ANNEX 6

Increased Cropping Diversity to Reduce Leaching and Runoff:

Economic and Environmental Analysis[1]

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Abstract:

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Analysis of variance on 34 Michigan fields and a whole-farm optimization analysis show nitrate leaching and phosphorus runoff can be reduced while maintaining profitability in corn-based crop systems. Gross margins are increased by crop rotation and manure use; cover crops reduce non-point source pollution without significantly reducing net returns.

Increased Cropping Diversity to Reduce Leaching and Runoff: Economic and Environmental Analysis

The dramatic productivity gains of U.S. agriculture in the last half-century have not come free of cost. Agriculture is the largest single non-point source of water pollution, including sediments, salts, fertilizers, pesticides, and manure (National Research Council 1989). It accounts for up to 64% of non-point source pollution of U.S. rivers, and 57% of U.S. lakes (Carey 1991).

Agronomists and many farmers have responded to the pollution challenge by developing alternative crop production systems that reduce chemical inputs and environmental hazards. Most of these systems use animal or crop residues along with legume and green-manure crops in rotation. Soil quality indicators such as organic matter content and biological activity have been shown to increase with these alternative systems (Doran et al. 1987; Reganold et al. 1993). These increases in organic matter and biological activity can result in reduced soil erosion, increased efficiency of nitrogen utilization, and retention of water in the soil (Karlen et al. 1992). However, while these new technologies may improve soil and water quality, little information is available about the potential multi-year economic benefits or costs associated with nutrient and soil quality management. Despite environmental successes with these systems, economic factors still determine the degree to which most farm managers are willing to diversify their cropping systems.

In this paper, we examine the economic and environmental effects on corn-based cropping systems of increased cropping diversity through rotations, cover crops, and manure. We combine statistical analysis of detailed enterprise budgets from 15 southcentral Michigan farms with a more general analysis linking economic optimization methods to biophysical simulation models in order to evaluate tradeoffs among profitability, reduced nitrate leaching and phosphorus runoff.

Research Objectives

From an economic perspective, as soil quality increases, operating costs can be expected to decline due to reductions in 1) fertilizer use, as biologically-fixed nitrogen (N) becomes more available, and 2) insecticide control of corn rootworm, as crop rotation reduces risk of damaging rootworm infestation. Yields may also increase directly with increased soil quality, resulting in increased farm profitability with attendant reductions in environmental contamination. However, other input costs may rise - notably for labor. It is hypothesized here that alternative production systems employing manure and cover crops in corn-based rotations with other crops can reduce agricultural non-point source pollution while maintaining or improving farm profitability.

We approach this hypothesis with two objectives: 1) to test the hypothesis that operating costs decline as crop diversity increases in central-Michigan corn-based cropping systems, using a small paired comparison of adjacent farmer fields employing different levels of crop diversity; and 2) to examine that hypothesis more generally by simulating different crop production systems and letting a mathematical programming model identify the optimal crop mixes which are able to satisfy joint environmental and economic objectives.

Field Crop Enterprise Budgets From 15 Central Michigan Farms, 1994

Forty-eight recent studies comparing alternative crop production systems were reviewed to identify an appropriate methodology for a joint economic and environmental comparison of alternative cropping systems (Roberts and Swinton 1996). Empirical methods were evaluated with respect to profitability, financial stability, and environmental impact criteria. Most studies failed to incorporate environmental criteria. Most of the studies offering balanced economic and environmental analyses integrated biophysical simulation with economic optimization.

Biophysical models can be used to simulate environmental parameters for an optimization model (see Crowder et al. 1985; Johnson et al.1991). Data on resource use levels and financial costs are needed, along with complete data on all financial and environmental parameters that vary significantly across systems. Enterprise budgets can provide much of the cost and return information required.

The most widely used method for measuring profitability in system comparisons is budgeting analysis using enterprise budgets. Testing differences in costs, yields, and gross margins (representing returns over direct expenses such as land, buildings, and management) through one-way ANOVA provides a clear picture of the relative differences between the alternative systems being compared. By doing this, it is possible to test the hypothesis that more diverse crop systems increases gross margins by reducing operating costs and increasing yields.

Thirty-four enterprise budgets were developed to estimate returns over variable costs per acre from 15 south-central Michigan farms during the 1994 growing season. Data were collected on labor and machinery by task and variable inputs used. For fields cropped in rotation, budgets were developed for each crop in the rotation by tracking fields with the rotational crops. For instance, if the farm operator followed a corn-soybean-wheat rotation with soybeans on the sampled field in 1994, corn and wheat fields similar to the sampled field were also monitored. The budgets are based on crop prices and input costs from mid-Michigan during the winter of 1994-95, along with custom work costs developed from a 1992 Michigan survey (Nott et al. 1995, Schwab and Siles 1994). Since the custom rates account for labor and equipment use, the returns over variable costs cover the returns to land, buildings, and management.

Results of the analyses are listed in Table 1. ANOVA tests were run between four different pairings of the surveyed fields. The first one paired farms growing corn continuously with farms growing more than one crop in rotation. The second paired farms using manure with those not using manure. The third paired those growing more than one crop and using manure with all other farms, and the fourth group compared those rotations with cover crops to those without cover crops. F-tests reveal mean differences at the 25% and 10% levels. These are higher than the conventional 5% threshold for Type II error (failure to reject the null hypothesis when it is false), but since there is no cost associated with a Type I error when means are equal (such as when testing for equal yields or costs), greater potential loss will occur if a false null hypothesis is accepted (Manderscheid 1965). Therefore, significant differences of up to 25% are treated as valid in the context of farmer decision making.

While use of manure shows no effect on yield, both cover crops and multiple crop rotations appear to increase yield significantly at the 25% level. On an individual basis, manure appears to have the greatest cost-reducing effect with significant differences at the 10% level. Multi-crop rotations reduce costs, but cover crops increase them (both at the 25% significant level). Differences in gross margins are evident in manure and multi-crop rotations both jointly and separately. The higher yields and reduced variable costs for the multi-crop rotations combine for a greater effect on gross margins than manure alone. The use of cover crops appears to increase both variable costs and crop yields significantly. Since these affect gross margin in opposite directions, there is little to no effect on gross margins.

Historical high and low price ratios of soybean:corn and wheat:corn, derived from the past 15 years of Chicago quoted prices (Ferris, 1993), were used in the budgets to determine sensitivity of the gross margin results to changes in price ratios between the crops. Table 2 summarizes the changes that occur with shifts in the price ratios. Table 3 lists the farm-gate prices and price ratios used. Both high and low price ratios generally resulted in smaller differences in gross margin across the groups than mean price ratios. The exception was rotation vs. no rotation under high price ratios. When the prices of soybean and wheat are low relative to corn, no significant differences existed in gross margins. The increased relative price of corn compensated for the lower yields of continuous corn, erasing the crop rotation difference. Under the high price ratio case, the higher relative prices of soybean and wheat make crop rotation advantageous. Farmers who chose to grow other crops in rotation to corn would be better off in two of the three scenarios and equally well off under high corn prices. Therefore, growing corn in rotation in this analysis would be the dominant strategy for a price risk-averse or risk-neutral farmer.

<u>The Representative Farm Model</u>

Having constructed and compared enterprise budgets, the next step in the analysis was to develop a representative farm that reflects as much as possible typical field-level practices and inputs used on the fields sampled. The primary objective was to determine the optimal mix of enterprises for the representative farm under various assumptions about tolerable levels of nitrate leaching and phosphorus runoff. A secondary objective was to identify conditions under which manure and interseeded crops enter the optimal activity mix. These objectives provide insight into the tradeoffs that exist between profitability and environmental impact.

A linear programming model was used to determine the optimal mix of enterprises for the representative farm. The model provides a mechanism to answer questions such as how the enterprise mix and management practices might change if restrictions were placed on tolerable levels of erosion or potential nitrate leaching. The LP model used in this study is PCLP, the Purdue Crop/Livestock Linear Programming Model, version 3.2 (Dobbins et al. 1994), a whole-farm LP software that explicitly accounts for limited field time and penalizes planting and harvest delays.

The key environmental coefficients used in PCLP came from PLANETOR, version 2.0 (Center for Farm Financial Management 1995). PLANETOR combines site-specific environmental models with farm enterprise budgeting to evaluate the impact of crop rotations or changes in levels of applied nutrients and manure. PLANETOR is not an optimization model; rather, it is designed to evaluate individual farm enterprises. It is used here to evaluate the environmental impact of typical field-level practices observed in the sample. While PLANETOR is able to estimate enterprise returns and environmental impacts, PCLP identifies the enterprise mix that maximizes whole-farm returns to resources while meeting environmental and economic resource constraints.

The representative farm is a cash grain operation with 1250 tillable acres located in south central Michigan on Kalamazoo sandy-loam soil. All the land farmed is owned. The farm is assumed to operate outside of government programs. Crops are produced using either conventional or minimum tillage. A conventional set of machinery is assumed, reflective of the equipment used by the farm operators surveyed. The farm is operated by one and a half full-time equivalents of family labor. Seasonal part-time help is available as needed at a cost to the farm of

$10 per hour. Working rates are based on Fuller et al. (1995). Primary crops allowed in the model include corn, soybeans, and wheat. Rotations consist of continuous corn or soybeans, corn-soybean, corn-soybean-wheat, and corn-corn-soybean-wheat. These rotations may include the use of manure, interseeded clover, or both.

For the purposes of this study, all crops are sold at harvest unprocessed and no storage is available on the farm. PCLP makes adjustments for yield and moisture levels based on the timing of planting and harvesting. This is important due to reductions in yield due to delays in planting and harvesting delays. Available field days estimates for a typical Kalamazoo producer represent the number of good working days in a ten day period at an 80 percent probability (Rosenberg et al. 1982). Input costs are the same as those used in the enterprise budgets. Farm-gate commodity prices reflect historic price ratios observed over the last fifteen years for corn, soybean, and wheat harvest prices (see Table 3). No per-unit cost is attached to manure since it is assumed to be acquired at no cost from a neighboring farm. This type of arrangement existed among two of the five surveyed farms using manure. The only cost associated with manure is the cost of spreading. Restrictions are placed on pounds of nitrate leaching allowed per year and phosphorus runoff. Yields are assumed equal across practices at 135 bu/ac for corn, 43 bu/ac for soybeans, and 61 bu/ac for wheat.

Mean nitrate leaching and phosphorus runoff levels for each cropping activity were predicted from two submodels in PLANETOR 2.0. These submodels are the Phosphorus Runoff Index, developed by the Natural Resources Conservation Service Phosphorus Index Core Team, and the Nitrogen Leaching and Economic Analysis Package (NLEAP), developed by Agricultural Research Service at Fort Collins, Colorado. The PLANETOR model runs through ten years of every rotation to account for carryover effects of the soil and crop diversity over time. Levels of phosphorus runoff and nitrate leached were simulated for each rotation on each field over a ten-year period. Results generated by PLANETOR represent the annual averages in the eleventh year of each rotation.

The nitrate leaching and phosphorus runoff estimates from PLANETOR provide the numerical values used as parameters in PCLP's activity matrix. Results are generated for an unconstrained, profit-maximizing scenario, followed by restrictions on each environmental factor separately and both together. Limits are placed at the whole-farm level at an average of 40 lbs. of nitrate leached per acre and 8 lbs. of phosphorus runoff allowed per acre. These levels represent the upper limits of low environmental risk as defined within PLANETOR.

Table 4 shows the returns to resources and the optimal crop mix for the initial unconstrained solution, as well as when restrictions are applied to the model. These represent the profit-maximizing solutions given the production alternatives, available resources, and current cost and price structure. The combination of enterprises that provides the highest returns is derived predominantly from a corn-soybean-wheat rotation using manure. Clover is not used in the optimal unconstrained solution. The "return to resources" of $220,016 represents the return that remains after all direct costs of production have been deducted from gross revenue. This covers returns to machinery and buildings, operator and family labor, management, and land.

The alternatives to the base model involve whole-farm restrictions on the total amount of nitrate leaching and phosphorous runoff. While all three scenarios decrease the return to resources, these reductions are very small, at the most $19 or $0.02 per acre. However, important changes do occur in the crop mix: Interseeded clover enters the optimal mix when phosphorus runoff restrictions are added to the model. The overall distribution of crops remains the same. The use of clover increases with nitrogen restrictions. While the corn-soybean-wheat rotation with manure dominates all scenarios, the use of second-year corn decreases as restrictions are placed on the model and clover is relied on more to reduce leaching and runoff.

These results are sensitive to changes in assumptions about price ratios (Table 5). When the prices of soybeans and wheat are high relative to corn, the optimal mix shifts away from corn to greater soybean production. At low price ratios, where the value of corn increases relative to other crops, the optimal mix shifts towards continuous corn production.

Conclusion

This research was motivated by the hypothesis that alternative production systems employing manure and cover crops in corn-based crop rotations with other crops will reduce environmental contamination while maintaining farm profitability. Results from both the empirical paired comparison study and from a representative farm optimization analysis support this hypothesis. Alternative practices hold the potential to reduce the risk of environmental contamination with little to no loss in profitability.

Results of the budgeting analysis suggest that cropping systems employing both manure and multiple crops in rotation can increase field level gross margins. Three distinct conclusions arise from the budgeting analysis:

1) Using multiple crops in rotation provides the biggest impact on gross margin.

2) Multiple crops in rotation appear to impact yield positively and reduce costs to raise gross margins.

3) Manure magnifies this effect, but acting alone, its impact is not as great as using multiple crops in rotation.

These findings are consistent with other recent studies on the economic advantages of certain alternative crop rotation systems over continuous cropping systems (Diebel et al. 1993; Dobbs et al. 1988; Helmers et al. 1986; Lazarus et al. 1979; Smolik et al. 1995; Zentner et al 1988).

The representative farm model adds two important contributions to these results. First, the use of manure decreases when restrictions are placed on nitrate leaching and phosphorus runoff. This reflects the potential environmental risk from excess applications (Legg et al. 1989; Parsons et al. 1994). The timing and amounts of manure applied will determine whether the application is beneficial or detrimental to water quality. Second, interseeding clover into a rotation becomes attractive as restrictions are placed on leaching and runoff. The fact that farm returns were lowered very little to comply with the environmental protection constraints indicates that while interseeding clover is not profitable alone, the economic tradeoffs are minimal to achieve lower environmental risks.

Table 1: One-way ANOVA tests of differences between means for 15 central-Michigan farms: yield, total costs that vary, and gross margin.

	Number of Farms	Yield (bu/ac)	Total Costs that Vary ($/ac)	Gross Margin ($/ac)
Continuous Corn	5	115*	163*	84*
Multi-crop Rotation	10	134*	146*	103*
No Manure	10	127	160**	90*
Uses Manure	5	127	134**	109*
Uses Manure or Multi-crop Rotation or Neither	11	125	157*	90*
Multi-crop Rotation and Manure	4	134	135*	115*
No Cover Crop	12	122*	147*	96
Uses Cover Crop	3	146*	170*	99

*F-test significant at the .25 level.
**F-test significant at the .10 level.

Table 2: One-way ANOVA test of differences between mean gross margins under alternative price ratios (soy/corn, wheat/corn) for 15 central-Michigan farms, 1994.

	Number of Farms	Gross Margin with Mean Price Ratio ($/ac)	Gross Margin with High Price Ratio ($/ac)	Gross Margin with Low Price Ratio ($/ac)
Continuous corn	5	84*	84**	84
Multi-crop rotation	10	103*	117**	90
No manure	10	90*	99	83
Uses manure	5	109*	120	99
Uses manure or multi-crop rotation or neither	11	90*	98*	83
Multi-crop rotation and manure	4	115*	128*	101
No cover crop	12	96	104	89
Uses cover crop	3	99	113	84

* F-test significant at the .25 level.
**F-test significant at the .10 level.

Table 3: Commodity prices used for alternative price ratios.

Corn Price	Soybean Price	Wheat Price	Soy/Corn Ratio	Wheat/Corn Ratio	Ratio Name
$2.16	$5.30	$3.15	2.45	1.46	Mean
$2.16	$5.94	$3.80	2.75	1.76	High
$2.16	$4.64	$2.51	2.15	1.16	Low

Table 4: Optimal crop mix when whole farm restrictions are placed on nutrient runoff and leaching.

Restrictions: 8 lb/ac P runoff 40 lb/ac N leached	Base Model	Phosphorus Runoff	Nitrate Leaching	P Runoff and N Leaching
Return to Resources	$220,016	$220,007	$219,997	$219,997
Crop Production:	**Acres:**	**Acres:**	**Acres:**	**Acres:**
Corn-corn-soy-wheat w/manure	72	38	21	7
Corn-soy-wheat w/manure	1014	1046	993	1063
Corn-soy w/manure	164	160	173	159
Corn-Soy w/clover	0	6	63	21

Table 5: Optimal crop mix for high and low soybean:corn and wheat:corn price ratios without restrictions on phosphorus runoff and nitrate leaching.

	Unconstrained		
	Mean Price Ratio	High Price Ratio	Low Price Ratio
Return To Resources	$220,016	$51,490	$204,961
Crop Production:	**Acres:**	**Acres:**	**Acres:**
Continuous corn	0	0	610
Continuous corn w/manure	0	0	168
Corn-corn-soy-wheat w/manure	72	0	0
Corn-soy-wheat w/manure	1014	861	472
Corn-soy-wheat w/manure & clover	0	0	0
Corn-soy w/manure	164	389	0
Corn-soy w/clover	0	0	0

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