ECONOMIC EFFECT OF IMPERFECT INFORMATION:
ON CONSERVATION DECISIONS

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ABSTRACT---
Cotton farmers in the Piedmont region incorrectly believe conservation systems with winter cover crop and no-till cultivation yield less than conventional systems. We model the effect of organic matter on productivity and show how ignoring this effect causes returns to be underestimated. Farmers with imperfect information underinvest in residue management.

-----KEY WORDS-----

residue management, organic matter, productivity, comparative statics

Economic Effect of Imperfect Information on Conservation Decisions

Cotton is a principal crop grown in Georgia, with 885,000 acres planted in 1994 and a harvested value of $540 million (Georgia Agricultural Statistical Service). Cotton production in Georgia is primarily under a conventional tillage system, in which a moldboard plow is used and little attention is given to residue management. Due to surface exposure and frequent disturbance of top soil, this management system degrades soil quality and reduces soil productivity. A solution to these problems is to switch to a residue management system that maintains surface cover year-round. The conservation system with the most promise for row crops grown on the highly eroded Piedmont soils of the Southeast is no-till cultivation combined with a winter cover crop (Langdale and Moldenhauer).

This conservation system is not popular for cotton in the Southeast. Christensen noted that there is a belief that reduced tillage with surface crop residues will not work on irrigated crop land in Southeast. Farmers hold several stereotypes that educational programs have failed to discredit. First, there is a perception that residues encourage growth of plant pathogens and nematodes. Second, the relationship between residue management and productivity gains is misunderstood and underappreciated, particularly since education programs highlight only erosion control. Third, farmers believe that the productivity gains are not realized for many years, and heavily discount the benefits. These stereotypes constitute imperfect information about the input value of organic matter accumulated through residue management, and lead to inaccurate economic assessments of the conservation system. We address the second and third stereotypes and show how decisions about the conservation system are affected by the imperfect information.

Cotton production with intensive tillage for more than 150 years on the sloping Piedmont soils of the southeastern U.S. has resulted in large areas of moderately to severely eroded land.

From 25% to more than 75% of the original A horizon has been lost due to accelerated erosion (Langdale *et al.*). Even without erosion, failure to manage residues on these heavy clay soils results in lower soil productivity. Nutrient cycling efficiency, water holding capacity, and soil nutrient reserve are all improved with no-till cultivation and winter cover. Conventional row cropping in this region is ultimately unsustainable.

Most farmers in the Southeast tend to believe 10 to 30 years are required to recognize efficiency gains from residue management. Langdale *et al.* and Mills *et al.* suggest that 3 to 5 years of conservation tillage are sufficient under rainfed conditions to increase soil carbon in the soil surface (up to 1 cm) enough to improve infiltration and other characteristics. Farmers usually fail to attribute resulting productivity improvements to the overall efficiency effects of increased organic matter, which is difficult to observe and measure. The visual cues used in other regions, such as darkening soil color and improved texture, are not as obvious in the red clay Piedmont soils under a no-till cultivation system.

If the advantages of the conservation system are not evident in the short run, farmers will not correctly value the benefits of the system. The purpose of this study is to demonstrate the effects of imperfect information about residue management on the conservation decision. We establish the link between crop residues and organic matter accumulation, and show how this accumulation affects productivity over time. By relating the efficiency gains to cost savings and yield improvement, we show that net benefits to the conservation system may be positive sooner than farmers usually assume, making it competitive with conventional systems.

Relationship Between Residues and Organic Matter

In the past scientist felt that incorporating crop residues into the soil was the best way to transform it into residual soil organic matter. Reicosky and Lindstrom showed that this intuition

was wrong. In fact, incorporating crop residues into the soil by moldboard plow accelerates the rate of oxidation of both the crop residues and the residual organic matter. Researchers in Georgia, Alabama, Ohio and Colorado measured increases in organic matter in no-tilled soils (Reicosky *et al.*). When no-till cultivation is practiced for 10 to 20 years, the residual organic matter in the top inch of soil may rise to more than 10% with beneficial effects noticeable up to 7.5 cm deep (Edwards *et al.*).   In Piedmont soils where cotton is planted with a winter wheat crop similar results occur even though cotton residues disintegrate rather than contributing to the organic matter pool (Reeves *et al.*). Nutrient cycling efficiency and soil nutrient reserves may substitute for fertilizer. Surface residues generate a more even microclimate for plants and aid in water infiltration and retention, which may improve yield.

To describe the relationship between residues and organic matter accumulation we assume the conservation system is a cotton row crop operation with a cover of winter wheat drilled in. The wheat is killed back in the spring using herbicides and no-till cultivation is used for the cotton, leaving the surface residues undisturbed. Cotton contributes little residue because stalks must be removed to control boll weevil overwintering and what residue remains degrades quickly after harvest.

Organic matter accumulates according to the difference equation

$$\Delta M = M_t - M_{t-1}$$
$$M_t = M_{t-1} + \Delta M$$

(1)

where ΔM is the change in organic matter from period *t-1* to *t*, M_t is the amount of organic matter present in period *t* and M_{t-1} is organic matter in *t-1*.

Cover crops such as winter wheat recycle nitrogen and reduce leaching of other nutrients (Meisinger *et al.*). Decomposition of crop residues to organic matter is a slow process and the

conversion rate depends upon soil microclimatic characteristics and properties. Both organic

matter and residues are lost each year due to chemical and physical degradation so that there is

not a one-to-one correspondence between organic matter in *t* and residues in *t-1*. Specifying

equation 1, organic matter in *t* may be expressed as

$$M_t = \alpha M_{t-1} + \beta R_t \tag{2}$$

where M_t is the organic matter in and on the soil in *t*, α is the rate of carryover from the previous

period, reflecting decomposition and plant uptake in the current period on organic matter from the

previous period.

At best, M_{t-1} is not lost, so $0 \le \alpha \le 1$. This is shown by setting $M_t \ge M_{t-1}$, indicating

that organic matter does not reproduce like a biological system, but must be transformed from

external inputs. R_t is crop residue in period *t*, and β is the rate of conversion of crop residues

into organic matter. Thus, βR_t represents ΔM_t from equation 1. We assume that crop residue

decomposition and carryover of organic matter are constant over time, but differ for the two

systems. For the conventional system, α is likely to be less than for the conservation system due

to the topsoil and surface disturbance. For the conventional system, βR_t may be as small as zero,

if no cover crop is planted. Even with winter cover, the effect of a moldboard plow in destroying

residues rather than permitting them to decompose to organic matter should cause β to be smaller

for the conventional system than for the conservation system.

To solve for the accumulation rate of organic matter, we first rearrange the difference

expression represented by equation 2 for organic matter in any period *t* as

$$M_t = M_0 \alpha^t + \beta \sum_{i=0}^{t-1} \alpha^i R_{t-i} \tag{3}$$

where all terms are as previously defined.

The stationary value of M_t is zero. The first term on the right-hand side of equation 3 is the discrepancy between the current value of M_t and the stationary value of $M_t = M^*$. The system is stable if α is less than one in absolute value, which we assumed for the carryover of organic matter. The dynamic effect of crop residue on organic matter accumulation is

$$\frac{dM_t}{dR_{t-i}} = \beta\,\alpha^i \tag{4}$$

Suppose there is a permanent change in crop residue so that $dR_{t-i} = dR$ for all i. This occurs if the same amount of crop residue is added every year. Equation 4 becomes

$$\frac{dM_t}{dR} = \frac{\beta}{1-\alpha} \tag{5}$$

which states that if the change in crop residue is constant over time, the rate of organic matter accumulation from conversion of crop residue is always positive and remains constant over time. The magnitude of conversion depends on both the carryover rate of organic matter in previous periods and the conversion rate from residues.

The accumulation of organic matter over time is

$$\frac{dM_t}{dt} = t\,\alpha^{t-1} + \beta\sum_{i=0}^{t-1}\alpha^i\,\frac{dR_{t-i}}{dt} > 0 \quad . \tag{6}$$

Equation 6 demonstrates how organic matter accumulates over time. The carryover rate, α, continues to have an effect, although a declining one, as organic matter degrades over time. Organic matter accumulates more slowly for the conventional system, where α, β and R_t are relatively lower than for the conservation system. If the rate of residue additions, dR_{t-i}, is constant, then dR_{t-i}/dt reduces to the number of years. Organic matter accumulation could be

zero for the conventional system if there is no carryover and no residue is added. By observation, we know that native organic matter in the clay Piedmont soil is extremely low under the conventional system, substantiating the form of equation 6. The multipliers in equation 6 show the time path of organic matter accumulation and the role of residues. This is the first step in demonstrating the environmental input value of crop residue to the farm.

Productivity Enhancing Effects of Organic Matter

Cotton yield is a function of variable and fixed inputs, and organic matter substitutes for some inputs and improves the efficiency of others. Mineralized soil nitrogen and phosphorus in organic matter provide plants with nutrients, making organic matter a substitute for at least some of the inorganic nutrients added by the farmer. Thus, increasing organic matter in soil reduces the amount of inorganic fertilizer required. Organic matter increases infiltration and water holding capacity, stabilizes the microclimate in the root zone and surface, and improves nutrient cycling capacity, making the production system more efficient and potentially higher yielding. To the extent that these effects are realized, returns may increase and costs decrease. We model both effects reflecting observed crop response in experimental trials in the Piedmont region.

To summarize, organic matter has two effects on the production function - improvement in efficiency of the system and substitution for fertilizer inputs. The first effect causes an upward shift in the production function and thus, is a Hicks neutral effect. The latter shifts the slope of the production function. Observation suggests that increases in organic matter generate progressive improvements in the technology set so that it is possible to produce more output from the same input bundles in the conservation system. This change is not attributed to organic matter addition and hence the imperfect information results in inaccurate economic decision. The substitution effect for inorganic fertilizer is generally known and can be measured with soil tests. However, organic matter may also exhibit substitution or complementary effects with other

factors of production including pesticides and soil water. Ignoring these effects when they are present understates the benefits to the production process.

Technical change is defined as neutral if at all points on the expansion path the marginal rate of technical substitution is independent of time. The neutrality assumption means that the rates of technical substitution remain the same no matter how much soil organic matter is present in the soil, so that the unit amount of organic matter substitutes for the same amount of fertilizer over all periods in the expansion path. The production function for cotton that denotes neutral technical change is

$$Y_t = A(M_t) \; f(M_t, \; X(M_t), \; F(M_t)) \qquad . \qquad\qquad \textbf{(7)}$$

Equation 7 shows the relationship between organic matter and cotton yield, Y_t, which in turn depends on the residue from the wheat cover crop. $A(M_t)$ represents the productivity shift due to organic matter, M_t. The productivity effect is $0 \le A(M_t)$. This component is greater than one for the conservation system and is at best equal to one for the conventional system as we have defined it, but could be less than one if organic matter is depleted over time and the system becomes unsustainable. Organic matter is itself an input, since it supplies nutrients. $F(M_t)$ is fertilizer, which is dependent on the organic matter in the conservation system. $X(M_t)$ is a vector of other inputs, some of which depend on organic matter levels. Both fertilizer and other inputs are invariant to organic matter in the conventional system because the farmer fails to recognize the effect of organic matter on the production function.

Dropping the time subscripts for convenience, and taking the first derivative of the cotton production function with respect to organic matter we get

$$\frac{dY}{dM} = \frac{dA}{dM} f(M, F(M), X(M)) + A(M) \left[\frac{df}{dM} + \frac{\partial f}{\partial X} \frac{dX}{dM} + \frac{\partial f}{\partial F} \frac{dF}{dM} \right] \qquad . \quad \textbf{(8)}$$

By signing the terms in Equation 8, we can show the total effect of organic matter on cotton yield. The productivity effect of organic matter is always positive and at least equal to 1, so dA/dM ≥ 1. This is the upward shift component in the production function. The nutrients provided by organic matter affect yield positively, as would any other input, so df/dM > 0. The effect of organic matter on nonfertilizer inputs could be positive, suggesting a complementary effect, or negative, indicating a substitution effect. Thus, dX/dM >0 or <0. As complementary factor, organic matter may increase the effectiveness of other inputs in the production process. By holding X constant, as M increases, output increases. This effect is either not apparent to the farmer or is ascribed to other factors, such as weather, and hence is likely to be ignored. The amount of input X yields more output with additions of organic matter. The marginal rate of technical substitution between organic matter and fertilizer is negative, so dF/dM <0.

The total effect of organic matter on yield will be positive if the direct effect of organic matter on yield, df/dM, plus any input augmenting effects, $\partial f/\partial X$ dX/dM, offset any negative effects of reduced fertilizer or other inputs. This is likely, since farmers would normally only reduce inputs such as fertilizer after being convinced that yield will not be adversely affected. We assume that all farmers are rational decision makers operating at the second stage of production function in which all partial marginal products are positive. One implication of ignoring the effect described in equation 8 is that farmers may fail to efficiently reduce use of inputs for which organic matter substitutes.

The time path for yield may be evaluated by differentiating equation 7 as

$$\frac{dY}{dt} = \frac{dA}{dM}\frac{dM}{dt}\, f\,(M_t,\; X(M_t),\; F(M_t))$$

$$+\; A(M_t)\left[\; \frac{\partial f}{\partial M}\frac{dM}{dt}\; +\; \frac{\partial f}{\partial X}\frac{\partial X}{\partial M}\frac{dM}{dt}\; +\; \frac{\partial f}{\partial F}\frac{\partial F}{\partial M}\frac{dM}{dt}\; \right]$$

(9)

We know from equation 6 that dM/dt is positive. We may substitute equation 6 into equation 9 for dM/dt to demonstrate the effect of residue production on yield over time. The use of inputs for which organic matter is a substitute, such as fertilizer, should decline over time if the substitution effect is recognized by the farmer. If the effect is ignored, not only are more inputs used than needed, but there is a potential for environmental impacts off-site from excess nutrient leaching and runoff. As long as the direct and indirect organic matter effects are positive and greater than any negative effects of decreasing input use, yield will increase over time, so that dY/dt > 0.

In steady state, dM/dt does not change, that is, dM/dt = 0, and thus dY/dt =0. Cotton yield reaches this dynamic equilibrium as organic matter effects stabilize. At some point on this time path, we expect the yield curve for the conservation system to intersect the yield curve for the conventional system from below. This effect is due to the greater change in dM/dt under the conservation system, which affects all parts of equation 9 proportionately more. We anticipate that equilibrium yield will be higher for the conservation system. From equation 8, the more organic matter increases, the more output increases, as dY/dM>0.

Economic Effects of Organic Matter

The effect of organic matter on cost may be determined from the total cost function. The summation of all inputs used multiplied by their prices is explicitly represented as

$$TC = r_1 X(M) + r_2 M + r_3 F(M) + C$$

(10)

where r_i are the input costs, and C are fixed costs, including equipment costs for the conservation system. Again, the time subscripts are dropped for convenience. We assume that cotton farmers are willing to pay fixed costs for the conservation system since we have observed substantial investments in cotton planting and harvesting equipment in the Piedmont in recent years. The effect of organic matter on total cost is

$$\frac{dTC}{dM} = r_1 \frac{dX}{dM} + r_2 \frac{dM}{dM} + r_3 \frac{dF}{dM} \quad . \tag{11}$$

The input prices r_1 and r_3 are positive. We know that dF/dM is negative, since organic matter substitutes for fertilizer, thus the third term is negative. If organic matter is a substitute for X, then the first term is also negative, and the change in total cost due to organic matter is negative if the sum of these terms is greater than r_2. If organic matter is a complement to X, then the sum of the first two terms must be less than the last term for the cost share to be negative. The price of organic matter, r_2, could be calculated as variable costs associated with producing organic matter, that is, the costs of residue generation. We expect that the total cost declines as organic matter increases under the conservation system, so that dTC/dM < 0.

The economic effect on the farmer's decision may be evaluated from the profit function. This function, and the profit-maximizing first-order condition are

$$\pi = pA(M) \, f(\cdot) - TC$$

$$\frac{d\pi}{dM} = p \left[A(M) \frac{df(\cdot)}{dM} + f(\cdot) \frac{dA}{dM} \right] - \frac{dTC}{dM} = 0 \tag{12}$$

where p is the output price for cotton in the competitive market and f(•) contains the elements described in equation 7. The farmer who is aware of the organic matter effect will choose M* to maximize profit, which determines the crop residue requirements over time.

With imperfect information as we describe it, the production function shifter will not be

accounted for in the profit function and the bracketed term in the first order condition in equation 13 reduces to Y when A(M) is 1. This result implies a lower marginal revenue is attributed to the conservation system with imperfect information. Thus, the level of organic matter build up that equates marginal cost and marginal revenue is below the true optimum. If farmers perceive that the marginal cost is greater than the marginal revenue from the organic matter accumulation, then the conservation system will not be adopted at all, and no cover crop will be produced. Morrison *et al.* showed that cotton yield is greater on clay soils under a no-till system, and that marginal revenue is greater than marginal cost for the system.

We can show the result of ignoring organic matter effects by comparing the net present values of the conservation and conventional systems. We can solve for the point in time, t*, that equates the discounted returns of the two systems, at which point the farmer should be indifferent between them. To the extent that the equilibrium yield is higher under the conservation system, the total discounted net benefits to the conservation system will outweigh the conventional tillage system as long as t* is not too far into the future.

Conclusions

Despite research evidence to the contrary, cotton farmers in the Piedmont region still believe that conservation systems with winter cover crop and no-till cultivation are lower yielding than conventional systems. We model the positive effect of organic matter on productivity and show how ignoring this effect causes farmers to underestimate the returns to crop residue management. The profit maximizing farmer with imperfect information about the private benefits of organic matter accumulation underinvests in the conservation system that generates crop residues, and attains a lower equililbrium yield of cotton than is optimum. Wesimplify the function describing organic matter accumulation. Future research should model carryover and residue transformation as stochastic processes and permit residue production to vary with time. This could account for realistic climatic and soil effects.

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