Agricultural Production Contracts to Reduce Nitrate Leaching : A Whole-Farm Analysis*

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Ten alternative seed corn contract specifications are evaluated with respect to nitrate leaching and profitability for the processor firm (principal) and contracted grower (agent). A whole-farm optimization and feasibility analysis suggest that contract terms can be used to reduce non-point source pollution.

Keywords: *whole-farm analysis, seed corn, nitrate leaching, nonpoint source pollution, agricultural production contracts, linear programming*

1. Introduction

The growth of contracted agricultural production in the United States is

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well recognized (Drabenstott, 1994). These trends are most evident in poultry, hogs, vegetables, fruits and some grains, such as seed corn. Contracts can specify product quality aspects, production practices, delivery dates and quantities, as well as prices. Because of these contract attributes, and because there tend to be many more contracted producers than contractors, it is possible that contracts could serve as vehicles to obtain higher environmental quality. In response to regulatory mandates, contracts could potentially specify the use of environmentally protecting practices or performance outcomes. However, a more voluntary approach to obtaining environmental protection using contracts requires additional analysis as to the magnitude and incidence of the opportunity costs of such contract redesign. This research will examine how to design seed corn contracts that can reduce nitrate leaching as a case study.

Nitrate is one of the most commonly seen nonpoint source water pollutants in the US (Kellogg et al. 1992), and agricultural activities are increasingly being held responsible for contributing it to groundwater (Follett, et al., 1991). It is a highly mobile nitrogen form that can be leached through the crop root zone and eventually into the groundwater. Nitrate concentrations can affect both surface water (eutrophication) and groundwater. The major potential health risks from excess nitrate in drinking water is clinical infant methemoglobinemia or "blue baby syndrome", where nitrate blocks the blood circulation. Other potential impact is reducing reproductivity (Fan et al., 1987; CAST, 1985; Keeney, 1986).

This paper explores the use of contract redesign to reduce non-point source pollution (NPSP) —specifically, nitrate leaching — by examining a case study of seed corn contracts in southwestern Michigan. The objective of the paper is to examine seed corn contract specifications which would induce a representative profit-maximizing contract grower to reduce voluntarily the nitrate leaching from seed corn production. Seed corn production is a useful case because price premiums are paid to encourage contracted growers to produce high yields, and one way to do this is to fertilize heavily, which can lead to excess nitrogen leaching or runoff.

2. A Principal–Agent Model

Chu et al. (1995) have shown that a principal-agent framework can be adapted to contracts between an agricultural processor (the principal) and a contracted grower (the agent) to reduce NPSP. 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):

$$\begin{aligned} & \underset{s}{Max} && E\{G[y - s(y)]\}, \\ & subject\ to && E\{U[s(y), n]\} \geq U_A^0 && (1) \\ & && n \ \epsilon \ argmax \ E\{U[s(y), n']\} && (2) \\ & && \quad n, n' \ \epsilon \ N \end{aligned}$$

where the processor chooses an incentive payment, s, based on observable seed corn yield, y, to induce the grower to choose a nitrogen application rate, n, conditioned on participation constraint (equation 1) and incentive compatibility constraints (equation 2). The participation constraint states that the seed corn contract must yield utility at least equal to what the agent might obtain from some alternative feasible enterprise, i.e., reaching his or her reservation utility level, U_A^0. The incentive compatibility constraint guarantees that the contract will provide incentives to the agent to choose those actions preferred by the principal over alternative feasible actions

n'. This insures that the choice made by the utility-maximizing agent will maximize the processor's objective function $G(.)$.

To adapt the general principal-agent problem to the one at hand, we add the constraint:

$$NL(n(s[y])) \leq NL_P^0 \tag{3}$$

This states that nitrate leaching $(NL(.))$, a function of nitrogen fertilizer use via the incentive payment $(s[.])$, may not exceed the principal's desired maximum level, NL_P^0. That level may be determined by company fears of future regulations or by concerns about maintaining a brand name untainted by criticism over environmental stewardship.

Applying this theoretical framework to seed corn contracts, Chu et al. determined that an optimal incentive payment must depend on crop yield to satisfy the incentive compatibility constraints as well as a fixed payment to meet the participation constraint. This paper applies that framework to a representative farm case for several different kinds of contract designs.

In one common class of seed corn contract, the seed conditioning company offers a per-acre payment of the general form (modified from Shaw et al., 1989):

$$\begin{aligned} s(y) &= [\alpha(y - y^0) + Q]\beta P \\ &= [(Q - \alpha y^0)\beta P] + (\alpha\beta P)y \\ &= \delta + ry \end{aligned} \tag{4}$$

where $s(.)$ denotes total payment from the seed processor to the contractor-grower; y, grower yield of seed corn per acre; y^0, regional yield per acre; Q, base crop yield per acre; P, the price of commercial corn per bushel; α, a coefficient that transforms seed corn yield to commercial corn equivalents; β, a price premium adjustment coefficient. Because the inbred seed corn varieties have lower yields than commercial hybrids, the value of α is always greater than one. The transaction costs associated with contract production are compensated through a price premium adjustment coefficient, β, which also is greater than one. Note that payment $s(y)$ can be written in a linear form consisting of two parts: a fixed and a variable payment, conditioned on the observed output level. Coefficients δ and r become the seed corn conditioning firm's choice variables to design an incentive payment.

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. 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, we decompose the general principal-agent model into two stages. Because any constrained optimization must first satisfy its constraints, we begin by modeling the behavior of the representative seed corn contractor-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, we evaluate the impacts of different contract specifications for both processor-principal and grower-agent. We then identify the preferred contract designs for each party and which of these are potentially acceptable to both parties.

3. Alternative Contract Designs

Given the externality of NPSP to profit-motivated agricultural production decisions, NPSP may exceed socially optimal levels[1] (e.g., Chu et al., 1995). For purposes of regulation avoidance or public relations, a processing firm may wish to reduce NPSP on the farms of contracted growers as implied by equation (4) constraining the principal's objective function. A number of contract designs are capable of achieving this result. However, these contracts vary in enforceability as well as economic impacts on principal and agent. We will examine how several contract designs would perform at reducing nitrate leaching in Michigan seed corn production. As a first step, we divide possible contract designs into four classes.

a. Restricting Practices within Contracts. The most direct approach to reduce nitrate leaching is for the contract to restrict the permissible ambient level of nitrate leaching in groundwater. However, nitrate leaching is difficult to monitor. More easily monitored are restrictions on permissible agronomic practices, such as amount of nitrogen (N) fertilizer applied, timing of N fertilization, or choice of crop rotation.

b. Specifying Financial "Punishment" within Contracts. One alternative to a rigid restriction is a financial penalty associated with exceeding a specified threshold level of NPSP. For example, if nitrate leaching from each field can be measured, a Pigouvian fee can be imposed on the amount exceeding a certain level, perhaps the safe drinking water standard. A flat-rate penalty on any field exceeding the permissible level would be simpler to apply . Given that N fertilizer use may be easier to observe, a fee on the rate applied might be less costly to administer.

c. Rearranging the Incentive Payment Schemes. Nitrate leaching above ambient levels appears to be directly related to N fertilizer applications that exceed seed corn uptake potential (Ritchie, 1987). Such high nitrogen applications can be induced by a high marginal value production due to a high seed corn contract variable payment (r in equation 4). If the principal internalizes the social cost of nitrate leaching into the incentive payment, the resulting variable payment r^a is less than the payment that would result if that negative externality were ignored (Chu et al., 1995) .

d. 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 grower contractors. The information might include certain recommended agronomic practices. Such information could be delivered through a required grower training program or information packet and certified through a stewardship test.

4. A Representative Seed Corn Grower

One means to evaluate contract performance subject to a participation constraint is to model the seed corn grower's whole farm. A variety of potential enterprises are included in a mathematical programming model in order to capture the opportunity cost of choosing seed corn production over alternative activities.

The grower's problem can be structured as:

$$\begin{aligned} & Max && \sum_j c_j x_j \\ & subject\ to && \sum_i \sum_j a_{ij} x_j \leq b_i \\ & && x_j \geq 0 \quad \forall j \end{aligned} \tag{5}$$

where x_j are crop input and output enterprises; the right-hand side constraints (b_i) include available stocks of owned land, rental land, family labor, seed corn contract land, and timeliness restrictions on attainable yield; and objective function coefficients (c_j) refer to prices for crops and marketed inputs as well as the seed corn contract fixed payment.

We examine a representative contract grower of seed corn in southwestern Michigan, one of three areas in the state where groundwater is known to have high nitrate concentrations (Kittleson, 1987). The irrigated sandy loam soils there have a high potential for nitrate leaching when excess nitrogen fertilizer is applied. The crops grown in this area include commercial corn, seed corn, soybeans, potatoes, dry beans, and wheat (King, 1994). Due to its high value, seed corn production is one of the most important crops in this area. Seed corn contracts are scarce; most growers would like to contract more acreage and many growers are currently unable to get any contract at all.

The representative cash crop farm owns 1200 irrigated, tillable acres, may rent up to 500 additional irrigated acres, and holds a contract allotment for up to 500 acres of seed corn. The farm is operated by one adult operating a set of machinery typical for Midwestern U.S. crop farms of this size. The farm has the option to hire supplementary labor. Crop enterprises include seed corn, commercial corn, soybean, and potato, this last being a cash rent contract. Crop rotations with associated nitrogen carryover and yield effects

Table 1. Enterprise prices, yields, and nitrate leaching (NL)[1]

Crop	Price ($/bu)	Enterprise Name	Yield bu/ac	NL lb/ac	Description
Commer-cial corn	$2.40	CCorn(H)	171	69	Continuous corn; 222.5 lbs/acre N
		CCorn(M)	168	51	Continuous corn; 187 lbs/acre N
		CCorn(L)	163	42	Continuous corn; 160 lbs/acre N
		BCorn(H)	172	67	Corn after soybean; 196 lbs/acre N
		BCorn(M)	171	57	Corn after soybean; 160 lbs/acre N
		BCorn(L)	167	52.5	Corn after soybean; 133.5 lbs/acre N
		PCorn(H)	176	91	Corn after potato; 222.5 lbs/acre N
		PCorn(M)	175	79	Corn after potato; 187 lbs/acre N
		PCorn(L)	171	73	Corn after potato; 160 lbs/acre N
Seed corn	$5.28/bu + $81/ac[2]	SSeed(H)	73.9	76	Cont. seed corn; 133.5 lbs/acre N
		SSeed(M)	73.5	58	Cont. seed corn; 107 lbs/acre N
		SSeed(L)	68.7	50	Cont. seed corn; 80 lbs/acre N
		BSeed(H)	75.1	55	Seed corn after soy; 107 lbs/acre N
		BSeed(M)	74.6	53	Seed corn after soy; 80 lbs/acre N
		BSeed(L)	67.9	52.5	Seed corn after soy; 53.5 lbs/acre N
		PSeed(H)	76.5	73	Seed corn after potato; 133.5 lbs/acre N
		PSeed(M)	76.4	69	Seed corn after potato; 107 lbs/acre N
		PSeed(L)	73.7	67	Seed corn after potato; 80 lbs/acre N
Soybean	$5.70	Bean	35.5	45	Soybean after corn or seed corn; no N
Potato	$225/ac	Potato	NA	146	Potato after corn or seed corn; 237 lb/acre N

[1]Commodity prices and input levels from Nott et al. (1995), Schweikhardt et al. (1995), and King (1994).

[2]This contract term is used as one of seed corn contracts in St. Joseph County.

are modeled with coefficients based on expert opinions and mean values from crop yield and nitrate leaching simulation using DSSAT 3.0 (Tsuji et al., 1994).[2] Crop enterprises and their price, yield and nitrate leaching coefficients are shown in Table 1.

Table 2. Alternative Contract Designs

a.1.1	Restrict nitrate leaching (NL) to 60 lb/acre for whole farm
a.1.2	Restrict NL to 60 lbs/acre average for all seed corn
a.1.3	Restrict NL to 60 lbs/acre on each seed corn field
a.2	Restrict nitrogen (N) fertilizer applied to 80 lb N/acre in seed corn
a.3	Restrict seed corn/potato rotation (due to high nitrate leaching from potato)
b.1.1	Charge grower $4/lb nitrate-N for leaching above 50 lb/acre in seed corn
b.1.2	Charge grower $5/lb nitrate-N for leaching above 50 lb/acre in seed corn
b.2	Charge grower $0.34/lb over cost for nitrogen fertilizer above 80 lb N/ac on seed corn
c.	Adjust incentive payment to $330/acre fixed payment plus $1.90/bu variable payment
c′.	Adjust incentive payment to $200/acre fixed payment plus $1.90/bu variable payment

5. Whole Farm LP Analysis to Compare Alternative Contract Designs

The model assumes the representative grower maximizes expected net returns from cash crop production and rental activities. The optimization analysis was conducted using PC-LP (Dobbins et al., 1994), a whole-farm linear programming software designed to model field time constraints and associated yield penalties (Apland, 1993). The whole-farm model is used to examine how nitrate leaching, as well as gross margins over nitrogen costs, differ between the current contract and alternatives, from both grower and processor perspectives.

Ten alternative contract designs were examined. The strategies are labeled according to the contract types described earlier except for the information contract (as full information is assumed in all scenarios reviewed here). Table 2 lists all alternative contracts. They include five restrictions on agronomic practices, of which three are restrictions on nitrate leaching (a.1.1, a.1.2, a.1.3), one on nitrogen fertilizer applications (a.2), and one on rotation with potatoes (a.3). Three designs charge the grower fees, two for excessive nitrate leaching (b.1.1, b.1.2) and one on "excessive" fertilizer use (b.2). The last two contract designs reduce the variable payment for seed corn yield; one increases the fixed payment enough to maintain grower net returns (c), while the other increases the fixed payment by a lesser amount, only enough to maintain processor net returns (c′).

The restriction on nitrogen use on seed corn fields is set at a mean 80 lb/ac. Below this level, yield response to nitrogen fertilizer is strong enough to justify 80 lb/ac of nitrogen under all plausible input and output price combinations. The nitrate leaching restriction in seed corn fields is set at 60 lb/ac, medium nitrate leaching level in seed corn production (after rounding). The nitrate leaching charge for nitrate leaching above 50 lb/ac raises the marginal cost of nitrogen use for all crop enterprises except soybean, the crop with the lowest nitrate leaching. Charging $4 /lb for nitrate leaching above the 50 lb/ac threshold will make the grower begin to lower nitrogen rates, resulting in reduced nitrate leaching. Charging $5 /lb on nitrate leaching above 50 lb/ac will result in a complete change in the seed corn enterprise. The processor-imposed fee on nitrogen applications over 80 lb/acre is set at 34¢/lb, the minimum fee to induce substitution of the base model seed corn enterprise with one that uses less nitrogen. The base scenario incentive payment includes a fixed payment of $81/ac plus a variable payment of $5.28/bu seed corn yield. The first alternative scenario increases the fixed payment to $330/ac and lowers the variable payment to $1.90/bu which induces a risk-neutral grower to lower the nitrogen rate while retaining the same income level as he/she earns in the base scenario. The second alternative scenario retains the variable payment of $1.90/bu while changing the fixed payment to $200/ac, the minimum payment that will keep a risk-neutral grower still growing 500 acres of seed corn.

Before examining how alternative contract designs performed, the nitrate leaching model parameters deserve scrutiny. As it turns out, the seed corn crop, which is susceptible to contract design manipulation, is not the crop responsible for the most nitrate leaching (Table 1). Potato causes more leaching than seed corn, as does commercial corn under many scenarios. Another factor that limits even further the nitrate-leaching reduction potential of seed corn contracts is the fact that the high nitrogen fertilization strategy on seed corn is not profitable, given nitrogen fertilizer price (18¢/lb in 1995), the $5.28/bu variable payment rate for seed corn, and the modest seed corn yield gained from moving to the high nitrogen fertilizer rate.[3] Hence, high nitrogen fertilizer on seed corn does not even enter the solution in the unrestricted base model (Table 3).

The relatively low leaching propensity of seed corn with medium to low nitrogen levels suggests that contract designs that focus strictly on seed corn will have little effect on whole-farm nitrate leaching. The optimization analysis bears this out (Table 3). The strategies that clearly reduce leaching are all ones that either a) target the entire farm (a.1.1) or b) change the crop rotation directly (a.3) or indirectly by targeting average leaching from the rotation (a.1.2, a.1.3, b.1.1, b.1.2), not those that focus strictly on seed corn.

Increased financial returns represent the other objective of the contract parties, apart from reduced nitrate leaching. These returns are represented in Table 4 as the whole-farm gross margin (GM) over variable costs. For the contract grower, they represent the maximum GM solution to the LP problem. For the seed corn processor, GM represents the value of seed corn

Table 3. Optimal Solutions for Representative Grower under Different Contract Designs

Strategy	Mean seed corn yield (bu/acre)	Mean nitrate leaching(lbs/acre)	Enterprises(acres)
Unrestricted base model	76.4	110(all) 69(seed)	PCorn(M)(350) PSeed(M)(500) Potato(850)
a.1.1 Restrict NL to 60lb/acre(all acres)	75.2	60(all) 58(seed)	BCorn(M)(350) BSeed(M)(338.7) PSeed(M)(161.3) Bean(688.7) Potato(161.3)
a.1.2 Restrict NL to 60lb/acre (avg. seed corn field)	73.1	96(all) 60(seed)	PCorn(M)(391.7) SSeed(L)(83.4) BSeed(M)(148.8) PSeed(L)(267.9) Bean(148.8) Potato(659.5)
a.1.3 Restrict NL to 60lb/acre (each seed corn field)	74.4	79(all) 54(seed)	PCorn(M)(391.7) SSeed(M)(83.4) BSeed(M)(416.6) Bean(416.6) Potato(391.7)
a.2 Restrict N fert. to 80 lb/acre (avg. seed field)	73.7	109(all) 67(seed)	same as base, except PSeed(L)(500)
a.3 No rotation with potato	74.4	same as a.1.3	same as a.1.3
b.1.1 Charge $4/lb. on NL>50 lb./ac.	75.1	107(all) 66(seed)	PCorn(M)(391.7) PSeed(M)(416.6) SSeed(L)(83.4) Potato(808.3)
b.1.2 Charge $5/lb. on NL>50 lb./ac.	73.6	78(all) 52(seed)	PCorn(M)(391.7) SSeed(L)(83.4) BSeed(M)(416.6) Bean(416.6) Potato(391.7)
b.2 Charge 34¢/lb. on N fert. > 80 lb./ac.	73.7	109(all) 67(seed)	same as base except PSeed(L)(500)
c. & c′. Seed corn contracts: w/$1.90/bu variable payt.	73.7	109(all) 67(seed)	same as base except PSeed(L)(500)

Table 4. Nitrate Leaching, Principal's and Agent's Gross Margins

Strategy	NL lb/ac	Principal GM($/ac)	Grower GM ($/ac)	Principal △ GM/△ NL ($/lb)[3]	Grower △ GM/△ NL ($/lb)[3]
Basic model	69	1,672,404	342,443		
a.1.1 Restrict NL to 60lb/ac(all)	58	1,645,140	290,726	4.95	9.40
a.1.2 Restrict NL to 60lb/ac(seed)	60	1,599,695	322,936	16.16	4.33
a.1.3 Res. NL 60lb/ac(ea. seed field)	54	1,628,053	307,149	5.91	4.71
a.2 Maximum of 80 lb N/ac.	67	1,612,032	337,880	60.37	4.56
a.3 No rotation with potato	54	1,628,053	307,149	5.91	4.71
b.1.1 Charge $4/lb on NL> 50 lb/ac)	66	1,675,685	304,517	-2.18	25.28
b.1.2 Charge $5/lb on NL>50 lb/ac)	52	1,615,151	299,214	6.74	5.09
b.2 Charge 34¢/lb for >80 lb N/ac	67	1,612,032	337,880	60.37	4.56
c. Seed corn @ $330/ac + $1.90/bu	67	1,607,485	342,427	64.92	0.02
c′. Seed corn @ $200/ac + $1.90/bu	67	1,672,485	277,427	-0.08	65.02

[1]GM of the principal is calculated as: [$50/bu − variable payment ($/bu) to grower) * yield per acre * acres per grower] - [fixed payment ($/acre) * acres per grower]

[2]GM of the grower represents the net return to grower resources.

[3]Figures are calculated with respect to the base model GM and NL levels.

yield (assumed to be $50/bu) minus payments made to growers plus revenues from fees charged to growers (e.g., for excessive nitrate leaching or nitrogen fertilizer application). One efficiency criterion for evaluation of the alternative contract designs is dominance analysis of mean nitrate leaching (lower levels preferred) versus mean gross margins (higher levels preferred). By this definition of dominance, strategy A dominates strategy B if and only if either $(NL_A < NL_B$ and $GM_A \geq GM_B)$ or $(NL_A \leq NL_B$ and $GM_A > GM_B)$.

By this definition of leaching-gross margin dominance, the efficient strategies that are not dominated from the processor's (principal's) perspective are a.1.1, a.1.3, a.3, b.1.1, b.1.2, and c′. If we consider the case where a grower might be willing to reduce gross margin if leaching could be reduced efficiently, then the efficient strategies for leaching reduction from the grower's perspective are a.1.2, a.1.3, a.3, b.1.2, and c. Interestingly, there are three strategies that fall into the efficient set for both parties: field-level restriction of leaching (a.1.3), restriction on rotation with potatoes (a.3), and a \$5/lb fee for excessive nitrate leaching (b.1.2).

To evaluate these strategies on the basis of aggregate efficiency, however, misses the cost of reaching the environmental quality objective of reduced leaching. One way to capture this cost is to measure the reduction in gross margin per pound reduction in nitrate leaching, as shown in the last two columns of Table 4. The△ GM and △ NL figures are calculated as the difference between the base model levels and those in each alternative scenario. The △ GM/△ NL ratios can also be evaluated by dominance analysis. In this instance, strategy A dominates strategy B if it reduces leaching at lower cost for the grower without increasing costs for the processor or vice-versa. Algebraically, strategy A dominates strategy B iff. $[(\triangle GM/\triangle NL)_A^P \geq (\triangle GA/\triangle NL)_B^P$ and $(\triangle GM/\triangle NL)_A^G > (\triangle GM/\triangle NL)_B^G]$ or $[(\triangle GM/\triangle NL)_A^P > (\triangle GM/\triangle NL)_B^P$ and $(\triangle GM/\triangle NL)_A^G \geq (\triangle GM/\triangle NL)_B^G]$. This efficiency criterion eliminates only four inefficient contract designs, a.2, b.2, b.1.2, and c′ (Figure 1), if linear combinations of contract designs are disallowed. However, it does rule out the \$5/lb fee on excessive leaching as too costly, even though this contract design achieves the lowest nitrate leaching in seed corn. The two contract designs that are efficient by both the whole-farm and the cost-per-pound-of-leachate criteria are the restriction on potato rotation (a.3) and the field-level restriction on nitrate leaching (a.1.3).

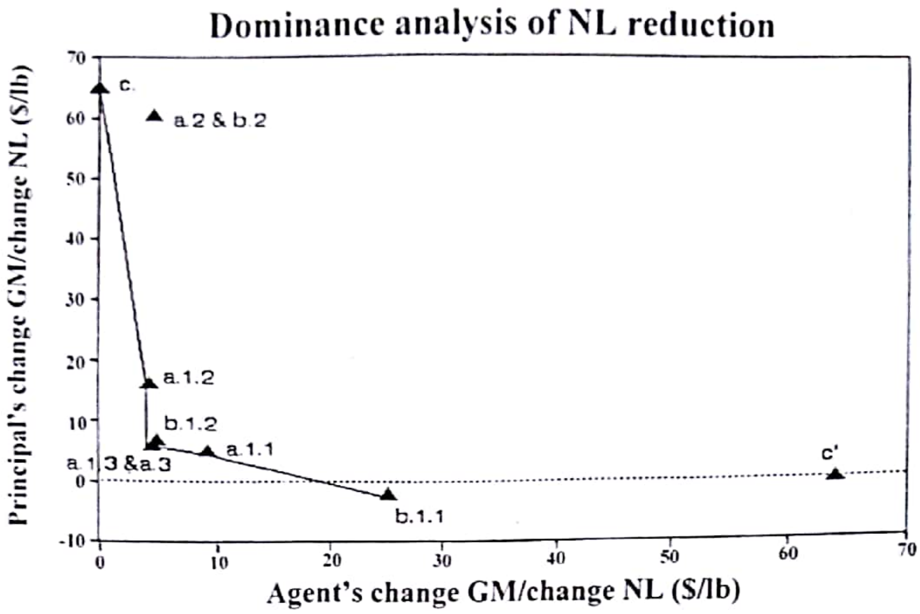

Figure 1. Dominance Analysis of Principal's Cost per Pound of Leaching Reduction.

Central to the principal-agent problem is the transaction cost of monitoring enforcement or otherwise insuring incentive compatibility. Whether contract enforcement is cost-effective determines whether the contract is feasible. Of the contract designs reviewed here, those based on nitrate leaching can only be monitored at prohibitive cost, unless by simulation. To date, the legal system has not accepted computer simulations as sufficient grounds for regulatory enforcement. There is no reason to suspect that agricultural processing businesses would feel otherwise about contract enforcement with input suppliers. Enforceability concerns eliminate the three a.1 strategies and both b.1 strategies. Similarly, the cost of monitoring the level of nitrogen fertilizer application is likely also to be high, despite the fact that methods for monitoring have been proposed (e.g., nitrate concentration in cornstalks at maturity (Binford, Blackmer and Messe, 1992; Binford, Blackmer and

El-Hout, 1990)). This cost would eliminate strategies a.2 and b.2.

Thus, on the basis of contract enforceability, only the restriction on rotation with potatoes and the revised variable payment contract are acceptable. The former is an easily observed crop rotation with low enforcement cost. The changed incentive payment in the latter meets the principal-agent incentive compatibility constraint, giving the contract grower an incentive to reduce nitrogen fertilizer rates without monitoring. As shown by contract designs c and c′ , the incidence of who bears the costs of leaching reduction in a linear payment scheme of this kind can be adjusted simply by changing the fixed payment.[4] Many other possible contract designs have not been reviewed here. These include permutations of the two enforceable strategy types, as well as various educational strategies which were not examined at all.

6. Conclusions

This case study of seed corn contract redesign to obtain reduced nitrate leaching demonstrates that such redesigns are possible. But they vary greatly in the magnitude and incidence of their opportunity costs and enforcement costs. If the processor-principal 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, low-cost, and effective, the range of feasible alternative contracts expands. Thus, the development of techniques that can easily be applied to measure compliance is an important research priority.

Price changes is not analyzed in this paper. If the price of corn (and hence seed corn) increases relative to alternative crops, the contractor-grower may be motivated to use more nitrogen than in the case examined here. Such a corn price rise would boost the shadow price of "green" contract specifications. How alternative contracts might react to relative price changes will require future empirical exploration.

Two methodological issues also need further research. The first issue is how to incorporate imperfect, asymmetrically-held information on probability distributions over crop yield and NL potential. Risk programming approaches might be suitable here. The second, more ambitious challenge, is to model explicitly the two-level programming problem imbedding the contract grower's objective function in that of the processor principal.

Footnotes

1. 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 it is in the instance of lower-value agronomic commodity production.
2. Forty-two years of maize yields and nitrate leaching were simulated for common Michigan seed corn and commercial corn genotypes using 1951-1992 temperature and precipitation data from Three Rivers, Michigan, and insolation data from Ft. Wayne, Indiana. The CERES-Maize component of DSSAT 3.0 has been validated not only for corn yield but also for cumulative nitrate leaching over time (Kovacs, Nemeth, and Ritchie, 1995).
3. Some growers in southwestern Michigan apply up to 180 lb/acre nitrogen on seed corn, well above the "high" nitrogen scenario of 133.5 lb/ac modeled here. This behavior implies that other factors may be at work, e.g., growers fertilize for high yield in case of an exceptionally good weather year, other seed corn inbred lines

are more responsive to nitrogen, growers overrate the yield response to nitrogen, or growers are averse to the risk of low yields that could put their contract in jeopardy in future.

4. To be successful over the long term, a reduced variable payment contract would also have to decouple annual yields from contract retention, or else growers might still fertilize heavily out of risk aversion.

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利用農產契約以減少氮肥滲透：整體農場分析

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本文的研究目的在於探討如何透過農業生產契約設計，以減少農化使用所引起的非點源污染。該研究系以玉米種籽契約和氮肥使用為例。根據(1)氮肥使用所起的滲透、(2)農民及農產加工廠的利潤，經由整體農場最適化分析和契約可行性評估，提供利用契約訂定以減少非點源污染的理論及實証模式。

關鍵詞： 農產契約、非點源污染、線性規劃、氮肥滲透、玉米種籽、整體農場分析