of risk-aversion increases, the contracted-grower will grow more potatoes (Table 8.2). Because cash-renting land to a potato grower is less risky than growing other crops, it generates a higher level of expected utility for a risk-averse grower. When the grower is highly risk-averse (the coefficient of absolute risk aversion $\lambda = 10^{-4}$), he or she will only cultivate 1200 acres of crops, rather than the 1700 acres in the other two cases where 500 acres were rented (Table 8.2). Renting land from other farmers is no longer attractive because the disutility from increased income variation outweighs the utility from increased mean income.

Table 8.1 shows that the processor's gross margin remains the same ($1,386,600/year) across different grower risk preference levels. This outcome is unchanging because three modeled growers produce seed corn in a seed corn/potato rotation using medium nitrogen levels (Table 8.2).

B. Nitrate Leaching from Growing Seed Corn and from the Whole Farm

Figure 8.2 shows how the grower risk aversion affect the mean nitrate leaching from growing seed corn and from the whole farm.

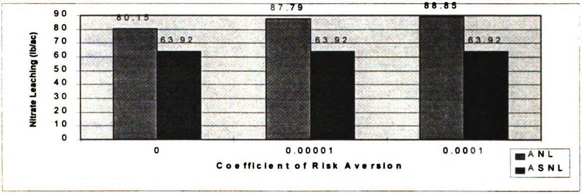

Figure 8.2: Average nitrate leaching from whole-farm (ANL) and from seed corn production (ASNL) under different levels of constant absolute risk aversion

Because growers with three risk preference levels all grow 500 acres of seed corn in the same way, mean nitrate leaching from seed corn production (*ASNL*) remains the same, 64 lb/ac (Table 8.2). In contrast, the mean level of nitrate leaching from the whole farm (*ANL*) is higher for a risk-averse grower than for a risk-neutral grower. This result is due to the switch from a commercial corn/soybean rotation to a commercial corn/potato rotation. Since potatoes have high nitrate leaching potential, this implies higher levels of nitrate leaching (88-89 lb/ac) from the whole farm.

C. Shadow Prices of Contracts and Land

The last two columns in Table 8.1 indicate how the shadow prices of seed corn contracts and land are affected by the grower's risk aversion. Both shadow values under three grower risk aversion coefficients are shown in Figure 8.3.

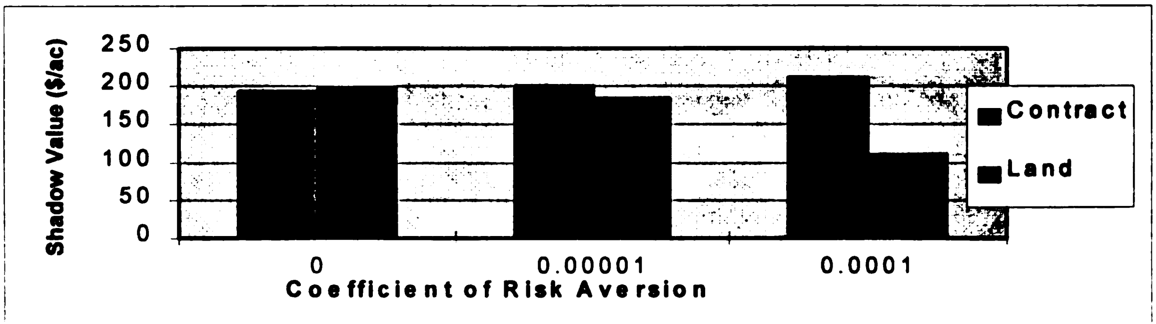

Figure 8.3: Shadow values of seed corn contract and land under various risk aversion coefficients

As shown in Figure 8.3, the shadow value of the contract is higher for risk-averse growers than risk-neutral growers. This result follows from the fact that a seed corn contract provides not only an income stream but also a mechanism to reduce farm income risk.

On the other hand, the shadow value of land decreases with the level of risk aversion. Figure 8.3 shows that the shadow price of land is less for the highly risk-averse grower than for the risk-neutral grower. This occurs because additional land cultivation increases income variation. For the highly risk-averse contracted-grower

($\lambda = 10^{-4}$), the shadow price of land is \$110.53/ac, which is less than the rental price for one acre of land (\$165/ac). Therefore, this grower will not rent any land.

From the above discussion, risk preferences affect the grower's expected utility and gross margin, nitrate leaching from the whole farm, and the shadow values of contracts and land. As a result, risk preferences could affect NPSP outcomes and cost incidence of alternative contract designs.

8.4 Alternative Contract Designs with Risk Aversion

This section examines the impacts of alternative contract designs under various grower risk preference levels. These alternative contract designs include the categories listed in Chapter 6 and contracts with four different leaching chance constraints from Chapter 7. The contract designs are restricting nitrate leaching (***a.1.1*** and ***a.1.2***) or nitrogen use (***a.2***), forbidding rotation with potatoes (***a.3***), charging a fee on nitrate leaching (***b.1.1***) or nitrogen use (***b.2***), reducing the variable payment (***c.1*** and ***c.2***), and imposing one of four leaching chance constraints. For simplicity, only two permissible probability levels from two leaching threshold levels are chosen and incorporated into the principal-agent framework. These chance constraints include two permissible probability levels, 1/2 and 1/10, under two threshold levels, 35 lb/ac per growing season (***r.1.1*** and ***r.1.2***) and 40 lb/ac per growing season (***r.2.1*** and ***r.2.2***). For convenience, the contracts imposing a leaching chance constraint are specified as follows: ***Prob(SNL≥35)≤1/2*** as ***r.1.1***; ***Prob(SNL≥35)≤1/10***, ***r.1.2***; ***Prob(SNL≥40)≤1/2***, ***r.2.1***; and ***Prob(SNL≥40)≤1/10***, ***r.2.2***. These contract designs are compared based on their ability to reduce nitrate leaching, and cost magnitude and incidence for leaching reduction.

The optimization results for the three grower risk-aversion levels under the twelve alternative contract designs are summarized in Table 8.3. These results include mean nitrate leaching from growing seed corn and from the whole farm (*ASNL* and *ANL*), the grower's expected utility and the processor's gross margin (*EU(G)* and *GM(P)*), and unit cost of leaching reduction (*MU(G)* and *MGM(P)*).

A. Reducing Nitrate Leaching

As seen in Table 8.3, several contract designs can reduce nitrate leaching from seed corn production and from the whole farm across three risk preference levels. The mean nitrate leaching from growing seed corn (*ASNL*) under alternative contract designs across the three risk preferences is shown in Figure 8.4.

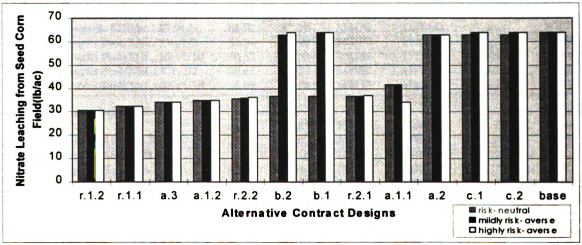

Figure 8.4: Mean nitrate leaching from growing seed corn (*ASNL*) under alternative contract design with three risk-aversion levels

Table 8.3: Summary of the results from various alternative contract designs for the growers with different risk preference levels

Coefficient of absolute risk-aversion (λ)		(1) ASNL (lb/ac)	(2) ANL (lb/ac)	(3) EU(G) ($)	(4) GM(P) ($)	(5) MU(G) ($/lb)	(6) MGM(P) ($/lb)
Risk-aversion coefficient $\lambda=0$							
Base model		63.92	80.15	357830	1386600	na	na
a.1.1	Restrict ANL≤35 lb/ac	41.51	35.00	355790	1385700	0.18	0.08
a.1.2	Restrict ASNL≤35 lb/ac	35.00	52.99	357140	1385400	0.05	0.08
a.2	Restrict N≤107 lb/ac	62.95	79.86	357500	1376100	0.68	21.60
a.3	No rotation w/ potato	33.97	51.76	357030	1385400	0.05	0.08
b.1	Charge 10¢/lb NL>30lb/ac	36.56	54.87	356960	1385800	0.06	0.06
b.2	Charge 15¢/lb on N>90lb/ac	36.47	54.84	357150	1384700	0.05	0.14
c.1	Payment: $253/ac+$3.96/bu	62.95	79.86	357830	1375790	0.00	22.24
c.2	Payment: $230/ac+$3.96/bu	62.95	79.86	347020	1386600	22.24	0.00
r.1.1	Restrict Prob(SNL≥35)≤1/2	32.34	55.45	356010	1375900	0.12	0.68
r.1.2	Restrict Prob(SNL≥35)≤1/10	30.52	58.21	353190	1375900	0.28	0.64
r.2.1	Restrict Prob(SNL≥40)≤1/2	36.61	54.93	357290	1385500	0.04	0.08
r.2.2	Restrict Prob(SNL≥40)≤1/10	35.51	53.61	357190	1385400	0.05	0.08
Risk-aversion coefficient $\lambda=10^{-5}$							
Base model		63.92	87.79	346480	1386600	na	na
a.1.1	Restrict ANL≤35 lb/ac	41.51	35.00	343060	1385700	0.57	0.08
a.1.2	Restrict ASNL≤35 lb/ac	35.00	52.59	343270	1385400	0.22	0.08
a.2	Restrict N≤107 lb/ac	62.95	87.51	346060	1376100	0.86	21.60
a.3	No rotation w/ potato	33.97	51.35	343060	1385400	0.23	0.08
b.1	Charge 10¢/lb NL>30lb/ac	63.92	87.79	344790	1388300	--	--
b.2	Charge 15¢/lb on N>90lb/ac	62.95	87.51	344770	1377400	3.52	18.93
c.1	Payment: $253/ac+$3.96/bu	63.92	87.79	349280	1386590	--	--
c.2	Payment: $230/ac+$3.96/bu	63.92	87.79	338470	1397400	--	--
r.1.1	Restrict Prob(SNL≥35)≤1/2	32.34	54.98	340790	1375900	0.36	0.68
r.1.2	Restrict Prob(SNL≥35)≤1/10	30.52	61.02	336260	1375900	0.61	0.64
r.2.1	Restrict Prob(SNL≥40)≤1/2	36.61	54.53	343590	1385500	0.21	0.08
r.2.2	Restrict Prob(SNL≥40)≤1/10	36.00	43.94	343430	1382300	0.22	0.31
Risk-aversion coefficient $\lambda=10^{-4}$							
Base model		63.92	88.85	289600	1386600	na	na
a.1.1	Restrict ANL≤35 lb/ac	33.97	35.00	269410	1385400	1.35	0.08
a.1.2	Restrict ASNL≤35 lb/ac	35.00	40.16	271960	1376400	1.22	0.71
a.2	Restrict N≤107 lb/ac	62.95	88.44	288540	1376100	2.18	21.60
a.3	No rotation w/ potato	33.97	37.79	271030	1385400	1.24	0.08
b.1	Charge 10¢/lb NL>30lb/ac	63.92	88.85	287900	1388300	--	--
b.2	Charge 15¢/lb on N>90lb/ac	63.92	88.85	287640	1388500	--	--
c.1	Payment: $253/ac+$3.96/bu	63.92	88.85	308070	1386590	--	--
c.2	Payment: $230/ac+$3.96/bu	63.92	88.85	297260	1397400	--	--
r.1.1	Restrict Prob(SNL≥35)≤1/2	32.34	42.93	261660	1375900	1.77	0.68
r.1.2	Restrict Prob(SNL≥35)≤1/10	30.52	51.49	245300	1375900	2.65	0.64
r.2.1	Restrict Prob(SNL≥40)≤1/2	36.96	43.45	273410	1377100	1.20	0.70
r.2.2	Restrict Prob(SNL≥40)≤1/10	36.20	42.30	272870	1375900	1.21	0.77

where ASNL, ANL: average nitrate leaching from seed corn production and from whole-farm operation
SNL: nitrate leaching from seed corn production in different states of nature
EU(G): grower's expected utility; MU(G): grower's marginal expected utility
GM(P): processor's expected gross margin; MGM(P): processor's expected marginal gross margin;
--: undefined number because of no nitrate leaching reduction.

Several conclusions can be drawn. First, any contract design that imposes a restriction can induce reduced leaching. Imposing a leaching chance constraint on 35 or 40 lb/ac per growing season as a threshold level (***r.1.1, r.1.2, r.2.1,*** and ***r.2.2***), restricting the permissible nitrate leaching (***a.1.1*** and ***a.1.2***), or forbiding rotation with potatoes (***a.3***) can effectively reduce seed corn nitrate leaching by 23-34 lb/ac across three growers' risk preference levels (Column 1). These outcomes are because the restrictions have to be met in order to grow seed corn. There is no flexibility to adjust the amount of nitrate leaching even under different risk preferences.

However, among the restriction strategies, the contract that restricts nitrogen use on seed corn (***a.2***) is least effective at reducing nitrate leaching. It only reduces seed corn nitrate leaching by 1 lb/ac. This result follows because restricting nitrogen use cannot target the most nitrate sensitive practices—rotation with potatoes.

Because seed corn/potato rotation generates much higher nitrate leaching than other seed corn rotation practices, the effective leaching reduction strategies are those that induce the grower to avoid rotation with potatoes, rather than just use less nitrogen on seed corn. Imposing restrictions on nitrate leaching or rotation can thus directly reduce nitrate leaching.

The second conclusion is that contract specifications that use financial disincentives cannot effectively reduce nitrate leaching from seed corn production when the grower is risk-averse ($\lambda > 0$). These strategies include charging a fee on nitrogen use or nitrate leaching (***b.1*** and ***b.2***), or reducing the variable payment (***c.1 and c.2***). Such financial penalty schemes provide the grower flexibility to make his or her decision based on the marginal benefit versus the marginal cost of reducing leaching.

Since the risk-averse grower is concerned about both mean income and income variance, the financial disincentives from charging a fee on nitrate leaching or nitrogen, or reducing the variable payment (***b.1, b.2, c.1,*** and ***c.2***) may be less than the risk reduction advantage from a seed corn/potato rotation. In such a case, the risk-averse grower would rather pay a penalty than reduce nitrate leaching. Contract designs that charge a financial fee on nitrate leaching or nitrogen (***b.1*** and ***b.2***) can reduce nitrate leaching for a risk-neutral grower, but they may not be effective strategies for a risk-averse grower.

Similar observations can be made concerning nitrate leaching from the whole farm (*ANL*; Column 2 from Table 8.3 and Figure 8.5).

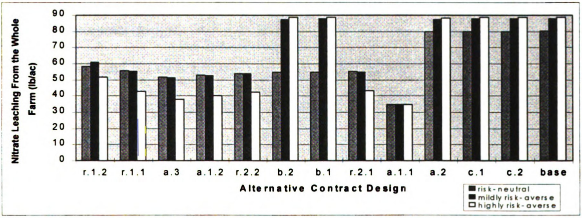

Figure 8.5: Mean nitrate leaching from the whole farm (*ANL*) under alternative contract designs with three risk preference levels

In this case, imposing a permissible nitrate leaching on the whole-farm (***a.1.1***) is the most effective contract design for reducing whole-farm nitrate leaching (***ANL***). It can reduce whole-farm nitrate leaching by 45-54 lb/ac per growing season. Other contract designs that impose a restriction on seed corn nitrate leaching (***r.1.1, r.1.2, r.2.1, r.2.2, a.1.2***), or no rotation with potatoes (***a.3***) are also able to reduce whole farm nitrate leaching by more than 20 lb/ac. This leaching reduction comes from reduced potato acres.

There is one similarity between nitrate leaching from growing seed corn (***ASNL***; Figure 8.4) and nitrate leaching from the whole farm (***ANL***; Figure 8.5) under alternative contract designs. Contract designs that impose restrictions on nitrate leaching or forbid rotation with potatoes can reduce nitrate leaching across all grower risk preferences shown, while using financial incentives cannot lower nitrate leaching when the grower is risk-averse. The reason is that the benefit from seed corn/potato rotations is greater than the financial disincentive to reduce leaching from seed corn production.

However, there is also a difference between these two leaching levels from alternative contract designs. All contract designs, except ***a.1.1*** (restricting the whole farm leaching) and ***b.1*** or ***b.2*** (charging a fee on nitrate leaching and nitrogen use), generate similar results on seed corn nitrate leaching across three risk preferences because the growers with different risk-aversion preferences use the same practices in seed corn production. On the other hand, these contract designs generate different whole-farm nitrate leaching when the grower is highly risk-averse. When a restriction on all agronomic practices (except on the whole-farm nitrate leaching ***a.1.1***), the highly risk-averse grower will switch using medium levels of nitrogen treatments on commercial corn to a low level, resulting in less whole-farm nitrate leaching. As in the unrestricted base scenario, contracts restricting nitrogen use (***a.2***) and reducing the variable payment (***c.1 and c.2***) have higher mean whole-farm nitrate leaching for the risk-averse grower than for the risk-neutral grower. This result is due to reduction in the percentage of corn acreage (a potentially low leaching crop).

B. Cost of Leaching Reduction

Both the processor and the grower incur some added costs due to alternative contract designs in many cases. As noted previously, the magnitude of leaching reduction cost is measured by the reductions in the grower's expected utility as well as in the processor's gross margin, (Table 8.3 Column 3 and 4).

The magnitude of leaching reduction cost under alternative contract designs varies by the grower's risk preference level as shown in Figure 8.6.

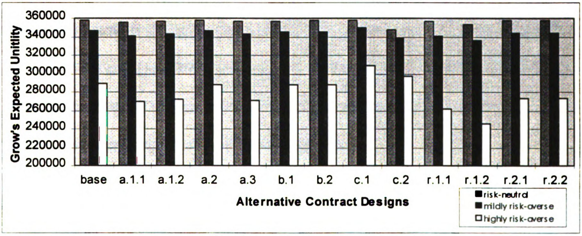

Figure 8.6: Grower's expected utility from alternative contract design under different risk preference levels

In general, the risk-averse grower has higher costs than the risk-neutral grower from complying with the restrictions from the alternative contract designs. All contract designs that can effectively reduce nitrate leaching will substantially reduce the highly risk-averse grower's expected utility. For example, a contract forbidding rotation with potatoes (***a.3***) causes a 0.2 percent expected utility reduction for a risk-neutral grower, while causing more than 6 percent of expected utility reduction for a highly risk-averse grower ($\lambda=10^{-4}$) . In terms of unit cost of nitrate leaching reduction, this strategy costs \$0.05/lb for a risk-neutral grower, \$0.23/lb for a mildly risk-averse grower ($\lambda=10^{-5}$), and \$1.24/lb for a highly risk-averse grower ($\lambda=10^{-4}$) (Column 5, Table 8.3). This result comes from the increase income variance which occurs from the switch from a seed corn/potato rotation to a seed corn/soybean rotation.

Among all alternative contract designs, imposing a leaching chance constraint of 35 lb/ac per growing season threshold level with 1/10 probability (***r.1.2***) always reduces the grower's expected utility to the lowest level across all risk preference levels. By contrast, reducing the variable payment plus increasing the fixed payment (***c.1*** or ***c.2***) increases the grower's expected utility, since it reduces income variability.

Grower risk preferences also affect the processor's gross margin. The impacts of alternative contract designs under different grower risk preferences on the processor's gross margin are illustrated in Figure 8.7.

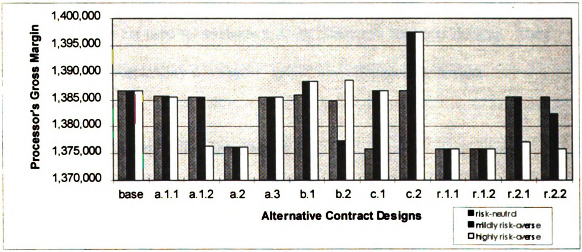

Figure 8.7: Processor's gross margins from alternative contract designs under three levels of risk preference

The processor's gross margin is reduced substantially under the contracts that impose restrictions on nitrate leaching (***a.1.2, r.2.1,*** and ***r.2.2***) when the grower is highly risk-averse. In contrast, the processor has a higher gross margin under the contracts that use financial incentives to reduce nitrate leaching (***b.1, b.2, c.1,*** and ***c.2***) when the grower is highly risk-averse than when the grower is risk-neutral or mildly risk-averse. As shown before, contracts using financial incentives do not necessarily reduce leaching.

From the above discussion, grower's risk preference is critical in determining the effectiveness of nitrate leaching reduction for non-restriction alternative contract designs. Imposing a strict restriction reduces nitrate leaching under all grower levels of risk aversion. However, reducing nitrate leaching may impose added costs on the processor and the grower.

8.5 Efficiency under Two Dominance Criteria

Due to the potential tradeoffs between nitrate leaching and profitability, two efficiency criteria are used for evaluation of the alternative contracts designs. They are: a) contract acceptability dominance, and b) cost efficiency dominance.

8.5.1 Contract Acceptability Dominance

The first criterion to be examined is *contract acceptability dominance*. This criterion identifies a contract as acceptable to the grower if it will reduce expected utility by less than 1 percent. For the processor, the criterion states that strategy ***A*** dominates strategy ***B*** if and only if either $(ASNL_A < ASNL_B$ *and* $GM_A \geq GM_B)$ *or*

($ASNL_A \leq ASNL_B$ and $GM_A > GM_B$), where ***ASNL*** is the mean nitrate leaching from seed corn production and ***GM*** is the processor's gross margin.

The contract designs that are not unacceptable under contract acceptability dominance across three grower's risk preference levels are summarized in Table 8.4.

Table 8.4: Contracts that are undominated under contract acceptability dominance under various levels of grower risk aversion

Coefficient of Risk-Aversion (λ)	Undominated Contract Designs
λ=0 (risk-neutral)	*a.3* *No rotation with potatoes*; *b.1* Charge 10¢/lb ASNL>30lb/ac; *c.2* *Payment: \$230/ac+\$3.96/bu*; *r.1.1* *Restrict Prob(SNL≥35)≤1/2.*
λ=10^{-5} (mildly risk-averse)	*a.1.1* Restrict ANL≤35 lb/ac; *a.3* *No rotation with potatoes*; *c.2* *Payment: \$230/ac+\$3.96/bu*; *r.1.1* *Restrict Prob(SNL≥35)≤1/2*; *r.2.1* Restrict Prob(SNL≥40)≤1/2.
λ=10^{-4} (highly risk-averse)	*a.1.1* Restrict ANL≤35 lb/ac; *a.3* *No rotation with potatoes*; *c.2* *Payment: \$230/ac+\$3.96/bu*; *r.1.1* *Restrict Prob(SNL≥35)≤1/2.*

Note: Italics represents the contracts that are undominated under three levels of grower risk aversion

Three contracts are undominated under this dominance definition across all three grower risk preference levels. They are "no rotation with potatoes" (***a.3***), reducing the variable payment to \$3.96/bu with the fixed payment raised to \$230/ac (***c.2***), and imposing a leaching chance constraint ***Prob(SNL≥35)≤1/2*** (***r.1.1***).

From the grower's perspective, a contract design (***r.1.2***) that imposes a leaching chance constraint on ***Prob(SNL≥35)≤1/10*** is not acceptable using the contract acceptability dominance criteria because it reduces the grower's expected utility by more than one percent across all risk preference levels.

Other contracts designs are undominated only for certain risk preference levels. Contract designs restricting the permissible whole-farm nitrate leaching to 35 lb/ac per growing season (*a.1.1*) are not dominated when the grower is risk-averse ($\lambda = 10^{-4}$ or 10^{-5}). Contracts charging a fee on nitrate leaching (*b.1*) are undominated only when the grower is risk-neutral. Imposing a leaching chance constraint ***Prob(SNL≥40)≤1/2*** (*r.2.1*) is undominated only for a mildly risk-averse grower ($\lambda = 10^{-5}$).

Contract acceptability dominance does not capture the degree of NPSP reduction or the unit cost of abatement achieved. In order to capture another efficiency criterion--cost efficiency dominance--needs to be examined as well.

8.5.2 Cost Efficiency Dominance

Cost efficiency dominance is defined such that strategy A dominates strategy B if it reduces leaching at lower unit cost for the grower without increasing unit cost for the processor or vice-versa. Unit cost is measured by the reduction in the grower's expected utility or in the processor's gross margin for per pound of leaching reduction. The contracts that are undominated under this criterion are listed in Table 8.5.

Table 8.5: Contracts that are not dominated under cost efficiency dominance under various levels of grower risk aversion

Coefficient of Risk-Aversion (λ)	Undominated Contract Designs	
λ=0 (risk-neutral)	*b.1*	Charge 10¢/lb NL>30lb/ac;
	c.1	Payment: \$253/ac+\$3.96/bu;
	c.2	Payment: \$230/ac+\$3.96/bu;
	r.2.1	*Restrict Prob(SNL≥40)≤1/2*;
	*a.1.2**	Restrict ANL≤35 lb/ac;
	*a.3**	No rotation w/ potato;
	*r.2.2**	Restrict Prob(ASNL≥40)≤1/10.
$\lambda=10^{-5}$ (mildly risk-averse)	*r.2.1*	*Restrict Prob(SNL≥40)≤1/2*;
	*a.1.2**	Restrict ANL≤35 lb/ac;
	*a.3**	No rotation w/ potato.
$\lambda=10^{-4}$ (highly risk-averse)	*a.3*	No rotation w/ potato;
	r.2.1	*Restrict Prob(SNL≥40)≤1/2.*

* indicates that the unit cost of leaching reduction is less than 2 cents, compared with contracts that are undominated in this analysis. Italics represents the contracts that are undominated under three levels of grower risk aversion

As Table 8.5 shows, the only contract design that is undominated across all grower risk preference levels is the one that imposes a leaching chance constraint on nitrate leaching from growing seed corn (*SNL*) exceeding 40 lb/ac with probability 1/2 (*r.2.1*). From the grower's perspective, this design is the least costly per pound of leaching reduction among the twelve alternative contract designs. It costs 8 ¢/lb for the processor when the grower is risk-neutral or mildly risk-averse. When the grower is highly risk-averse($\lambda=10^{-4}$), the unit cost of leaching reduction escalates from 8 ¢/lb to 70 ¢/lb. As noted above, this result is due to the reduction in seed corn/potato rotation acreage and the switch from the medium to the low nitrogen treatment in a seed corn/soybean rotation. Both reasons reduce seed corn yield by 253 bushels from the base scenario, and subsequently reduce the processor's gross margin.

Using this cost efficiency criterion, three contract designs using financial incentives are undominated when the grower is risk-neutral. They are contract designs charging a fee on nitrate leaching (***b.1***), or reducing the variable payment (***c.1*** and ***c.2***). However, as discussed previously these contract designs fail to reduce nitrate leaching when the grower is risk-averse.

Contracts that forbid the seed corn/potato rotation (***a.3***) are not dominated only when the grower is highly risk-averse. They are dominated by contracts with a leaching chance constraint ***Prob(SNL≥40)≤1/2 (r.2.1)*** when the grower is risk-neutral or mildly risk-averse. Nevertheless, the unit cost from "no rotation with potatoes (***a.3***)" is only 1-2 ¢/lb more than imposing a leaching chance constraint***Prob(SNL≥40)≤1/2***.

8.5.3 Evaluation Under Both Efficiency Criteria

There is no contract design that is undominated across all risk preference levels under both *contract acceptability dominance* and *cost efficiency dominance*. Contract designs that impose a chance constraint on nitrate leaching above the threshold 40 lb/ac with probability ½ (***r.2.1***), or that restrict seed corn/potato rotations (***a.3***) are undominated in most cases under the two efficiency criteria.

A contract design that imposes a chance constraint on nitrate leaching above the 40 lb/ac threshold level with probability ½ (***r.2.1***) is undominated across all risk preference levels under *cost efficiency dominance* while it is only undominated for the mildly risk-averse grower under *contract acceptability dominance*. This contract fails to achieve *contract acceptability dominance* because it is relatively costly for the processor to reduce nitrate leaching compared to a) contracts charging a fee on nitrate leaching (***b.1***) when the grower is risk-neutral, and b) contracts restricting the whole-farm nitrate leaching or forbidding rotation with potatoes (***a.1.1*** and ***a.3***) when the grower is highly risk-averse.

Contract designs forbidding seed corn/potato rotations (***a.3***) are undominated under *contract acceptability dominance* at every risk preference level, but they are undominated only when the grower is highly risk-averse under *cost efficiency dominance*. This contract design is dominated by the one with a chance constraint on nitrate leaching above the 40 lb/ac threshold level with probability ½ (***r.2.1***) under *cost efficiency dominance* for the risk-neutral or mildly risk-averse grower. However, it only costs 1 to 2 ¢ more per pound of leaching reduction than strategy ***r.2.1***. Given the same cost (8 ¢/lb) for the processing firm across all risk preference levels, forbidding rotation with potatoes costs the processor 62 ¢ less for per pound of leaching reduction than does a contract with a leaching chance constraint. This contract forbidding rotation with potatoes would be the most preferable contract design, if cost transfer were possible.

In addition to efficiency criteria, contract enforceability is another essential element to be considered in contract designs.

8.6 Enforcement of Contract Specifications

All the above discussions come from a hypothetical efficiency perspective; however, a contract that is unenforceable is unlikely to be efficient. Well sampling is the primary current means to monitor groundwater nitrate levels. But there is typically no way to identify the source or individual contribution level of nitrates. Indirect methods to assess crop nitrogen needs include soil testing and plant tissue testing (such as grains, stalks, leaves, etc.) (Silva, 1996). These tests, however, can be costly and do not directly measure nitrate leaching. More reliable methods, such as lysimeter sampling, are prohibitively expensive. Without a low-cost verification technique to detect and measure nitrate leaching, it is difficult to prevent cheating on contracts that restrict or charge an effluent fee on nitrate leaching.

By contrast, a contract that targets observable agronomic practices is relatively easy to enforce. Hence, when enforceability is added to the two dominance evaluation criteria, the contract forbidding seed corn rotation with potatoes comes up as the most promising one for reducing nitrate leaching under varying levels of grower risk aversion.

8.7 Summary

Ordinary business risk is an important element in designing contracts to control NPSP. This chapter illustrates a principal-agent framework that uses a mean-variance (EV) objective function to model contracted-growers with different levels of risk aversion. In the unrestricted base scenario, all growers at all three levels would grow seed corn in rotation with potatoes with medium nitrogen treatments because this practice generates the highest expected income and has lowest yield risk among all seed corn rotations. However, this rotation generates higher nitrate leaching than other rotation practices. In terms of nitrate leaching from the whole farm, the more risk-averse the grower is, the higher the nitrate leaching. The risk averse grower solutions included a cash-rent potato contract which ensures income stability but causes serious nitrate leaching.

This analysis showed that risk attitude is crucial in determining the effectiveness of

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of alternative contract designs to reduce nitrate leaching from seed corn production. Imposing restrictions through contract specifications on emission (nitrate leaching) or agronomic practices (rotations) are the most effective ways to reduce nitrate leaching. Restricting nitrogen input use is not necessarily an effective strategy. Using financial incentives (user fees, variable payment) does not necessarily reduce nitrate leaching when the grower is risk-averse. In this model, the effectiveness of a contract design to reduce nitrate leaching comes from its ability to induce the grower to switch from a seed corn/potato rotation to a seed corn/soybean rotation.

Some contract designs targeted at seed corn fields can only effectively reduce nitrate leaching from seed corn production, but they do not successfully reduce leaching from the whole farm. Apparently, targeting only one crop does not necessarily abate whole farm NPSP.

Contract acceptability dominance and *cost efficiency dominance* criteria are used to evaluate the efficiency of alternative contract designs. There is no contract design that is undominated across all risk preference levels. The two contract designs that impose a chance constraint on nitrate leaching above the threshold 40 lb/ac with probability ½ (*r.2.1*), and that forbid seed corn/potato rotation (*a.3*) are undominanted in most cases. When enforceability is also considered, forbidding seed corn in rotation with potatoes is the only strategy that succeeds under all criteria--reduction of nitrate leaching, mutual acceptability to both the processor and the grower, and enforceability.

CHAPTER 9

CONCLUSIONS AND IMPLICATIONS

This study has examined how to redesign contracts to reduce nonpoint source pollution. Conclusions and policies implications are made based on these results. Suggestions for future research are advanced as well.

9.1 Review of Research Objectives

Nonpoint source pollution (NPSP) abatement is a regulatory challenge. Due to natural variability of NPSP as well as imperfect monitoring and/or measurement, standard public policy remedies tend to incur high transaction costs. However, the restructuring of U.S. agriculture toward more contractual arrangements between the processor and the producer brings new opportunities for the creative design of contracts to reduce NPSP voluntarily.

Within a production contract, the processing firm often specifies details such as production practices and specific inputs in order to ensure product quality. This vertical coordination of processors with contracted growers has transferred substantial influence over the management of crop and livestock enterprise to agricultural processors. Some of these contracts incorporate production incentives that may cause environmental damage due to high rates of agrochemical use.

There are at least two potential rationales for an agribusiness firm to seek voluntarily to reduce NPSP. One is fear of future environmental regulation. A processing firm may wish to pre-empt environmental liability by addressing a potential problem before it receives regulatory scrutiny. The other factor is consumer demand for improved environmental quality. Because brand reputation becomes increasingly important in agriculture, a processing firm may want to pursue and protect a "green" image. Thus a firm may wish to design contracts that offer incentives not only for the pursuit of traditional profit and product quality goals, but also for the pursuit of environmental goals.

The research issue addressed in this study is the design of a contract that is acceptable to both the processor and the contracted-grower, and that can eventually induce contracted growers voluntarily to reduce agricultural nonpoint source pollution. In order to design and evaluate alternative "green" contracts, this research examined the potential use of seed corn production contracts to reduce nitrate leaching. The research on seed corn contracts was focused on St. Joseph County of Michigan where large acreage of seed corn is grown under production contracts on sandy, irrigated soil and where there is significant nitrate concentration in the groundwater.

Five specific objectives were identified in this research. The first objective was to identify the relationships among contract specifications, nitrogen use, yield and nitrate leaching. The relationships between nitrogen use, yield, and nitrate leaching from seed corn production were estimated using a crop growth simulation model. These data showed that as nitrogen fertilizer rates increased, seed corn yields reached a plateau, whereas nitrate leaching from growing seed corn increases geometrically. Two interrelated institutional arrangements could encourage the grower to use high nitrogen fertilizer rates, resulting in excessive nitrate leaching. One is contract specifications which place a high premium on seed corn yields, and the other is assignment of contracts based directly on yield performance.

The second objective was to identify production practices that can reduce nitrate leaching. Crop rotation turned out to be an important element in addition to nitrogen use in determining nitrate leaching since certain crops rotated with seed corn receiving heavy fertilization caused substantial nitrate leaching. Therefore, appropriate nitrogen application rates and elimination of rotations with potatoes generated the least nitrate leaching. As discussed in chapters 2 and 3, knowledge of nitrogen fertilizer response can also influence the adoption of improved agronomic practices.

The third objective was to identify contractual terms that could result in reduced nitrate leaching. Chapter 2 summarized several instruments that could reduce nitrate leaching from seed corn production. The potential instruments included fees, "green" payments (or incentive payments), and penalties. The instruments were based on: a) output levels, by using seed corn yields as an index; b) purchased nitrogen fertilizer inputs; c) production practices such as an appropriate nitrogen application rate or other agronomic practices; d) nitrate leaching (emission) levels; e) the ambient nitrate concentration in the ground water; and f) liability risk due to potential health and environmental damages caused by nitrate leaching.

The fourth objective was to structure a theoretical framework to analyze alternative "green" contract designs. A principal-agent model was used to examine the relationship between the processor and a representative contracted-grower. The essential elements in designing a "green" contract within a principal-agent model included participation constraint, incentive compatibility constraint, and risk attitude. This research illustrated four kinds of potential contract designs that would incorporate environmental concerns into agricultural production contracts. They were a) restricting ambient nitrate leaching levels or nitrogen application rates, or forbidding rotation with potatoes; b) charging the contracted-grower a fee on nitrate leaching levels, or nitrogen applications; c) reducing the variable payment per bushel of seed corn output; and d) incorporating relevant nitrogen management information within a contract or as a grower educational program.

The fifth objective of this research was to formulate an empirical principal-agent analysis to examine and evaluate the impacts from alternative contractual specifications. Only the first three alternative contract categories were incorporated into a whole-farm math programming model, because the fourth scenario, incorporating relevant information, was not compatible with the mathematical programming approach. Modeling the feasibility of alternative contract designs to reduce nitrate leaching was done in two steps. First, the seed corn grower's decisions were modeled within a whole-farm math programming framework. This modeling was intended to specify the grower's participation constraint in terms of the opportunity cost of forgone income from growing other crops if the grower chose to grow seed corn. Second, the net revenue to the processing firm was modeled as the residual after subtracting contract payments from the gross revenue estimated from seed corn sales. The incentive compatibility constraint was examined using dominance criteria that evaluated whether the processor or the grower would suffer unduly under the terms of the contract compared with the baseline contract.

Three criteria were used to evaluate the efficiency of alternative contract designs. These are the ability to reduce nitrate leaching from growing seed corn (targetability) and from the whole farm (correlation with water quality), and the magnitude as well as incidence of abatement costs. Two forms of dominance analysis were used to compare relative efficiency among all alternative "green" contract designs from the perspectives of targetability and cost efficiency. The first, *contract acceptability dominance*, evaluates each pair of contracts separately for the grower (based on expected utility from mean-variance analysis) and for the processor (based on mean gross margin and mean nitrate leaching from seed corn fields). The second, *cost efficiency dominance*, evaluates each pair of contracts based on the unit cost of nitrate leaching reduction for the grower and for the processor. Nitrate leaching from the whole farm is used as a proxy to examine the correlation with water quality among all alternative contracts.

Several major findings emerged. First, crop growth and nitrogen fate simulations demonstrated that seed corn might be responsible for much less nitrate leaching than certain other crops such as potatoes.

Second, relative prices among nitrogen fertilizer, corn, soybeans, and potatoes are important in determining nitrate leaching levels. If the price of corn increases or the price of nitrogen decreases, the contractor-grower may be motivated to use more nitrogen than in the cases examined in this study. The sensitivity tests also show that if the relative price of soybeans (a low-nitrate-leaching crop) rises compared with the price of potatoes (a high-nitrate-leaching crop), this price change could shift seed corn acreage away from rotation with potatoes into rotation with soybeans, resulting in less leaching.

Third, contracts restricting nitrate leaching and rotation can effectively reduce nitrate leaching under various grower risk preference levels. Restricting nitrogen use in only seed corn contracts may not be effective in reducing nitrate leaching, especially when the more severe leaching results from a rotation crop.

Fourth, charging fees on nitrate leaching or nitrogen fertilizer was shown to be effective in reducing nitrate leaching only when the grower is risk-neutral. Charging a fee on nitrate leaching gives the risk-neutral grower enough incentive to adopt reduced leaching practices, such as a seed corn/soybean rotation. Placing a fee on nitrogen fertilizers could reduce nitrate leaching by causing a risk-neutral grower to switch to an agronomic practice (seed corn/soybean) that requires lower fertilization rates. However, such charging strategies did not reduce nitrate leaching under the risk-averse grower scenarios modeled. This conclusion was because potatoes had no income risk in this model (as in the real situation), therefore, the risk-averse grower would not change his or her seed corn production practices and nitrate leaching would not be reduced.

Fifth, rearranging the contract compensation scheme by reducing the yield-based variable payment is not necessarily an effective way to reduce nitrate leaching. Other agronomic practices are also important in determining nitrate leaching. In this analysis, the benefits from a seed corn/potato rotation exceeded the disincentive from reducing variable payments. This design could only induce the risk-neutral grower to apply lower levels of nitrogen application, but was not effective in reducing leaching.

Sixth, nitrate leaching reduction could reduce the processor's gross margins and the grower's expected utility. The magnitude and the incidence of costs from alternative contract designs depended on the specification of nitrate leaching threshold levels and the grower's risk preference. The risk-averse growers modeled bore more cost from leaching reductions than the risk-neutral grower.

Seventh, the analysis indicated that contracts targeting nitrate leaching only from seed corn production do not necessarily reduce nitrate leaching from the whole farm. If the ultimate target is to improve the water quality, then targeting only seed corn production is not sufficient.

Enforceability as well as efficiency is the key to effective contract designs. Unfortunately, it is difficult to come up with a low-cost way of enforcing contract designs that are based on nitrogen use or nitrate leaching. Without enforcement, contract redesigns may not be acceptable to both the processor and the grower. However, targeting observable agronomic practices is a feasible alternative to design "green" contracts.

9.2 Conclusions

The results demonstrate that seed corn contracts can be redesigned to reduce nonpoint source pollution. Such contracts can be mutually acceptable to both the processor and the grower at reasonable costs; but enforcement is a key issue. A principal-agent model is a workable approach in modeling and evaluating nitrate leaching reduction strategies in a contractual relationship. Several strategies can be employed as a means to control nitrate leaching. The effectiveness of these alternative contract designs depends on three factors: the risk of losing contracts, alternative crop selection, and risk preference of the contracted grower.

The grower concern over risk of contract loss could induce a high nitrogen application rate, resulting in excessive nitrate leaching. If high yields are a primary basis for a processing firm to allocate production contracts then risk of contract loss will be a serious obstacle inhibiting growers to accept alternative contract designs that may reduce NPSP at the expense of maximum crop yield. Model results indicated that alternative crop enterprises are very important to contract design, not only for the participation constraint, but also for the environmental consequences from alternative contract designs. The grower risk attitude mattered in reducing nitrate leaching as well as the incidence of who bore the cost of leaching reduction.

A contract based on seed corn yield can be easily enforced, but it cannot effectively reduce NPSP as well as improve water quality, especially when the relationship between output and emission is also affected by other managerial practices. Although a contract based on input use may be monitored through some indirect techniques, input and NPSP may be influenced by agronomic practices in addition to natural variability. Targeting certain agronomic practices is a feasible way to control NPSP because it is relatively easy to monitor, and it is correlated with water quality. Nitrate leaching, on the other hand, is difficult to measure although it is related to water quality. In theory, targeting whole-farm nitrate leaching is a way to induce growers to use improved practices to improve water quality. However, enforcement can be a problem.

Using three criteria proposed by Braden and Segerson (1993), the evaluation of alternative contract designs to reduce nitrate leaching is summarized in Table 8.1.

Table 9.1: Evaluation of alternative contract designs under various criteria

Instruments for Alternative Contract Designs	Targetability	Enforceability	Correlation w/ Water Quality
1) Seed corn yield output:			
c.1&c.2: Reduce the variable payment	L	H	L
2) Purchased nitrogen fertilizers:			
a.2 Restrict nitrogen use	L	M	L
b.2 Charge a fee on nitrogen use	M*	L	M*
3) Agronomic (rotation) practices:			
a.3 No rotation with potatoes	H**	H	M
4) Nitrate leaching from seed corn (*ASNL*):			
a.1.2 Restrict ASNL	H	L	M
b.2 Charge a fee on ASNL	M*	L	
r.1.1, r.1.2, r.2.1, r.2.2 impose a leaching chance constraint	H	M	
5) Nitrate leaching from the whole farm (*ANL*)			
a.1.1 Restrict ANL (screen)	M	L	H

Note: H : high performance; M: medium performance; L: low performance;
* : indicate that this level depends on the grower's risk-attitude;
**: indicate that this contract designs can effectively reduce nitrate leaching from seed corn production in this analysis; however, this result does not consider other substitute practices, which might indeed increase nitrate leaching. Examples are the switch from a seed corn/potato rotation to a seed corn/tomato rotation. In this case, nitrate leaching might not be reduced.

As Table 9.1 indicates contracts can be redesigned to to encourage "green" production practices. However, enforcement is the key to determining the feasibility of alternative contract designs. These "green" contract designs may affect the stability of earnings and their impacts will depend on grower risk aversion. It is possible to shift the NPSP abatement cost between the processor and the grower through the contract payment; however, it will depend on their relative bargaining power. If the current contract payment is just meeting the participation constraint, the processor may have to absorb the full cost to induce the growers to change practices. However, if the payment is higher than the participation constraint, the processor and the grower can share the NPSP abatement costs.

9.3 Policy Implications

Contract farming provides a new way of production in U.S. agriculture. This trend is expected to intensify for three reasons. First, consumers increasingly demand "identity-preserved" products (including ones produced in environmentally friendly fashion). A second reason is the increase in proprietary technologies, especially, genetic engineering. The third reason is due to the new change in the U.S. farm policy. "Freedom to Farm" in the 1996 Farm Bill is a cornerstone for changes in the U.S. governmental farm programs. This policy indicates that less subsidies as well as restrictions will be made by the government in the future. As a result, contract farming will become an attractive way for agricultural production because it provides a means of risk management as well as attractive income. Improving environmental quality through appropriate design of contractual production or arrangement becomes a promising alternative.

Evidences have shown that agribusiness has begun business-led self-regulation (Batie, 1997). If processing firms are willing to undertake voluntary nonpoint source pollution reduction, one issue to be addressed is how to achieve socially optimal abatement. Appropriate information on social benefits (or social damage costs) has to be provided to the processing firms. Such information can be obtained through various nonmarket valuation methods, such as contingent valuation and hedonic prices.

Looking beyond grain crops, a much broader set of contract design potentials emerge. The applicability of the concept to redesign contracts goes beyond merely managing nitrate leaching. What is the role for government? Several possibilities include:

1. To develop and promote less environmentally harmful practices and whole-farm systems.
2. To provide more information on identifying pollutant thresholds that are socially optimal.
3. To develop reliable and low cost monitoring techniques to verify the grower's pollution-generating actions. Enforceability is a key issue in designing a workable contract design that will induce a contracted-grower voluntarily to reduce nonpoint source pollution.
4. To provide cost-sharing to processing firms to enhance their environmental stewardship.
5. To provide clear signals as to future liability if serious NPSP persists.

9.4 Limitations and Suggestions for Future Research

Although the results of the principal-agent approach were successful in meeting the research objectives in this case study, there are limitations to this research. First, the use of nitrate leaching data simulated from DSSAT 3.0 as a proxy for the real nitrate leaching data ignores the variations across different locations, soils, slopes, and aquifers. The public is concerned with environmental and health damages, not leaching *per se*. The relationship between nitrate leaching, nitrate concentration, and exposure as well as dose-response resulting in actual damages has to be considered.

Second, although this one-period representative whole-farm approach demonstrates how alternative contract designs influence the representative farmer's behavior, variations in farm locations, socio-demographic characteristics, management practices, and technological differences are not incorporated in this analysis. In both NPSP control and contract design contexts, the dynamic relationship between the processor and among growers is important. For instance, contracted growers can negotiate to abate NPSP, or can collude with the processors. If negotiation is feasible, a high abatement grower can "bribe" a low abatement-cost grower to reduce leaching. This problem could potentially be modeled in the context of game theory to examine the dynamics among multiple players, though it was not modeled in the analysis.

Third, the agronomic practices examined in this analysis are limited to four crops and three nitrogen treatments (that is, high, medium, and low). Although forbidding rotation with potatoes grants a promising way to reduce nitrate leaching from seed corn production, this conclusion ignores the possibility for alternative substitute crops, such as cucumbers and carrots, which require high levels of nitrogen fertilizer and could result in high nitrate leaching as well.

Fourth, high product quality is one of the main objectives of production under contract. How input use is related to product quality is not examined in this analysis, since grain quality is not a major factor in seed corn contracts. However, reducing nitrogen use in horticultural crops may lead to product quality reduction, with concomitant reduction in the prices received. This result implies that product price itself can become an indirect function of nitrogen fertilizer or other input use.

The fifth limitation is related to the assumption that growers are not concerned about direct environmental benefits. In fact, there is evidence to the contrary. A grower's health might be associated with water quality, especially when growers directly use groundwater near their farms. If growers do care for environmental quality, they could reduce nitrogen use voluntarily (Swinton et al., 1997), as some have already in St. Joseph County (Hesterman et al., 1993; MASA, 1997).

Although this research has shown the feasibility of designing a "green" contract, three areas deserve further research. First, if the processor is motivated to reduce nitrate leaching and expects the contracted grower to bear the attendant costs, the prevention of cheating is quite important. If enforcement mechanisms are available and effective, the range of feasible alternative contracts expands. Thus, the development of accurate, low-cost verification techniques that can easily be applied to detect and measure compliance is an important research priority. The development of accurate monitoring techniques also can lead to better nitrogen management. For instance, one potential approach is to incorporate a nitrogen use efficiency ratio into the contract design (Ritchie, 1997). The ratio is calculated by nitrogen removed by harvested mass divided by nitrogen fertilizer input and growers are penalized if their ratios fall below a certain level. Nitrogen fertilizer is ultimately leached if not used by the plant in a sandy loam soil. Through this method, the amount of nitrate leaching can be effectively controlled.

The second area is to incorporate the dynamics of multiple heterogeneous polluters in a nonpoint source pollution abatement model. An NPSP contract design needs to consider each polluter's characteristics (location and technology) and potential behavior (cooperation or cheating). A nonpoint source pollutant may involve multiple environmental media (surface- and ground- water) and multiple processors. Furthermore, the interactions among these factors need further exploration.

The third area is the exploration of other new means for nonpoint source pollution control. Using contract designs is only one approach for voluntary NPSP reduction. There are other approaches, such as green codes and ecolabeling. Voluntary nonpoint source pollution reduction is a growing phenomenon.

APPENDICES

APPENDIX A

PARAMETERS USED IN CROP GROWTH SIMULATION MODEL DSSAT 3.0

CULTIVARS: GENOTYPE
1 Soybean: 990002 M GROUP 2
2 Seed corn: IB0070 P38
3 Commercial corn: PIO 3475
4 Potato: Russet burbank

FIELDS
Specify field location (St. Joseph County), weather data (Three Rivers and Ft. Wayne), and soil data (sandy loamy).

SOIL PROFILE INITIAL CONDITIONS
Specify water content, soil ammonium, soil nitrate, and soil pH all by layer.

PLANTING DETAILS
Specify the planting data (5/16/51 in this case), plant population, and planting depth.

IRRIGATION AND WATER MANAGEMENT
Assume to be automatically managed, i.e., when water is needed, the system will turn on irrigation.

FERTILIZERS MANAGEMENT DATA (INORGANIC)
Specify fertilizer application date, type of nitrogen fertilizer, total amount applied, depth of application.

RESIDUES AND OTHER ORGANIC MATERIALS

HARVEST DETAILS
Specify the harvest date.

SIMULATION CONTROLS
Specify starting date of the simulation, date of measuring, and years.

APPENDIX B

WEATHER INPUT FOR DSSAT 3.0

Table B.1: Mean average weather data during 1951-1992

Year	Total rainfall[1] (mm)	Average max. temp.[1] (°C)	Average min. temp.[1] (°C)	Average sol. rad.[2]
1951	1152.9	15.55	3.69	13.40
1952	978.9	16.43	4.17	17.37
1953	792.9	17.43	4.73	14.53
1954	1317.6	16.09	4.33	14.05
1955	913.5	16.38	3.87	14.83
1956	807.4	15.76	3.31	14.23
1957	1038.4	15.44	3.92	13.60
1958	910.8	14.93	2.84	14.21
1959	943.1	15.95	4.26	14.12
1960	786.2	14.97	3.66	14.01
1961	918.4	15.37	3.55	13.95
1962	674.8	15.47	3.55	14.40
1963	612.4	16.07	2.85	14.91
1964	703.1	16.43	3.99	14.39
1965	1022.2	15.46	4.09	14.11
1966	771.3	15.00	3.34	14.65
1967	909.2	14.00	3.26	13.85
1968	1011.3	14.66	3.86	14.22
1969	834.3	14.35	3.49	13.80
1970	905.2	14.85	3.85	13.74
1971	631.2	15.95	3.99	14.58
1972	979.7	14.68	3.80	13.50
1973	962.8	16.40	5.37	13.45
1974	859.6	15.68	3.90	13.99
1975	959.0	15.80	4.27	14.02
1976	977.8	15.05	1.92	15.11
1977	957.6	16.31	3.83	14.16
1978	966.7	14.78	2.87	14.52
1979	1065.6	14.73	3.30	13.56
1980	1037.4	14.96	3.62	13.80
1981	1137.0	15.32	4.04	13.59
1982	1052.5	15.58	4.10	13.86
1983	951.2	16.33	4.40	14.05
1984	997.0	15.58	4.34	13.82
1985	1094.6	16.03	4.50	14.27
1986	1072.7	16.02	4.84	13.75
1987	963.6	16.97	5.24	14.32
1988	940.1	15.42	3.01	15.13
1989	958.5	14.12	2.44	14.36
1990	1248.5	15.47	4.04	13.90
1991	849.6	15.71	5.00	14.55
1992	922.9	14.01	3.22	13.58

(Source: national weather station from [1]Three Rivers, Michigan and [2]Fort Wayne, Indiana)

APPENDIX C

COEFFICIENTS IN THE WHOLE-FARM PROGRAMMING MODEL

Table C.1: Machinery working rates

Machine Name	Total Hours/ day	Resource Required Per Machine Hour		Working Rate (Acre/Hr)
		Tractor hrs	Labor hrs	
Machinery for Field Preparation				
P&K spreader	12	1.00	1.00	20.00
Chisel plow 18 ft	12	1.00	1.00	10.47
V-ripper 30" O.C. 17ft	12	1.00	1.00	10.51
Machinery for Pre-planting				
Finish tmd disk 33ft	12	1.00	1.00	17.00
Comb fld cul incorp 33ft	12	1.00	1.00	23.80
Machinery for planting				
Min-til planter 16-30	11	1.00	1.50	12.73
Machinery for Post-Planting				
Rotary hoe	12	1.00	1.00	37.09
Cultivator	12	1.00	1.00	15.40
Anhydrous 30ft	12	1.00	1.00	12.73
Center pivot irrigation	24	0.00	10hrs (all)	
Machinery for Harvesting				
Combine	10	1.00	2.50	5.09

(Source: Doane's Agricultural Report, 1996)

Table C.2: Time periods and suitable days for field work

No.	Description	Total Days	Suitable Days for field work
1	Apr 15-Apr 21	7	3.0
2	Apr 22-Apr 25	4	1.7
3	Apr 26-May 2	7	3.1
4	May 3-May 9	7	3.5
5	May 10-May 16	7	3.8
6	May 17-May 23	7	4.3
7	May 24-May 30	7	5.0
8	May 31-Jun 6	7	5.1
9	Jun 7-Jun 13	7	5.1
10	Jun 14-Jun 20	7	4.2
11	Jun 21-Jun 27	7	3.8
12	Jun 28-Jul 4	7	4.8
13	Jul 5-Jul 11	7	5.5
14	Jul 12-Aug 29	49	36.7
15	Aug 30-Sep 12	14	10.3
16	Sep 13-Sep 19	7	4.8
17	Sep 20-Sep 26	7	4.8
18	Sep 27-Oct 10	14	13.9
19	Oct 11-Oct 31	21	10.8
20	Nov 1-Nov 21	21	5.1
21	Nov 22-Dec 5	14	1.3
22	Dec 6-Mar 31	116	0.0
23	Apr 1-Apr 14	14	4.0

(Sources: Rosenberg et al., 1982; Doster et al., 1994; and King, 1995)

Table C.3: Yield adjustment and moisture level sets

A. Commercial Corn

A.1 Yield adjustment for commercial corn (percent)

Plant Period	Harvest Period: Sep 27 to Oct 10	Oct 11 to Oct 31	Nov 1 to Nov 21	Nov 22 to Dec 5
Apr 22-Apr 25	96.0	96.0	93.0	86.0
Apr 26-May 2	100.0	100.0	95.0	90.0
May 3-May 9	96.0	98.0	95.0	90.0
May 10-May 16	91.0	94.0	91.0	86.0
May 17-May 23	0.0	84.0	84.0	81.0
May 24-May 30	0.0	74.0	74.0	71.0
May 31-Jun 6	0.0	0.0	0.0	55.0

(Source: Black and King, 1995)

A.2 Moisture level (precent)

Plant Period	Harvest Period: Sep 27 to Oct 10	Oct 11 to Oct 31	Nov 1 to Nov 21	Nov 22 to Dec 5
Apr 22-Apr 25	26.0	22.0	19.0	18.0
Apr 26-May 2	28.0	22.0	19.0	18.0
May 3-May 9	26.0	24.0	20.0	19.0
May 10-May 16	28.0	26.0	21.0	19.0
May 17-May 23	0.0	24.0	23.0	20.0
May 24-May 30	0.0	27.0	26.0	22.0
May 31-Jun 6	0.0	0.0	0.0	23.0

(Source: Black and King, 1995)

B. Soybean yield adjustment (percent)

Plant Period	Harvest Period: Sep 20 to Sep 26	Sep 27 to Oct 10	Oct 11 to Oct 31
Apr 26-May 2	98.0	98.0	94.0
May 3-May 9	99.0	99.0	95.5
May 10-May 16	100.0	100.0	97.0
May 17-May 23	99.0	99.0	96.0
May 24-May 30	0.0	95.0	92.0
May 31-Jun 6	0.0	91.0	88.0
Jun 7-Jun 13	0.0	86.0	83.0

(Source: Black and King, 1995)

C. Seed Corn yield adjustment (percent)

Plant Period	Harvest Period: Aug 30 to Sep 12	Sep 13 to Sep 19	Sep 20 to Sep 26
Apr 26-May 2	100.0	100.0	100.0
May 3-May 9	0.0	100.0	100.0
May 10-May 16	0.0	0.0	100.0

(Source: Miron and King, 1995)

Table C.4: Tillage practices for seed corn

Category	Activities/machine	Working rate (ac/hr)	Operat. Cost ($/acre)	Timing	Inputs	Note
Field preparation	Moldboard plow	8.35	3.80	10/11-4/15		contin. corn
	Disc chisel plow	10.47	2.30			rotate w/bean, potato
	P&K, lime spreader	23.76	4.03		P & K, lime	Rent equipment
	V-ripper 30" O.C. 17ft	10.51	1.68			rotate w/potato
Pre-plant tillage	finish temdan disk 33ft	17.00	1.02	4/15-5/16		Every 2 years
	comb fld cul incorp 33 ft	23.80	1.11			
Planting	min-til planter16-30	12.73	5.78	5/1-5/31	seed, nutrient starter, Counter	compensated by $5/acre
Post-plant tillage	pre-emergenct: boom sprayer 50ft	22.50	4.75	1-14	BicepII & Dual	Custom
	rotary hoe30ft (optional)	37.09	0.31	1 week		
	cultivator12-30 (optional)	15.45	0.99	4 weeks		
	post-emergenct: boom sprayer 50ft	22.50	2.38	6 weeks	Buctril+AAtrex	Custom; every 2 years
	side-dress: anhy 30ft	12.73	8.25	Mid June	Anhydrous N	rent equipment
	irrigation: central pivot		24.00	6 times		
	detasseling[1]	100ac/day	17.50	7/10-8/10		M-W cutter+wheel puller+personal carrier
	remove male row: Haggie	10.00	5.00	7/20-8/21		Custom
Harvest	sweet corn picker[1]	100ac/day	32.00	8/30-10/20		

[1] Indicate the processor's cost; otherwise, the grower's expense.

(Sources: Miron and King, 1996; Doane's Agricultural Report, 1996)

Table C.5: Tillage practices for commercial corn

Category	Activities/machine	Working rate(ac/hr)	Cost ($/acre)	Timing	Inputs	Note
Field preparation	Moldboard plow	8.35	3.80	11/1-5/23		contin. corn
	Disc chisel plow	10.47	2.30			rotate w/bean, potato
	P&K, lime spreader	23.76	4.03		P & K, lime	Rent equipment
	V-ripper 30" O.C. 17ft	10.51	1.68			rotate w/potato
Pre-plant tillage	finish tmd disk 33ft	17.00	1.02	4/15-5/25		Every 2 years
	comb fld cul incorp 33 ft	23.80	1.11			
Planting	min-til planter16-30	12.73	5.78	4/22-5/25	seed, starter, counter	
Post-plant tillage	pre-emergenct: boom sprayer 50ft	22.50	4.75	1-14	BicepII & Dual	Custom
	rotary hoe30ft (optional)	37.09	0.31	1 week		
	cultivator12-30 (optional)	15.45	0.99	4 weeks		
	post-emergenct: boom sprayer 50ft	22.50	2.38	6 weeks	Buctril+AAtrex	Custom; every 2 years
	side-dress: anhy 30ft	12.73	8.25	Mid June	Anhydrous N	rent equipment
	irrigation: central pivot		24.00	6 times		
Harvest	combine +corn head+gravity grain box	5.09	9.96	9/27-12/5		

(Sources: King, 1996; Doane's Agricultural Report, 1996)

Table C.6: Tillage practices for soybeans

Category	Activities/machine	Working rate(ac/hr)	Cost ($/acre)	Timing	Inputs	Note
Field preparation	Disc chisel plow	10.47	2.30	11/1-4/21		every other year
	P&K, lime spreader	23.76	4.03		P & K, lime	Rent equipment
Pre-plant tillage	finish tmd disk 33ft	17.00	1.02	4/22-5/30		Every 2 years
	comb fld cul incorp 33 ft	23.80	1.11			
Planting	min-til planter16-30	12.73	5.78	4/22-6/6	seed	
Post-plant tillage	pre-emergenct: boom sprayer 50ft	22.50	4.75	1-14	BicepII & Dual	Custom
	rotary hoe30ft (optional)	37.09	0.31	1 week		
	cultivator12-30 (optional)	15.45	0.99	4 weeks		
	post-emergenct: boom sprayer 50ft	22.50	2.38	6 weeks	Buctril+AAtrex	Custom; every 2 years
Harvest	combine+grain head+gravity grain box	5.09	9.96	9/27-12/5		

(Sources: King, 1996; Doane's Agricultural Report, 1996)

Table C.7: Tillage practices for potatoes

Category	Activities/machine	Working rate(ac/hr)	Cost ($/acre)	Timing	Inputs	Note
Field preparation	Disc chisel plow	10.47	2.30	11/1-4/21		
	lime spreader	23.76	2.02		lime	Rent equipment
Post-plant	irrigation: central pivot		24.00	6 times		

(Sources: King, 1996; Doane's Agricultural Report, 1996)

APPENDIX D

OPTIMAL CROP ENTERPRISES FROM EXPECTED UTILITY MAXIMIZATION

Table D.1: Optimal mixed of crop enterprises from expected utility maximization for alternative contract designs under three levels of risk-aversion

	Coefficient of Risk-Aversion (λ)					
	$\lambda = 0$		$\lambda = 10^{-5}$		$\lambda = 10^{-4}$	
Strategies	Enterp. Name	Acreage	Enterp. Name	Acreage	Enterp. Name	Acreage
	PSEED(M)	500	PSEED(M)	500	PSEED(M)	500
Unrestricted base model	PCORN (M)	246	PCORN (M)	350	PCORN (L)	100
	BCORN(L)	103	POTATO	850	POTATO	600
	SOYBEAN	103				
	POTATO	746				
a.1.1	BSEED(M)	374	BSEED(M)	374	BSEED(M)	500
Restrict ANL to 35 lb/ac	PSEED(M)	126	PSEED(M)	126	PCORN (L)	73
(Whole farm)	BCORN(L)	350	BCORN(L)	350	BCORN(L)	27
	SOYBEAN	724	SOYBEAN	724	SOYBEAN	527
	POTATO	126	POTATO	126	POTATO	73
a.1.2	BSEED(M)	483	BSEED(M)	483	BSEED(L)	475
Restrict ASNL to 35 lb/ac	PSEED(M)	17	PSEED(M)	17	PSEED(M)	25
(Seed corn)	PCORN(M)	350	PCORN(L)	350	PCORN(L)	100
	SOYBEAN	483	SOYBEAN	483	SOYBEAN	475
	POTATO	367	POTATO	367	POTATO	125
a.2	PSEED(L)	500	PSEED(L)	500	PSEED(L)	500
Restrict N fert. to 107 lb/ac	PCORN (M)	246	PCORN (M)	350	PCORN(L)	100
	BCORN(L)	104	POTATO	500	POTATO	600
	SOYBEAN	246				
	POTATO	746				
a.3	BSEED(M)	500	BSEED(M)	500	BSEED(M)	500
No rotation with potato	PCORN (M)	350	PCORN (L)	350	PCORN(L)	100
	SOYBEAN	500	SOYBEAN	500	SOYBEAN	600
	POTATO	350	POTATO	350	POTATO	100
b.1	BSEED(M)	457	PSEED(M)	500	PSEED(M)	500
Charge 10 ¢/lb on NL>30	PSEED(M)	43	PCORN (M)	350	PCORN(L)	100
lb/ac	PCORN (M)	350	POTATO	850	POTATO	600
	SOYBEAN	43				
	POTATO	807				
b.2	BSEED(M)	457	PSEED(L)	500	PSEED(M)	500
Charge 15 ¢/lb on N fert.	PSEED(L)	43	PCORN (M)	350	PCORN(L)	100
> 90 lb/ac	PCORN (M)	350	POTATO	850	POTATO	600
	SOYBEAN	43				
	POTATO	807				
c.1	PSEED(L)	500	PSEED(M)	500	PSEED(M)	500
Fixed pay: $253 /ac plus	BCORN (L)	104	PCORN(M)	350	PCORN(L)	100
var. pay: $3.96	PCORN(M)	246	POTATO	850	POTATO	600
	SOYBEAN	104				
	POTATO	746				
c.2	PSEED(L)	500	PSEED(M)	500	PSEED(M)	500
Fixed pay: $230 /ac plus	BCORN (L)	104	PCORN(M)	350	PCORN(L)	100
var. pay: $3.96	PCORN(M)	246	POTATO	850	POTATO	600
	SOYBEAN	104				
	POTATO	746				

(Source: GAMS whole-farm optimization)

Table D.1: Optimal mixed of crop enterprises from expected utility maximization for alternative contract designs under three levels of risk-aversion (continuous)

	Coefficient of Risk-Aversion (λ)					
	$\lambda = 0$		$\lambda = 10^{-5}$		$\lambda = 10^{-4}$	
Strategies	Enterp. Name	Acreage	Enterp. Name	Acreage	Enterp. Name	Acreage
Unrestricted base model	PSEED(M)	500	PSEED(M)	500	PSEED(M)	500
	PCORN (M)	246	PCORN (M)	350	PCORN (L)	100
	BCORN(L)	103	POTATO	850	POTATO	600
	SOYBEAN	103				
	POTATO	746				
r.1.1	SSEED(L)	115	SSEED(L)	115	SSEED(L)	115
Restrict Prob(SNL≥35)≤ 1/2	BSEED(L)	385	BSEED(L)	385	BSEED(L)	385
	PCORN(M)	407.5	PCORN(L)	407.5	PCORN(L)	157.5
	SOYBEAN	385	SOYBEAN	385	SOYBEAN	385
	POTATO	407.5	POTATO	407.5	POTATO	157.5
r.1.2	SSEED(L)	299	SSEED(L)	299	SSEED(L)	299
Restrict Prob(SNL≥35)≤	BSEED(L)	201	BSEED(L)	201	BSEED(L)	201
1/10	PCORN(M)	454	PCORN(M)	499.5	PCORN(L)	249.5
	BCORN(L)	46	SOYBEAN	201	SOYBEAN	201
	SOYBEAN	247	POTATO	499.5	POTATO	249.5
	POTATO	454				
r.2.1	PSEED(L)	500	PSEED(L)	500	PSEED(L)	500
Restrict Prob(SNL≥40)≤ 1/2	PCORN (M)	246	PCORN (M)	350	PCORN(L)	100
	BCORN(L)	104	POTATO	500	POTATO	600
	SOYBEAN	246				
	POTATO	746				
r.2.2	BSEED(M)	500	BSEED(M)	500	BSEED(M)	500
Restrict Prob(SNL≥40)≤	PCORN (M)	350	PCORN (L)	350	PCORN(L)	100
1/10	SOYBEAN	500	SOYBEAN	500	SOYBEAN	600
	POTATO	350	POTATO	350	POTATO	100

(Source: GAMS whole-farm optimization)

APPENDIX E

PROOF THE EQUIVALENT CONDITION OF A CHANCE CONSTRAINT

To prove ***prob($y \leq y_0$) $\leq 1/g^*$*** implies ***$t - g^*\theta(\alpha,t) \geq y_0$***, this study uses the low partial moment (LPM), presented by Fishburn (1977). A general form of the low partial moment is defined as:

$$\rho(\alpha,t) = \int_{-\infty}^{t} (t-x)^{\alpha} f(x)dx$$

where ***t*** is a risk reference level of income, and α is a positive constant. Let ***θ*** be defined as the positive ***α^{th}*** root of Fishburn's lower partial moment, i.e., .***$\theta = \rho^{1/\alpha}$***.

$$\begin{aligned}\rho(\alpha,t) &= \int_{-\infty}^{t} (t-x)^{\alpha} f(x)dx \\ &= \int_{-\infty}^{t-p\theta(\alpha,t)} (t-x)^{\alpha} f(x)dx + \int_{t-p\theta(\alpha,t)}^{t} (t-x)^{\alpha} f(x)dx \\ &\geq \int_{-\infty}^{t-p\theta(\alpha,t)} (t-x)^{\alpha} f(x)dx\end{aligned}$$

Because ***$x \in [-\infty, t-p\theta(\alpha,t)]$***, the minimum value of (***t-x***) equals ***$p\theta(\alpha,t)$***. Therefore,

$$\rho(\alpha,t) \geq p^{\alpha}\rho(\alpha,t) \int_{-\infty}^{t-p\theta(\alpha,t)} f(x)dx$$

Therefore, implies:

$$Prob(x \leq t - p\theta(\alpha,t)) \leq 1/p^{\alpha}$$

The upper limit can be derived to satisfy this constraint. Let α=1, p=g*; the sufficient condition to satisfy this constraint is:

$$x_0 \leq t - p\theta(1,t) = t - g^*\theta(1,t)$$ Q.E.D.

The next section proves that $L^t - h^* \sum_{L_i \geq \bar{L}} (L_i - \bar{L})p_i \geq 0$ is sufficient to ensure the constraint $Prob(L \geq \underline{L}) \leq 1/h^*$ (Atwood, Watts, and Helmers, 1988).

$$Pr(L \geq \underline{L}) = Pr(\underline{L} - L \leq 0)$$

Because it was proven above that the sufficient condition to satisfy the constraint

$$Prob(x \leq t - p\theta(1,t)) \leq 1/p$$

is $x_0 \leq t - p\theta(1,t) = t - g^*\theta(1,t)$, hence, the sufficient condition for $Pr(\underline{L} - L \leq 0) \leq 1/h^*$ becomes:

$$L^t - h^* \sum_{L_i \geq \bar{L}} (L_i - \bar{L})p_i \geq 0.$$

APPENDIX F

GAMS VERSION OF PC-LP WHOLE-FARM PROGRAMMING MODEL

```
$TITLE " Michigan Seed Corn Farm (PCLP a la GAMS) "
*
* The authors would like to promote the dissemination of this
* program through as many channels as possible.  However, we
* do wish to rain copyright on the program and request
* notification of any plans to redistribute the program.
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* authors.  Please contact the program use coordinator
* <preckel@agecon.purdue.edu>.

* The orginal program developed by Dobbins et al., has been modified by
* Mei-Chin Chu.  Several changes are made in order to meet
* the following goals:
* 1. The whole-farm planning of a seed corn contracted-grower
* 2. Chance constraints on contract loss and nitrate leaching reduction
* 3. Mean-Variance Expected utility of the grower
* 4. The gross margin of the seed corn processing firm
*

$OFFSYMLIST
$OFFSYMXREF
option lp=minos5 ;
OPTION DECIMALS =  6 ;
OPTION LIMROW   =  2 ;
OPTION LIMCOL   =  0 ;
OPTION ITERLIM = 100000;
*%%%%%%%%%%%%%%    SETS      %%%%%%%%%%%%%

SETS

  CROP          Crops
                   /CO, SC, BN, PO /
  PRODUCT       Commodities primary
                   /CORN, SEED, BEAN, POTATO /
  PER           Periods
                  /APR3,APRMAY,MAY1,MAY2,MAY3,MAY4,MAYJ,JUN1,JUN2,
                   JUN3,JUNJLY,JULY,JLYAUG,AUGSEP,SEP1,SEP2,SEPOCT,OCT,NOV,
                   NOVDEC,APR1,APR2/

* The time periods are defined as follows:
* APR3 : Apr.22-25;      APRMAY: April 26-May 2;
* MAY1 : May 3-9;         MAY2 : May 10-16; MAY3 : May 17-23 ; MAY4 : May24-30;
* MAYJ : MAY31-June 6;    JUN1 : June 7-13; JUN2 : June 14-20; JUN3: June 21-27;
* JUNJLY: June 28-July 4; JULY : July 5-11;JLYAUG:July 12-Aug. 29;
* AUGSEP: Aug.30-Sep.12;  SEP1 : Sep.13-19; SEP2 : Sep. 20-26;

* SEPOCT: Aep.27-Oct.10;  OCT  : Oct.11-31;
* NOV  : Nov.1-21;        NOVDEC: Nov.22-Dec.5.
* APR1 : Apr.1-14;         APR2 : Apr.15-21;
* Source: Rod King, Extension Director in St. Joseph County, Michigan
```

```
  state           states of nature
                    / 1 * 10 /
  PPER(PER)       Planting periods
                    /APR3,APRMAY,MAY1,MAY2,MAY3,MAY4,MAYJ,JUN1/
  HPER(PER)       Harvesting periods
                    /AUGSEP,SEP1,SEP2,SEPOCT,OCT,NOV,NOVDEC/
  PLPER(PER)      Plowing periods
                    /OCT,NOV,NOVDEC,APR1,APR2/
  NOPER(PER)      Periods when no activities take place
  PRAC            Production practice (nitrogen fertilizers applied here)
                    /HIGH, MEDIUM, LOW, NNA/
  ITEMS           Cost items
                   /FERTIL,herb,insect,SEED,IRRIG,OTHER/
  EQUIP           Farm equipment types
                   /PKS,MOLDB,CHISEL,vrip,DISC,COMB,PLANT,CULT,ROTHOE,ANHY/
  EPLOW(Equip)    Plowing equipment
                    /PKS, CHISEL,vrip/
  EPREP(Equip)    Preparation equipment
                    /DISC, COMB/
  EPLANT(Equip)   Planting equipment
                    /PLANT/
  EPOST(Equip)    Postplanting equipment
                    /CULT,ROTHOE,ANHY/ ;

ALIAS (PER,PERIOD,per1,period1), (CROP,PRCROP,cr1,prc1),
      (state,states),(product,prod1),(prac,prac1),(hper,hper1);

*%%%%%%%%%%%      RESOURCES       %%%%%%%%%%%%%%%%%%%%%%%%%

SCALAR  LANDRHS   Land availability (acres)              /1200/
        HARVESTER Number of combine harvesters           /1/
        MAXLAND   Maximum amount of rented land (acres)  /500/
        MAXSEED   Maximum amount of seed corn contract (acres) /500/
        TRACTOR   Number of tractors              /2/

PARAMETER
   DAYS(Per) number of working days by time period
    / APR1    4.0, APR2    3.0, APR3    1.7, APRMAY 3.1,
      MAY1    3.5, MAY2    3.8, MAY3    4.3, MAY4   5.0,MAYJ 5.1,
      JUN1    5.1, JUN2    4.2, JUN3    3.8, JUNJLY 4.8,
      JULY    5.5,JLYAUG 36.7, AUGSEP 10.3, SEP1   4.8,SEP2 4.8,
     SEPOCT 13.9, OCT    10.8, NOV     5.1, NOVDEC 1.3/

 PARAMETER
   WORKER(Per)   Number of hired workers in each period
    / APR1    2, APR2    2, APR3    2, APRMAY 2,
      MAY1    2, MAY2    2, MAY3    2, MAY4    2, MAYJ   2,
      JUN1    2, JUN2    2, JUN3    4, JUNJLY 4,
      JULY    4, JLYAUG 4, AUGSEP 2, SEP1    2, SEP2   2,
      SEPOCT 2, OCT     2, NOV     2, NOVDEC 2/

   FARMER(Per)   Number of family members available for farm work
    / APR1    1, APR2    1, APR3    1, APRMAY 1,
      MAY1    1, MAY2    1, MAY3    1, MAY4    1, MAYJ   1,
      JUN1    1, JUN2    1, JUN3    1, JUNJLY 1,
      JULY    1, JLYAUG 1, AUGSEP 1, SEP1    1, SEP2   1,
      SEPOCT 1, OCT     1, NOV     1, NOVDEC 1/

SCALARS
         HRSPERDAY   Number of net field work hours per day    /12/
         HRSPERDAYC  Number of field hours for combine         /10/
         HRSPERDAYP  Number of field hours for planter         /11/ ;

PARAMETERS  TRACRHS(Per) Tractor power capacity (hrs)
            EQUIPRHS(Equip,Per)  Farm equipment capacity (hrs)
            COMBRHS(Per) Combine harvester capacity (hrs)
            MAXHIRE(Per) Maximum amount of hired labor (hrs)
```

```
            OWNLAB(Per)  Self employed labor in regions  (hrs) ;
            EQUIPRHS(Equip,Per) = Days(Per)*hrsperday;
            EQUIPRHS('PLANT',PER) = Days(Per)*hrsperdayp;
            TRACRHS(Per) = TRACTOR*DAYS(Per)*HrsPerday;
            COMBRHS(Per) = HARVESTER*DAYS(Per)*HrsPerDayc;
            OWNLAB(Per)  = FARMER(Per)*DAYS(Per)*HrsPerDay;
            MAXHIRE(Per) = WORKER(Per)*DAYS(Per)*HrsPerDay;
*%%%%%%%%%%%%%    INPUT REQUIREMENTS & TECHNOLOGY PARAMETERS   %%%%%%%%%%%%%%%

* Tractor times are obtained by inverting the working rates (i.e. 1/workrate)
* Source: Doane's Agricultural Report 58 (April 1995).

Parameter  POSTLAG(CROP)   Time lag between planting and postplanting
          /CO 3, SC 3, BN 3, PO 0/;

TABLE  PLEQUIP(PrCrop,Crop,Equip) plowing equip rates(hrs per acre)

                 PKS    CHISEL     vrip     MOLDB
      CO.CO     0.042    0.0       0         0.120
      BN.CO     0.042    0.0953    0          0
      PO.CO     0.042    0.0953    0.0951     0
      SC.SC     0.042    0.0       0         0.120
      BN.SC     0.042    0.0953    0          0
      PO.SC     0.042    0.0953    0.0951     0
      SC.BN     0.042    0.0953    0          0
      CO.BN     0.042    0.0953    0          0
      CO.PO     0.042    0.0953    0          0
      SC.PO     0.042    0.0953    0          0   ;

parameters  PLOWLAB(PrCrop,CROP) Labor requirement for plowing
            PLOWTRAC(PrCrop,CROP) Labor requirement for plowing;
            PLOWLAB(PrCrop,CROP) = sum(equip,plequip(PrCrop,crop,equip));
            PLOWTRAC(PrCrop,CROP) = sum(equip,plequip(PrCrop,crop,equip));

TABLE  PrEQUIP(CROP,EQUIP) Preparation equip rates (hrs per acre)

         DISC       COMB
    CO   0.05882    0.042
    SC   0.05882    0.042
    BN   0.05882    0.042
    PO   0          0 ;
parameters  PrepLAB(CROP)    Labor requirement for plowing
            PrepTrac(CROP)   Tractor requirement for plowing;
            PrepLab(CROP)  = prequip(crop,'disc')*0.5+prequip(crop,'comb');
            PrepTrac(CROP) = prequip(crop,'disc')*0.5+prequip(crop,'comb');
*            PrepLab(CROP)  = sum(equip,prequip(crop,equip));
*            PrepTrac(CROP) = sum(equip,prequip(crop,equip));


TABLE  NFERkg(PrCrop,Crop,Prac) Nitrogen fertilizer applied (kgs per hacter)

                 HIGH      MEDIUM        LOW   NNA
  CO.CO          190         170         150    0
  BN.CO          150         130         110    0
  PO.CO          190         170         150    0
  SC.SC          140         130         120    0
  BN.SC          100          90          80    0
  PO.SC          140         130         120    0;

Parameters  NFER(PrCrop,Crop,Prac) nitrogen fertilizer applied (lbs per acre);
            NFER(PrCrop,Crop,Prac)=NFERkg(PrCrop,Crop,Prac)/1.12;

parameters  PLANTeq(CROP,equip) Planting equipment rates(hrs per acre)
          / CO.plant 0.0787, SC.plant 0.1574, BN.plant 0.0787, PO.plant  0/
            PLTLAB(Crop)   Planting labor coefficients  (hrs per acre)
          / CO  0.11811, SC 0.23438, BN  0.11811, PO  0/
            PLTTRAC(Crop)  Tractor coeffs. for planting Crop (hrs per acre)
```

```
        / CO  0.11811, SC 0.23438, BN  0.11811, PO 0/ ;

TABLE POSTEQUIP(PRCROP,CROP,EQUIP)  Postplanting equip rates (hrs per acre)
                  ROTHOE    CULT      ANHY
     CO.CO        0.0270    0.0647    0.0833
     BN.CO        0.0270    0.0647    0.0833
     PO.CO        0.0270    0.0647    0.0833
     SC.SC        0.0270    0.0647    0.0833
     BN.SC        0.0270    0.0647    0.0833
     PO.SC        0.0270    0.0647    0.0833
     CO.BN        0.0270    0.0647    0
     SC.BN        0.0270    0.0647    0       ;

parameter  PostLab(PrCrop,Crop)  labor requirement for post-planting
           PostTrac(PrCrop,Crop) tractor requirement for post-planting ;

PostLab(PrCrop,Crop)=sum(equip,postequip(prcrop,CROP,EQUIP));
           PostTrac(PrCrop,Crop)=PostLab(prcrop,CROP);

parameter  PostTime(Crop)  Time period for doing postplanting
             /CO 3, SC 3, BN 2, po 0/;

parameters  HAVLAB(Crop)   Harvesting labor coefficients (hrs per acre)
             / CO   0.4912,  SC 0, BN   0.4912, PO   0/
            HAVTRAC(Crop)  Tractor coefficients for harvest (hrs per acre)
             / CO   0.1961,  SC 0, BN   0.1961, PO   0/
            COMB(Crop)  Harvester coefficients (harvesting) hrs per acre
             / CO   0.1961,  SC 0, BN   0.1961, PO   0/ ;

* The above figures are inverse of working rates for plowing and chiseling
* Source:  Doane's Agricultural Report 58 (April 1995).

TABLE   PERCYLD(Crop,Per,Period) Crop yield changes (%) from optimum yields
*       Per is planting time, Period is harvest time

               AugSep   Sep1   Sep2    SepOct  Oct     Nov    NovDec
  CO.Apr3                               0.96   0.96    0.93   0.86
  CO.AprMay                             1.00   1.00    0.95   0.90
  CO.May1                               0.96   0.98    0.95   0.90
  CO.May2                               0.91   0.94    0.91   0.86
  CO.May3                                      0.84    0.84   0.81
  CO.May4                                      0.74    0.74   0.71
  CO.MayJ                                                     0.55
  SC.AprMay     1.00     1.00    1.00
  SC.May1                1.00    1.00
  SC.May2                        1.00
  Bn.AprMay                      0.98  0.98    0.94    0.     0.
  Bn.May1                        0.99  0.99    0.955   0.     0.
  Bn.May2                        1.00  1.00    0.97    0.     0.
  Bn.May3                        0.99  0.99    0.96    0.     0.
  Bn.May4                        0.00  0.95    0.92    0.     0.
  Bn.MayJ     0.00                     0.91    0.88    0.     0.
  Bn.Jun1     0.00                     0.86    0.83    0.     0.0
  Po.may1     1.00                                                ;
*Source: Consult with Rod King and Dr. Roy Black (1996).

 PERCYLD(Crop,Per,Period)$(NOT PPER(Per))= 0;
 PERCYLD(Crop,Per,Period)$(NOT HPER(Period))=0;
 PARAMETER  FIRSTPLANT(Crop)  First planting period for crops ;
 FIRSTPLANT(Crop) = 0 ;

LOOP(CROP,
 LOOP(PER$(FIRSTPLANT(Crop) EQ 0),
 FIRSTPLANT(Crop)=ORD(Per)$(SMAX(PERIOD,PERCYLD(CROP,PER,PERIOD)) GT 0))) ;

PARAMETER  LASTPLANT(Crop)  Last planting of crops ;
 LASTPLANT(Crop) = 0 ;
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```
LOOP(CROP,
 LOOP(PER$(ORD(PER) GE FIRSTPLANT(CROP) AND LASTPLANT(CROP) EQ 0),
         LASTPLANT(CROP) = (ORD(PER)-1)$(SMAX(PERIOD,
                             PERCYLD(CROP,PER,PERIOD)) EQ 0)));
* DISPLAY FIRSTPLANT,LASTPLANT ;

TABLE MOIST(Per,Period) Moisture content Points (for corn only)

               SEPoct      OCT         Nov       NOVdec
     APR3       0.26        0.22        0.19       0.18
     APRmay     0.28        0.22        0.19       0.18
     MAY1       0.26        0.24        0.20       0.19
     MAY2       0.28        0.26        0.21       0.19
     MAY3       0.00        0.24        0.23       0.20
     MAY4       0.00        0.27        0.26       0.22
     MAYJ       0.00        0.00        0.00       0.23;

SCALAR
     MOISTSTAN  Dry corn moisture standard  /0.155/;

TABLE  sYLD1(PRODUCT,PrCrop,Crop,Prac,state)   Expected crop yields (kg per
hectare)

                             1          2          3          4          5
 CORN   . CO.CO.high      7833.5    10518.5   11034.25   12800.5    11930.5
 CORN   . BN.CO.high      7905.25   10517     10966.5    12798.75   11929
 CORN   . PO.CO.high      7833.5    10519.00  10966.00   12807.75   11929.25
 SEED   . SC.SC.high      4614.00    5257.75   5679.25    5943.25    6069.75
 SEED   . BN.SC.high      4604.00    5250.50   5667.50    5929.75    6060.00
 SEED   . PO.SC.high      4627.75    5250.25   5667.25    5958.25    6060.50
 CORN   . CO.CO.medium    7762.75   10491.25  10916      12700.5    11921
 CORN   . BN.CO.medium    7823.5    10497.75  10945.5    12766.5    11917
 CORN   . PO.CO.medium    7900.25   10501.50  10927.50   12789.50   11917.50
 SEED   . SC.SC.medium    4601.75    5225.75   5644.00    5917.75    6058.00
 SEED   . BN.SC.medium    4615.50    5224.75   5632.00    5896.75    6043.50
 SEED   . PO.SC.medium    4616.00    5218.50   5629.75    5930.00    6044.50
 CORN   . CO.CO.low       7712.75   10431.75  10774.5    12526.25   11817.75
 CORN   . BN.CO.low       7762.25   10421.25  10827.50   12631.75   11869.75
 CORN   . PO.CO.low       7837.0    10375.50  10749.75   12623.75   11870.50
 SEED   . SC.SC.low       4578.50    5176.75  5510.75     5827.25    6029.00
 SEED   . BN.SC.low       4577.00    5189.25   5585.50    5823.00    6016.75
 SEED   . PO.SC.low       4581.50    5177.00   5510.00    5885.50    6021.50
 BEAN   . SC.BN.nna       2686.50    3137.25   3278.50    3331.50    3143.50
 BEAN   . CO.BN.nna       2682.75    3128.25   3272.00    3321.25    3130.50
 POTATO. CO.PO.nna          1.0        1.0        1.0        1.0        1.0
 POTATO. SC.PO.nna          1.0        1.0        1.0        1.0        1.0

+
                             6          7          8          9         10
 CORN   . CO.CO.high     11747      12347      13476.5    13222.5    13531.51
 CORN   . BN.CO.high     11749.75   12347.5    13473.25   13262.25   13584.75
 CORN   . PO.CO.high     11747.00   12347.00   13475.75   13112.75   13449.70
 SEED   . SC.SC.high      6336.25    6541.75    6737.75    6845.00    7161.50
 SEED   . BN.SC.high      6344.25    6531.00    6714.50    6830.00    7154.25
 SEED   . PO.SC.high      6338.00    6533.00    6721.50    6827.75    7160.25
 CORN   . CO.CO.medium   11730.25   12338      13338.25   13116.25   13446.25
 CORN   . BN.CO.medium   11740.75   12337.75   13441      13168.25   13489
 CORN   . PO.CO.medium   11908.25   12341.00   13139.00   12998.50   13383.75
 SEED   . SC.SC.medium    6308.50    6529.00    6720.00    6833.00    7140.75
 SEED   . BN.SC.medium    6307.75    6517.75    6684.75    6808.00    7130.75
 SEED   . PO.SC.medium    6314.00    6519.50    6696.75    6803.00    7139.75
 CORN   . CO.CO.low      11687.75   12301.5    12844.5    12920.25   13195
 CORN   . BN.CO.low      11688.50   12313.50   13109.00   13029.25   13328.50
 CORN   . PO.CO.low      11737.00   12316.75   12781.25   12713.00   13077.25
 SEED   . SC.SC.low       6264.00    6503.75    6681.00    6799.50    7100.75
 SEED   . BN.SC.low       6268.75    6497.50    6640.50    6771.00    7095.25
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 SEED   . PO.SC.low        6274.50   6501.00    6658.25   6758.00    7109.00
 BEAN   . SC.BN.nna        3070.75   3172.25    3209.75   3164.00    3196.75
 BEAN   . CO.BN.nna        3075.25   3168.25    3190.00   3145.00    3192.25
 POTATO. CO.PO.nna           1.0       1.0        1.0       1.0        1.0
 POTATO. SC.PO.nna           1.0       1.0        1.0       1.0        1.0 ;

parameters
  sYLD(PRODUCT,PrCrop,Crop,Prac,state) Converted yield (bushels per acre);
  sYLD('corn',PrCrop,Crop,Prac,state)=sYLD1('corn',Prcrop,crop,Prac,state)/62.71
;
  sYLD('seed',PrCrop,Crop,Prac,state)=0.80*sYLD1('seed',PrCrop,Crop,Prac,state)/
62.71;
*  sYLD('corn','co','co',Prac,state)=sYLD('corn','co','co',Prac,state)*0.98;
*  sYLD('seed','sc','sc',Prac,state)=sYLD('seed','sc','sc',Prac,state)*0.98;
  sYLD('bean',PrCrop,Crop,Prac,state)=sYLD1('bean',PrCrop,Crop,Prac,state)/67.19
;
  sYLD('potato',PrCrop,Crop,Prac,state)=sYLD1('potato',PrCrop,Crop,Prac,state);

display syld;

* The above yields must be the best yields obtained when planting and
*      harvesting activities occur at their optimum times.

PARAMETERS
  YLD(PRODUCT,PrCrop,Crop,Prac) Average crop yields;
  YLD(PRODUCT,PrCrop,Crop,Prac)
      = sum(state,sYLD(PRODUCT,PrCrop,Crop,Prac,state))/(card(state));
Display yld;

** MEAN YIELD

PARAMETERS
  d1(PRODUCT,PrCrop,Crop,Prac,state) Deviation from average crop yields;
  d1(PRODUCT,PrCrop,Crop,Prac,state)
      = sYLD(PRODUCT,PrCrop,Crop,Prac,state)-YLD(PRODUCT,PrCrop,Crop,Prac);

** DEVIATION FROM MEAN YIELD

PARAMETERS
  vYLD(PRODUCT,PrCrop,Crop,Prac,prod1,prc1,cr1,prac1) var-covariance of crop
yields;
  vYLD(PRODUCT,PrCrop,Crop,Prac,prod1,prc1,cr1,prac1)
   = sum(state,d1(PRODUCT,PrCrop,Crop,Prac,state)*
     d1(PROD1,PrC1,Cr1,Prac1,state))/(card(state)-1);
Display vyld;

PARAMETERS
  YIELD(PRODUCT,PrCrop,Crop,Prac,Per,HPer) Adjusted crop yields;
  YIELD(PRODUCT,PrCrop,Crop,Prac,PPer,HPer)
       = YLD(PRODUCT,PrCrop,Crop,Prac)*PERCYLD(Crop,PPer,HPer);

*   The above statement adjusts crop yields with respect to planting and
*   harvesting dates which are different from optimum dates

TABLE NLS(PRODUCT,PrCrop,Crop,Prac,state)Expected nitrate leaching (kg per ha)

                              1          2          3          4          5
 CORN   . CO.CO.high        18.50      17.75      25.25      28.25      25.25
 CORN   . BN.CO.high        20.75      24.75      27.75      32.00      28.00
 CORN   . PO.CO.high        55.50      52.25      46.75      57.50      64.00
 SEED   . SC.SC.high        21.00      22.25      27.25      34.50      32.50
 SEED   . BN.SC.high        20.75      26.00      27.50      33.25      32.25
 SEED   . PO.SC.high        53.25      51.75      44.75      56.50      69.75
 CORN   . CO.CO.medium      15.75      16.00      23.00      25.75      23.25
 CORN   . BN.CO.medium      18.75      23.50      26.00      30.25      26.75
 CORN   . PO.CO.medium      52.25      50.00      44.75      55.00      61.00
 SEED   . SC.SC.medium      18.00      18.75      24.25      30.25      28.75
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 SEED   . BN.SC.medium    19.25       25.25       26.00       32.00        30.50
 SEED   . PO.SC.medium    52.00       50.00       44.00       54.75        65.50
 CORN   . CO.CO.low       13.00       14.00       20.25       23.00        20.50
 CORN   . BN.CO.low       20.25       22.50       24.75       28.75        25.75
 CORN   . PO.CO.low       49.00       48.50       42.50       52.25        58.25
 SEED   . SC.SC.low       15.50       17.00       21.50       27.00        25.75
 SEED   . BN.SC.low       21.75       24.50       25.25       30.50        29.75
 SEED   . PO.SC.low       51.50       50.25       43.25       54.75        63.50
 BEAN   . SC.BN.nna       16.25       23.00       24.00       35.25        30.25
 BEAN   . CO.BN.nna       15.50       21.25       23.25       32.75        29.00
 POTATO. CO.PO.nna        89.75      116.00      184.50      184.25       133.25
 POTATO. SC.PO.nna        87.25      117.75      186.00      186.75       133.25

+
                           6           7           8           9          10
 CORN   . CO.CO.high     20.25       29.25       24.25       25.75       23.25
 CORN   . BN.CO.high     24.25       30.50       27.00       28.75       27.00
 CORN   . PO.CO.high     40.75       67.00       71.50       56.25       63.25
 SEED   . SC.SC.high     20.75       35.50       30.25       31.50       29.50
 SEED   . BN.SC.high     24.25       32.50       29.50       30.00       30.25
 SEED   . PO.SC.high     40.50       71.25       72.25       55.75       64.75
 CORN   . CO.CO.medium   17.75       25.50       21.50       23.25       21.00
 CORN   . BN.CO.medium   23.50       29.25       25.75       27.50       26.50
 CORN   . PO.CO.medium   39.50       64.00       68.50       53.50       62.25
 SEED   . SC.SC.medium   19.75       30.00       26.75       27.00       25.75
 SEED   . BN.SC.medium   24.00       30.75       28.50       28.75       29.25
 SEED   . PO.SC.medium   39.25       67.25       68.75       55.00       63.25
 CORN   . CO.CO.low      16.75       23.00       19.25       20.25       18.75
 CORN   . BN.CO.low      22.75       28.00       25.00       26.25       25.75
 CORN   . PO.CO.low      38.25       60.25       66.75       51.00       62.00
 SEED   . SC.SC.low      18.75       26.50       23.50       24.00       23.00
 SEED   . BN.SC.low      23.50       30.00       27.75       28.50       28.00
 SEED   . PO.SC.low      39.00       64.25       68.25       53.75       62.00
 BEAN   . SC.BN.nna      18.00       30.00       28.00       27.50       27.25
 BEAN   . CO.BN.nna      17.25       29.00       26.75       25.75       26.00
 POTATO. CO.PO.nna       82.00      175.25      154.25      108.75      122.50
 POTATO. SC.PO.nna       82.50      117.50      149.75      110.00      125.75 ;

* Source: simulation data from DSSAT 3.0

PARAMETERS
  NLL(PRODUCT,PrCrop,Crop,Prac,state) crops' nitrate leaching (lbs per acre);
  NLL(PRODUCT,PrCrop,Crop,Prac,state)
      = NLS(PRODUCT,PrCrop,Crop,Prac,state)/1.12;
  NLL('seed',PrCrop,'sc',Prac,state)
      = (0.8*NLS('seed',PrCrop,'sc',Prac,state)+
         0.2*(29.1248+1.87447*NLS('seed',PrCrop,'sc',Prac,state)))/1.12;
display NLL;

PARAMETERS
  NLA(PRODUCT,PrCrop,Crop,Prac) mean nitrate leaching (kg per ha);
  NLA(PRODUCT,PrCrop,Crop,Prac)
      = sum(state,NLL(PRODUCT,PrCrop,Crop,Prac,state))/(card(state));
  NLA('seed',PrCrop,'sc',Prac)
      = sum(state,NLL('seed',PrCrop,'sc',Prac,state))/(card(state));
Display NLA;


*%%%%%%%%%%%%%%%%%%%%%%%%%    ECONOMIC DATA  %%%%%%%%%%%%%%%%%%%%%%%%

PARAMETERS
  PRICE(PRODUCT) Commodity market prices  (dollars per bushel)
    / CORN 2.40, SEED 5.28, BEAN  6.00, POTATO 235 /
  Truck(product) trucking cost (dollars per bushel)
    / corn 0.15, seed 0.08, bean 0.15/

Scalars
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  RENTLAND  rental price for land  (dollars per acre)  /165/
  DRYCOST   Corn drying cost per pct. moisture ($ per point per bu) /0.025/
*           including storage cost
  NITCOST   Nitrogen cost per pound (dollars)           /0.25/
  WAGE      Market wage (dollars per hour)              /7.5/
  avgyld    hybrid average yield                        /66.56/
  byld      plant base yield                            /190/
  alpha     variety convert factor                      /2.0/
  beta      premium factor                              /1.1/
  RSCMC     seed conditioning plus marketing costs over income /0.40/
  WPS       wholesale price of a 80000 kernel bag seed corn    /71.5/

TABLE  COSTS(PrCrop,Crop,Items) Itemized costs by crop
            FERTIL   herb    insect     SEED    IRRIG      OTHER
  CO.CO      33.10   20.35   16.30      26.88    24.00      39.49
  BN.CO      33.10   20.35    3.25      26.88    24.00      37.99
  PO.CO      25.30   20.35    3.25      26.88    24.00      39.67
  SC.SC      29.04   20.35   10.75      20.00    24.00      32.42
  BN.SC      29.04   20.35    0.00      20.0     24.00      30.92
  PO.SC      21.70   20.35    0.00      20.0     24.00      32.60
  CO.BN      16.50   26.63    0.00      13.20     0.00      26.16
  SC.BN      16.50   26.63    0.00      13.20     0.00      26.16
  CO.PO      10.00    0.00    0.00       0.00    28.00       4.32
  SC.PO      10.00    0.00    0.00       0.00    28.00       4.32;

**Fertil: P($0.25/lb)+ K($0.13/lb) + Lime($20/ton)
*    CO: 30 lbs (P), 120 lbs (K), 0.5 ton (Lime); for PO.CO 60lbs (K)
*    SC: 18 lbs (P), 113 lbs (K), 0.5 ton (Lime)
*    BN:             50 lbs (K), 0.5 ton (Lime)
*    PO:                         0.5 ton (Lime)
*
**Seed: Corn: 28 K  @$0.96
*   Soybean:  60 lbs@$0.22
**Seed corn: $20/A license fee
**Other: variable cost from machinery operation
**Source : 1995 Crops and Livestock Budgets Estimates for Michigan (Nott et al.
1995)
**         and Rod King.

PARAMETER
   P_HCOST(PrCrop,Crop,Prac)  Planting PostPlanting and Harvesting costs ;
   P_HCOST(PrCrop,Crop,Prac) = Sum(Items, Costs(PrCrop,Crop,Items))
            + NFER(PrCrop,Crop,Prac)*nitcost;
Display yld,price,p_hcost ;

*%%%%%%%%%%%%%%%%%%%%%%   Alternative contract terms  %%%%%%%%%%%%%%%%%%%%%
Scalars
** Impose a Restriction **
  maxn    maximum allowed nitrogen (lbs per acre)       /150/
  maxnl   maximum allowed nitrate leaching for seed corn (lbs@acre)      /100/
  maxwnl  maximum allowed nitrate leaching for the whole-farm (lbs@acre) /100/
  rindex  restriction on rotation with potato (one--yes) /0/
** Charge a Fee **
  MAXNF   nitrogen without user charge (lb@acre)        /90/
  MAXNLF  nitrate leaching without fee (lbs@acre)       /30/
  nfee    user charge on nitrogen use ($ per ac)        /0/
  nlfee   user charge on nitrate leaching ($ per ac)    /0/
  scale   scale that changes the variable payment       /1/;

scalars
  FIXPAY  fixed payment for seed corn contract (dollars per acre) ;
  fixpay = (byld - alpha*avgyld)*beta*price("corn")+
          price('corn')*alpha*beta*(1-scale)*yld('seed','sc','sc','medium');

scalars
  VARPAY  variable payment for seed corn contract (dollars per bushel) ;
  VARPAY =price('corn')*alpha*beta*scale;
```

```
 Price('seed')=price('corn')*alpha*beta*scale;

Display fixpay, varpay;

Parameter
   Feel(PrCrop,Crop,Prac)  financial charge on nitrogen use or nitrate leaching;
   Feel(prcrop,'sc',prac) = max(0,NFER(PrCrop,'sc',Prac)-maxnf)*nfee
                         + max(0,NLA('seed',PrCrop,'sc',Prac)-maxnlf)*nlfee;
display feel;

Parameter
   rr(PrCrop,Crop,Prac)  index of restriction on rotation with potato;
   rr('po','sc',prac)=rindex;

Parameter
   Punish(PrCrop,Crop,Prac)  Violation of contraint on contracts;
   Punish(prcrop,'sc',prac) = max(NFER(PrCrop,'sc',Prac)-maxn,0)*100000
                       + rr(prcrop,'sc',prac)*100000;

Parameter
   Fee(PrCrop,Crop,Prac) Financial charge on nitrogen use or nitrate leaching;
   Fee(PrCrop,'sc',Prac)=Feel(PrCrop,'sc',Prac)+Punish(PrCrop,'sc',Prac);

*%%%%%%%%%%%%    MISCELLANEOUS  DATA  %%%%%%

Table PracYes(Crop,Prac) Flag parameter for production practices
     HIGH    MEDIUM    LOW    NNA
  CO   1        1       1      0
  SC   1        1       1      0
  BN   0        0       0      1
  PO   0        0       0      1;

Table  RotYes(PrCrop,Crop)  Flag parameter for rotation
               CO    SC    BN    PO
  CO           1     0     1     1
  SC           0     1     1     1
  BN           1     1     0     0
  PO           1     1     0     0;

PARAMETER
  ACTYES(PRCROP,CROP,PRAC,PER,PERIOD) Flag parameter for planting variables ;

* This parameter shows whether each planting variable (by crop, by time of
* planting and harvesting) is included in the model. 1 means the activity
* is included, else it is not included.

ActYes(PrCrop,Crop,Prac,Per,Period)$(PercYld(Crop,Per,Period)$PPer(Per)
 $HPer(Period)$PracYes(Crop,Prac)$RotYes(PrCrop,Crop))=1;
Display ACTYES;

PARAMETER  PREPYES(Crop,Per)  Flag parameter for land preparation;
        PREPYES(Crop,Per)=1$(ORD(Per) LE LASTPLANT(Crop));

PARAMETER  POSTYES(Crop,Per,Period)  Flag parameter for postpl activities;
   POSTYES(Crop,Per,Period) = 1$((ORD(Per) GE FIRSTPLANT(Crop))
   AND (ORD(Period) GE ORD(Per)+POSTLAG(Crop))
   AND (ORD(Period) LE ORD(Per)+POSTLAG(Crop)+POSTTIME(Crop)-1)
   AND (ORD(Per) LE LASTPLANT(Crop)));
POSTYES(CROP,PER,PERIOD)$(NOT POSTLAG(CROP))= 0;
NOPER(PER) = YES ;
NOPER(PER)$PPER(PER)   = NO ;
NOPER(PER)$PLPER(PER) = NO ;
NOPER(PER)$HPER(PER)   = NO ;
NOPER(PER)$(ORD(PER) LE
  SMAX((CROP),POSTLAG(CROP)+POSTTIME(CROP)+LASTPLANT(CROP)-1)) = NO ;
DISPLAY NOPER,prepyes,postyes ;
```

```
PARAMETERS
  vpYLD(PRODUCT,PrCrop,Crop,Prac,PROD1,PrC1,Cr1,Prac1) Adjusted crop yields;
  vpYLD(PRODUCT,PrCrop,Crop,Prac,PROD1,PrC1,Cr1,Prac1)$(pracYes(Crop,Prac) and
  rotYes(prcrop,crop) and pracYes(Cr1,Prac1) and rotYes(prc1,cr1))
   = price(product)*
     vYLD(PRODUCT,PrCrop,Crop,Prac,PROD1,PrC1,Cr1,Prac1)*price(prod1);



*%%%%%%%%%%       MODEL       %%%%%%%%%%%%
 VARIABLE
   EU         Expected utility funtion (maximize);

 POSITIVE VARIABLES
   NETREV                        Expected net revenue
   NETGM                         Expected net gross margin of the processor
   TNL                           Total amount of nitrate leaching from whole
farm
   TSNL(crop)                    Total amount of nitrate leaching from seed corn
   TSYLD(crop)                   Total amount of seed corn yield
   PLOW(Prcrop,Crop,Per)         Plowing activity after crop
   PREP(Crop,Per)                Prep done in PERIOD for crop planted per
   POST(prcrop,Crop,Per,Period)  Postplanting done in period planted per
   ACRE(PrCrop,Crop,Prac,Per,Period)  Acreage of each cropping activity (acres)
   RLAND                              Rented land (acres)
   LABHIRE(Per)                       Seasonal hired labor (hrs)
   yy(product,crop,state)         Deviation of seed corn yield
   ety(product,crop)              Endogeneous target yield level
   y(product,crop,state)         Deviation of nitrate leaching
   et(product,crop)              Endogeneous target leaching level;
**  y & et are transfer columns
   PLOW.up(Prcrop,Crop,Per)          = 10000 ;
   PREP.up(Crop,Per)                 = 10000 ;
   POST.up(prcrop,Crop,Per,Period)   = 10000 ;
   ACRE.up(PrCrop,Crop,Prac,Per,Period) = 10000 ;
   RLAND.up                          = 10000 ;
   LABHIRE.up(Per)                   = 10000 ;

 EQUATIONS
     OBJECTIVE                 Objective function
     NETREVE                   Expected net revenue
     GME                       Gross margin of the processor
     TNLE                      Total nitrate leaching from the whole farm
     TSNLE(crop)               Total amount of nitrate leaching from seed corn
     TSYLDE(crop)              Total seed corn yield
     LAND                      Land availability constraints
     SEEDL(crop)               Seed corn contract availability constraints
     PLOWFALL(Crop)            Land plowed in the Fall
     ROTATE(prCrop,crop)       Crop Rotation constraint
     LABOR(Per)                Total labor use accounting
     TRACTR(Per)               Tractor power constraints in planting seasons
     EQUIPCON(Equip,Per)       Farm equipment constraint
     PREPPLANT(Crop,Period)    Land prepared for planting
     PLANTPOST(Crop,Per)       Land cultivated after planting
     HARVEST(Per)              Combine harvester constraint in harvest seasons
     HARVPLOW(per,Crop)        Harvesting and plowing sequencing constraint
     PLOWACRE(Crop,PrCrop)     Make number of acres of plowing equal cropping
     varsy(product,crop,state)   variation of seed corn yield
     chancey(product,crop)      chanced contraint for seed corn contract loss
     vars(product,crop,state)   variation of seed corn leaching
     chance(product,crop)      chanced contraint for seed corn leaching
     tsnlup(crop)              maximum allowed nitrate leaching
     twnlup                    maximum allowed nitrate leaching;

OBJECTIVE..

   EU =E= Sum(Product,Sum((PrCrop,Crop,Prac,Per,HPer)
```

```
     $ActYes(PrCrop,Crop,Prac,Per,HPer),
     Yield(Product,PrCrop,Crop,Prac,Per,HPer)*
     ACRE(PrCrop,Crop,Prac,Per,HPer)*(Price(Product)-truck(product))))
    +sum((prcrop,Prac,pper,hper)$ActYes(PrCrop,'sc',Prac,PPer,HPer),
     (fixpay-Fee(PrCrop,'sc',Prac))*acre(prcrop,"sc",Prac,pper,hper))
    -Sum((PrCrop,Crop,Prac,Per,HPer)$ActYes(PrCrop,Crop,Prac,Per,HPer),
     (P_HCost(prcrop,Crop,Prac)+
     DryCost*Max(MOIST(PER,HPER)-MOISTSTAN,0)
     *100*Yield("corn",PrCrop,Crop,Prac,Per,HPer))*
     ACRE(PrCrop,Crop,Prac,Per,HPer))
     -Sum(per,wage*LABHIRE(Per))-rland*rentland
*     - (0.00005/2)*sum((product,PrCrop,Crop,Prac,Per,HPer),
*     (ACRE(PrCrop,Crop,Prac,Per,HPer)$ActYes(PrCrop,Crop,Prac,Per,HPer))*
*     sum((prodl,PrCl,Crl,Pracl,Perl,HPerl),
*     (ACRE(PrCl,Crl,Pracl,Perl,HPerl)$ActYes(PrCl,Crl,Pracl,Perl,HPerl))*
*     vpYLD(PRODUCT,PrCrop,Crop,Prac,prodl,prcl,crl,pracl)))
     ;
*    RISK CALCULATION

NETREVE..

    NETREV =E= Sum(Product,Sum((PrCrop,Crop,Prac,Per,HPer)
     $ActYes(PrCrop,Crop,Prac,Per,HPer),
     Yield(Product,PrCrop,Crop,Prac,Per,HPer)*
     ACRE(PrCrop,Crop,Prac,Per,HPer)*(Price(Product)-truck(product))))
    +sum((prcrop,Prac,pper,hper)$ActYes(PrCrop,'sc',Prac,PPer,HPer),
     (fixpay-Fee(PrCrop,'sc',Prac))*acre(prcrop,"sc",Prac,pper,hper))
    -Sum((PrCrop,Crop,Prac,Per,HPer)$ActYes(PrCrop,Crop,Prac,Per,HPer),
     (P_HCost(prcrop,Crop,Prac)+
     DryCost*Max(MOIST(PER,HPER)-MOISTSTAN,0)
     *100*Yield("corn",PrCrop,Crop,Prac,Per,HPer))*
     ACRE(PrCrop,Crop,Prac,Per,HPer))
     -Sum(per,wage*LABHIRE(Per))-rland*rentland;

GME..
    NETGM =E=    Sum((PrCrop,Prac,Per,HPer)$ActYes(PrCrop,'SC',Prac,Per,HPer),
     ACRE(PrCrop,"SC",Prac,Per,HPer)*
     ((WPS*(1-RSCMC)-VARPAY)*Yield("SEED",PrCrop,'SC',Prac,Per,HPer)-FIXPAY
     +Feel(PrCrop,'sc',Prac)));


TNLE..

    TNL =E= Sum(Product,Sum((PrCrop,Crop,Prac,Per,HPer)
     $ActYes(PrCrop,Crop,Prac,Per,HPer),
     NLA(Product,PrCrop,Crop,Prac)*
     ACRE(PrCrop,Crop,Prac,Per,HPer)));

TSNLE('sc')..

    TSNL('sc') =E= Sum(Product,Sum((PrCrop,Prac,Per,HPer),
     NLA(Product,PrCrop,'sc',Prac)*
     ACRE(PrCrop,'sc',Prac,Per,HPer)
      $ActYes(PrCrop,'sc',Prac,Per,HPer)));

TSYLDE('sc')..

    TSYLD('sc') =E= Sum(Product,Sum((PrCrop,Prac,Per,HPer),
     YLD(Product,PrCrop,'sc',Prac)*
     ACRE(PrCrop,'sc',Prac,Per,HPer)
      $ActYes(PrCrop,'sc',Prac,Per,HPer)));

LAND..

  Sum((PrCrop,Crop,Prac,Per,HPer)$ActYes(PrCrop,Crop,Prac,Per,HPer),
     ACRE(PrCrop,Crop,Prac,Per,HPer)) =L= LandRhs+rland;
```

```
SEEDL("sc")..

   Sum((PrCrop,Prac,Per,HPer)$ActYes(PrCrop,'SC',Prac,Per,HPer),
    ACRE(PrCrop,"SC",Prac,Per,HPer)) =L= MAXSEED;

ROTATE(PrCrop,Crop)$rotyes(PrCrop,Crop)..

   Sum((Prac,Per,Period),ACRE(PrCrop,Crop,Prac,Per,Period)
       $ActYes(PrCrop,Crop,Pra c,Per,Period))
    =E=Sum((Prac,Per,Period),ACRE(Crop,PrCrop,Prac,Per,Period)
       $ActYes(Crop,PrCrop,Pra c,Per,Period));

PLOWFALL(Crop)..


Sum((Prcrop,PlPer)$rotyes(prcrop,crop),PLOW(Prcrop,Crop,PlPer))
    =G=Sum(Per,PREP(Crop,Per)$PREPYES(Crop,Per));

PREPPLANT(Crop,Period)$prepyes(crop,period)..

   Sum(Per$(ORD(Per) LE ORD(Period)),PREP(Crop,Per)$PREPYES(Crop,Per))
    =G= Sum(Per$(ORD(Per) LE ORD(Period)),
    Sum((PrCrop,Prac,HPer),
    ACRE(PrCrop,Crop,Prac,Per,HPer)$ActYes(PrCrop,Crop,Prac,Per,HPer))) ;

PLANTPOST(Crop,Per)$(SMAX((HPer,PrCrop,Prac), ActYes(PrCrop,Crop,Prac,Per,HPer))
           AND POSTLAG(CROP))..

   Sum(PERIOD$((ORD(PERIOD) GE ORD(PER)+POSTLAG(Crop))
    AND(ORD(PERIOD) LE ORD(PER)+POSTLAG(Crop)+POSTTIME(Crop)-1)),
   sum(prcrop,POST(prcrop,Crop,Per,Period)
       $(POSTYES(Crop,Per,Period)$rotyes(prcro p,crop))))
    =E=Sum((PrCrop,Prac,HPer),
       ACRE(PrCrop,Crop,Prac,Per,HPer)$ActYes(PrCrop,Crop,Prac,Per,HPer)) ;

HARVPLOW(per,Crop)$PlPer(Per)..

   Sum(Period$((ORD(Period) LE ORD(Per))$HPer(Period)),
    Sum((PrCrop,Prac,PPer),
       ACRE(Crop,PrCrop,Prac,PPer,Period)
       $ActYes(Crop,PrCrop,Prac,PPer,Period)))
    =G=Sum((Period,Prcrop)$((ord(Period) le ord(Per))$PlPer(Period)),
       PLOW(Prcrop,Crop,Period)$rotyes(prcrop,crop));

LABOR(Per)$(NOT NOPER(Per)) ..

Sum((PrCrop,Crop,Prac,HPer)$ActYes(PrCrop,Crop,Prac,Per,HPer),
    PltLab(Crop)*ACRE(PrCrop,Crop,Prac,Per,HPer))+
    Sum((Crop),PREPLAB(Crop)*PREP(Crop,Per)$PREPYES(Crop,Per))
    +Sum((prcrop,Crop,Period)$rotyes(prcrop,crop),
    Post(prcrop,Crop,Period,Per)*Postlab(prcrop,Crop)
    $POSTYES(Crop,Period,Per))
    +Sum((Crop,PrCrop)$rotyes(crop,prcrop),
    PlowLab(crop,prcrop)*PLOW(Crop,prCrop,Per)$(PlPer(Per)))+
    Sum((PrCrop,Crop,Prac,PPer)$ActYes(PrCrop,Crop,Prac,PPer,Per),
    HavLab(Crop)*ACRE(PrCrop,Crop,Prac,PPer,Per))
    =L= LABHIRE(Per) + FARMER(PER)*HRSPERDAY*DAYS(PER) ;

TRACTR(Per)$(NOT NOPER(Per)) ..

   Sum((PrCrop,Crop,Prac,HPer)$ActYes(PrCrop,Crop,Prac,Per,HPer),
    PltTrac(Crop)*ACRE(PrCrop,Crop,Prac,Per,HPer))+
    Sum((Crop),PrepTrac(Crop)*PREP(Crop,Per)$PREPYES(Crop,Per))
    +Sum((prcrop,Crop,Period),
    Post(prcrop,Crop,Period,Per)*PostTrac(prcrop,Crop)$POSTYES(Crop,Period,Per))
    +Sum((Crop,PrCrop),
    PlowTrac(crop,prCrop)*PLOW(Crop,PrCrop,Per)$(PlPer(Per)))
```

```
   + Sum((PrCrop,Crop,Prac,PPer)$ActYes(PrCrop,Crop,Prac,PPer,Per),
    HavTrac(Crop)*ACRE(PrCrop,Crop,Prac,PPer,Per))
    =L= Tractor*HRSPERDAY*DAYS(PER) ;

EQUIPCON(EQUIP,PER)..

Sum((Crop)$EPREP(EQUIP),PREQUIP(Crop,Equip)*PREP(Crop,Per)$PREPYES(Crop,Per))
    +Sum((Prcrop,Crop,Prac,HPer)$EPLANT(EQUIP),PLANTeq(crop,equip)*
    ACRE(PrCrop,Crop,Prac,Per,HPer)$ActYes(PrCrop,Crop,Prac,Per,HPer))
    +Sum((Prcrop,Crop)$EPLOW(EQUIP),PLEQUIP(Prcrop,crop,Equip)*
    Plow(Prcrop,Crop,Per)$(Plper(Per)))
    +Sum((prcrop,Crop,Period)$EPOST(EQUIP),POSTEQUIP(prcrop,CROP,EQUIP)*
       POST(prcrop,Crop,Period,Per)$POSTYES(Crop,Period,Per))
    =L= (HrsPerDay$(NOT Eplant(Equip))+HrsPerDayP$Eplant(Equip))*DAYS(PER) ;

HARVEST(HPer)..


Sum((PrCrop,Crop,Prac,PPer)$ActYes(PrCrop,Crop,Prac,PPer,HPer),
    Comb(Crop)*ACRE(PrCrop,Crop,Prac,PPer,HPer)) =L= CombRhs(HPer);

PLOWACRE(Crop,PrCrop)$rotyes(prcrop,crop)..
    Sum(PlPer,PLOW(prcrop,Crop,PlPer))
     =E= sum((Prac,PPer,HPer)$ActYes(PrCrop,Crop,Prac,PPer,HPer),
           ACRE(PrCrop,Crop,Prac,PPer,HPer)) ;

varsy("seed","sc",state)..

   Sum((prcrop,prac,per,HPer),(syld("seed",prcrop,"sc",prac,state)
   $(pracYes('sc',prac) and rotyes(prcrop,'sc')))*
   ACRE(PrCrop,"SC",Prac,Per,HPer)$ActYes(PrCrop,"sc",Prac,Per,HPer))
  -ety("seed","sc")
  +yy("seed","sc",state)
   =g= 0;

** the following four equations are used to set up chance constraints
** for contract loss risk and for nitrate leaching abatement
** Reference: Atwood et al. (Western Journal of Agr. Econ. 1988)

chancey("seed","sc")..

   ety("seed","sc")
   -10/5*sum(state,yy("seed","sc",state)*(1/card(state)))
   -70*Sum((prcrop,prac,per,HPer),
   ACRE(PrCrop,"SC",Prac,Per,HPer)$ActYes(PrCrop,"sc",Prac,Per,HPer))
   =g=0;

vars("seed","sc",state)..

   Sum((prcrop,prac,per,HPer),(45-NLL("seed",prcrop,"sc",prac,state)
     $(pracYes('sc ',prac) and rotyes(prcrop,'sc')))*
     ACRE(PrCrop,"SC",Prac,Per,HPer)$ActYes(PrCrop,"sc",Prac,Per,HPer))
   -et("seed","sc")
   +y("seed","sc",state)
   =g= 0;

chance("seed","sc")..

   et("seed","sc")
   -5*sum(state,y("seed","sc",state)*(1/card(state)))
   =g= 0;

tsnlup('sc')..
   tsnl('sc') =l= sum((prcrop,prac,per,hper),maxnl*
             acre(prcrop,'sc',prac,per,hper)$ActYes(PrCrop,"sc",Prac,Per,HPer));
*  maximum amount of nitrate leaching from growing seed corn
```

```
twnlup..
   tnl =l= sum((prcrop,crop,prac,per,hper),maxwnl*
              acre(prcrop,crop,prac,per,hper)$ActYes(PrCrop,crop,Prac,Per,HPer));
*  maximum amount of nitrate leaching from growing whole-farm operation


LABHIRE.UP(Per) = maxhire(Per);
RLAND.UP = MAXLAND;


MODEL MICHIGAN
/    OBJECTIVE
     NETREVE
     GME
     TNLE
     TSNLE
     TSYLDE
     LAND
     SEEDL
     PLOWFALL
     ROTATE
     LABOR
     TRACTR
     EQUIPCON
     PREPPLANT
     PLANTPOST
     HARVEST
     HARVPLOW
     PLOWACRE
     tsnlup
     twnlup
     varsy
     chancey
     vars
     chance
     /;

*  OPTION SOLPRINT = OFF;

SOLVE  MICHIGAN MAXIMIZING EU USING NLP;
```

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