FS 98-06 June, 1998

Dynamic Economic Analysis of a Residue Management System in Cotton

Krishna P. Paudel and Luanne Lohr

Paper presented at the 1998 AAEA Annual Meeting. Research supported by NRI Grant "Nutrient and Pesticide Loss in Cotton as Affected by Tillage and Fertility Management."

FS 98-06 June, 1998

DYNAMIC ECONOMIC ANALYSIS OF A RESIDUE MANAGEMENT SYSTEM IN COTTON

KRISHNA P. PAUDEL
LUANNE LOHR

Krishna P. Paudel is a Graduate Student and Luanne Lohr is an Assistant Professor, Department of Agricultural and Applied Economics, The University of Georgia, Athens, Ga, 30602.

Dept. of Agricultural & Applied Economics
College of Agricultural & Environmental Sciences
University of Georgia

DYNAMIC ECONOMIC ANALYSIS OF A RESIDUE MANAGEMENT SYSTEM IN COTTON

KRISHNA P. PAUDEL
LUANNE LOHR

Department of Agricultural and Applied Economics

University of Georgia

Athens, GA 30602-7509

llohr@agecon.uga.edu

ABSTRACT---
Residue management system (RMS), comprised of no till cultivation, a winter cover crop, and poultry litter, could be an alternative to existing management system in cotton production in the Georgian Piedmont. We compare the productivity and profitability of RMS with the current system over time, focusing on the role of organic matter. Using dynamic bioeconomic modelling technique, we show that the net return and land value difference between these two systems increase as the terminal period increases. We conclude that if financial and capital markets based on organic matter work efficiently, farmers will choose RMS in cotton production.

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

residue management, organic matter, productivity

Dynamic Analysis of a Residue Management System in Cotton

Cotton production in the heavy clay soils of the Georgia Piedmont follows a traditional method using moldboard plow and chemical fertilizer with little attention to residue management other than a winter cover crop killed with herbicides before spring and incorporated. Due to surface exposure, frequent disturbance of topsoil and depletion of soil organic matter, the traditional method both degrades soil structure and reduces soil productivity. We define this system as the conventional tillage system (CTS). An alternate system designed for soil enhancement as well as protection is designated as the residue management system (RMS). RMS is comprised of no till cultivation, a winter cover crop and poultry litter used for fertilizer. The winter cover crop is killed in spring using herbicide and residues are left on the ground. Cotton seeds are planted by drill through the surface residue. Poultry litter is applied at time of cotton planting.

Agronomic experiments with RMS have shown both environmental and economic benefits with this system. RMS increases the organic matter in soil which results in a productivity increase in soil. Because farmers are not adequately informed about the positive dynamic relationship between organic matter and yield, they fail to incorporate continuous productivity gains due to residue management into their production decisions. We demonstrate the effects of this imperfect information problem on farm decision making by comparing productivity and profitability of RMS and CTS over time, focusing on the role of organic matter. To do this, farmers do not substitute for decreasing amount of organic matter with other inputs.

Soil productivity is a renewable resource; it can be altered dynamically and continuously. RMS improves soil productivity over time. We evaluate the contribution of RMS in terms of yield gain due to increased soil organic matter and increased land value due to quality improvement. We measure changes in these values by simulating long term change in soil organic matter for RMS and CTS and comparing yield and profitability of the systems under dry land cotton farming conditions. Our results demonstrate that evaluating systems over time provides more meaningful information for farm planning.

Relationship Between Organic Matter and Productivity

Knowledge regarding the relationship among management systems, organic matter build up, and crop yields is central to the formulation of a sound cropping system. Most research on soil productivity has focused on the relationship of soil loss and crop yield to no-till or conservation tillage practices (Burt; Walker; McConnell; Miranowski; Krause and Roy; Goetz). However none have explored the linkage between farmers' incentives to adopt alternative systems, organic matter induced productivity change, and future farm land productivity. We highlight the effect of productivity benefits on the system choice using a dynamic model.

Cotton production, Y_t, is a function of inputs that depend on organic matter and inputs that do not depend on organic matter. Organic matter may substitute for some inputs and complement others. Fertilizer is an example of a substitutable input, since organic matter provides plant nutrients. Complementary relationships due to enhancement of ecosystem function such as improved nutrient cycling capacity and water holding capacity increase input efficiency.

If we represent organic matter in time t by M(t), then we can describe inputs in terms of their relationship to M(t). Let $Z_t(M(t))$ be a vector of inputs for which organic matter may substitute, and let $K_t(M(t))$ be an efficiency term for inputs whose functional value increases as organic matter increases. The inputs that are not related to organic matter are given by Q_t. The production function is

$$Y_t = f\left(Z_t(M(t), \; K_t(M(t)), \; Q_t \right) \quad . \qquad \textbf{(1)}$$

Input requirements change over time as soil productivity is altered by organic matter content. Organic matter change depends upon the initial level of organic matter in soil and residue treatment over time. For convenience, we assume the substitution and complementary effects are additive and technology, once chosen, is constant. Then the change in yield over time is

$$\frac{dY_t}{dt} = \frac{\partial Z_t}{\partial M}\frac{\partial M}{\partial t} + \frac{\partial K_t}{\partial M}\frac{\partial M}{\partial t} + \frac{dQ_t}{dt} \quad . \qquad \textbf{(2)}$$

If technology is constant, the last term in equation (2) equals zero. If farmers are not allowed to change the level of Z_t over time, change in yield over time is described solely by the change in the organic matter. The substitution effect is $\partial Z/\partial M < 0$ and the efficiency effect is $\partial K/\partial M > 0$, which does not differ by system. If the improvement is slow, the effects may be unobservable to the farmer in the relevant planning horizon. If the maximum obtainable organic matter for a system is below the threshold needed to observe these effects, the farmer will not choose the system. We tested and compared observable changes for RMS and CTS due to organic matter.

The rate of organic matter gain or loss depends on the rate at which biomass is added to the soil, the rate of conversion of residue to organic matter and the rate at which erosion and biological oxidation deplete organic matter in the soil. Depletion effects are accelerated by tillage because it speeds physical and biological degradation. This is true even with heavy manure treatment as long as the CTS is practiced. In RMS the microenvironment is favorable for the decomposition of crop residue and its conversion into organic matter earlier than for CTS.   RMS also prevents loss of topsoil by surface residue deposition and minimal soil disturbance.

RMS offers both lower cost and higher yield advantages to cotton farmers compared to CTS. The cost saving advantage of RMS can be explained in terms of the technical change component. Once enough organic matter accumulates the farmer can produce the same output at lower cost with RMS than with CTS. With increased productivity in the soil, application of other inputs can be reduced as the system becomes more efficient in their use. Once enough organic matter accumulates in the soil , the effect of RMS is observable in both profit and yield.

Productivity and Profitability of Cropping Systems

Soil productivity is affected by the amount of organic matter, which can be increased with the proper use of residue management practices. Soil productivity gains occur in small increments and have cumulative effects on soil quality and yield. Models that examine the relationships among productivity and economic variables must be dynamic to account for change over time. We focus on the role of organic matter in the cotton production function. Since organic matter change over time can be accumulative or decumulative, it is modelled as a stock variable. The present value of per acre profit at any terminal time T when organic matter effects are included is

$$J_T(M,R) = \int_0^T \left[p \;\; Y_t(Z_t(M(t)),\; K_t(M(t)),\; Q_t) \;\; - \; c(R(t),\; K_t(M(t)),\; Z_t(M(t)),\; Q_t \;;\; w) \right] e^{-\delta t}\, dt \; + \; e^{-\delta T} s_T\, [M(T)] \qquad \textbf{(3)}$$

The first part of equation (3) is the present value of net return from the cotton production. Y_t is per acre cotton yield in time t, c(.) is the cost function, p is the price of cotton per bale and w is the vector of input prices, with p and w assumed constant over time. R(t) is a piecewise continuous function that represents residue applied in time t. In the RMS, R(t) includes winter cover crop residue and poultry litter both left on the soil surface. In the CTS, R(t) is cover crop residue disked into the soil. Other terms are as previously described. Profit is summer over a planning horizon T years long, discounted at rate δ. The impacts of a positive change in organic matter in soil are increased cotton yield and cost savings due to enhanced efficiency of input application.

The second part of equation (3) is the present value of land at the time T due to organic matter accumulation, where S_T is the function related to change in land value due to organic matter increment. Farmers should be willing to pay more rent for land that has higher organic matter as it helps to get higher yield and lower costs. Land value increases with organic matter so that $\partial S/\partial M > 0$. Since the farmer is interested in the land value at the end of planning horizon, we discount it using $e^{-\delta T}$. Depending on the sign of $\partial M/\partial t$, economic returns may be higher or lower at any time $t_1 > t_0$, but should be always higher for RMS than for CTS.

The amount of organic matter in time t depends on how much crop residue is added in the current year plus the residual organic matter present from the previous two year. The rate at which R(t) is transformed to M(t) depends on tillage system, amount of residue added, amount of organic matter already in the soil and climatic conditions, which can be captured in the time parameter. We define organic matter, M(t), as the state variable and residue R(t) as the control variable. A costate variable λ gives the shadow value of organic matter but is excluded from the discussion since we are focusing only on J_T. The equation of motion and boundary condition are

$$\begin{gathered} \dot{M} = g\ (R(t),\ R(t-1),\ R(t-2)) - \beta\ M(t) \\ M(0) = M_0,\quad M(T)\quad free \end{gathered} \quad . \tag{4}$$

Equation (4) shows the change in organic matter over time. The growth in organic matter is given as g(.), the decomposition of current residue addition R(t), and carryover from previous years R(t-1) and R(t-2). From growth we subtract the organic matter extraction function β M(t). The extraction function represents loss of organic matter in the form of carbon dioxide during the process of conversion and the movement from one form (metabolic, structural, active, slow, and passive) of organic matter to another. The total carbon content is the sum of the pools. β gives the rate of transformation of residue to organic matter. Crop residue takes three year to decompose so the growth function takes R(t), R(t-1) and R(t-2) as its arguments. The equations of motion for both CTS and RMS are specified in unpublished work by Paudel and Cabrera. M_0 is the initial value of organic matter available in soil at time t_0 equal to a baseline of 2000 grams carbon per square meter for both systems assuming that the field history was planted with cotton without any cover crop before. This is equivalent to one percent organic matter content in soil. The upper limit of organic matter is bounded by natural soil capacity of three to four percent.

Data and Simulation Approach

To determine net revenue and land value, we used an agronomic relationship based on Mitchell and Entry and Bruce et al. which relates cotton yield to organic matter level. The cost and price information for outputs and variable inputs were obtained from the cotton enterprise budget developed by the Georgia Cooperative Extension Service (Givan and Shurley). Winter wheat contributed residue in both systems but was disked in under CTS and left on the surface under RMS. Poultry litter was used as a nutrient and residue source in RMS whereas inorganic fertilizer was used in CTS. The recommended amount of inorganic fertilizer in CTS is 60-50-75 lbs (NPK), which costs $36.60. This compares with the cost of poultry litter application at $32 per acre, which includes hauling and spreading operation. The labor and machinery costs are higher by $16 in the CTS due to disking and cultivating to incorporate residue.

This simulation is based on the assumption that the plot has been under conventional cotton cultivation with no cover crop for 200 years. Before that organic matter level in the natural state was assumed to be about three to four percent. To sustain cotton yield in the region, farmers have been substituting for loss of organic matter with improved plant breeding techniques and other inputs such as fertilizer. In this simulation, we do not allow either of these, therefore dQ/dt =0 and dZ/dt =0. Consequently, yield depends solely on the level and growth of organic matter over time. Due to conventional cotton cultivation and lack of a residue management system, the organic matter has been decreasing in this region for the last several years. The average yield of cotton in the Georgia Piedmont is about 1.5 bales per acre with technological substitution. According to W. Givan, Georgia Cooperative Extension row crop specialist, an acre of land producing 1.5 bales of cotton rents for $35 per acre, which increases with yield. If organic matter decreases below a level such that cotton production is less than one bale per acre, then the land is diverted to pasture land rented at $25 per acre. We simulated the model for values of T from one year to the time at which the asymptotic limit for organic matter is reached.

Results and Discussion

The results in table 1 show the cotton lint yield per acre in bales for both systems. Cotton yield is lower for the first three years in RMS but then reaches a minimum of 1.42 bales at three years before increasing to 1.67 bales at 30 years and 3.10 bales at 300 years. Yield decreases in CTS for the first 20 years reaches a low of 1.24 bales before increasing to 1.5 bales per acre only after 500 years. The simulation result reveals that the upper limit of cotton yield under CTS is typically 1.52 bales per acre where as the yield could be as high as 3 to 3.1 bales per acre for RMS. The initial decrease in yield in both systems is due to less favorable soil physical characteristics for decomposition of crop residue by soil micro organisms.

The important point to note between the two systems is that the yield difference increases as the terminal period is extended. The lowest cotton yield in RMS was 1.42 bales whereas the lowest cotton yield in CTS was 1.24 bales per acre. At the end of 30 years, yield is about nine percent higher in RMS compared to the initial yield but about 33 percent higher than the yield obtained under CTS at the same terminal time. Yield reaches equilibrium level only after 500 years in both systems as soil structure does not allow organic matter to build up forever. The RMS more quickly compensates for the damage to soil structure after 200 years of conventional cotton. If the farmers were permitted to use Z_t and Q_t to compensate for organic matter loss, costs would increase over time under CTS. It is possible that average yields will decline even with substitution since $dK/dt < 0$ under CTS.

Profit and terminal land value were calculated using a five percent discount rate. The results are shown in table 2. To be realistic one should look at the benefit of adopting RMS within a farmer's planning horizon which we assume is 30 years. If a farmer does not adopt RMS but instead adapts CTS, he would be essentially loosing more than 200% of net present value of return. This difference is lower for the initial year, but increases very fast if a farmer continues CTS. We calculated the annualized net returns to find the constant rate of annual return for RMS and CTS for 30 years which are shown to be $108.84 and $35.53, respectively. The annualized return is, therefore, 3 times higher than CTS if RMS is followed. Even though the net return does not exceed the initial value within 30 years, it shows an increasing trend and it surpasses this initial annualized return value soon after 30 years. Annualized net return is at the lowest level in RMS when terminal period is ten years after which it starts to increase as yield increases. For CTS, the annualized net return value decreases very sharply reaching to a $35.53 per acre in 30 years from the initial level of $109.78.

Land rental rate at the end of 30 years in RMS is $38.90 which is substantially higher than the land rental rate in CTS which is $29.45 per acre. Land rental rate based on organic matter requires the existence of an efficient market. If farmers cannot separate the productive land from the unproductive land, adding organic matter probably does not matter very much. If financial and capital market based on organic matter work efficiently, farmers will adopt the RMS.

Farmers have been told that in the long run a conventional tillage system exhausts the productivity of soils, builds up hard pan and lowers water tables. Farmers should consider the gains to organic matter accumulation over time in their decisions about farm practices. Future research needs to look at the possibility of allowing the technical change and the substitution of organic matter by other inputs.

Table 1. Cotton Lint Yield (Bales Per Acre) at Terminal Year Under RMS and CTS

Terminal Year	Cotton Yield	
	RMS	CTS
0	1.52	1.52
1	1.50	1.44
2	1.41	1.35
3	1.42	1.32
4	1.42	1.29
5	1.43	1.27
10	1.46	1.24
20	1.56	1.24
30	1.67	1.26
40	1.77	1.28
50	1.86	1.30
100	2.23	1.37
200	2.69	1.44
300	2.92	1.47
400	3.04	1.48
500	3.10	1.49

Table 2. Profit and Land Rent Under RMS and CTS ($/acre)

Terminal Year	Annualized Net Return		Present Value of Land Rent	
	RMS	CTS	CTS	RMS
0	118.26	109.78	35.47	35.47
1	112.89	98.08	33.70	34.97
2	103.08	84.51	31.45	32.94
3	98.64	75.45	30.73	33.09
4	96.15	68.60	30.15	33.16
5	94.68	63.19	29.72	33.25
10	93.79	47.59	28.82	34.11
20	100.80	37.80	28.98	36.48
30	108.84	35.53	29.45	38.90

References

Bruce, R.R., G.W. Langdale, L.T. West, and W. P. Miller. " Soil Surface Modification by Biomass Inputs Affecting Rainfall Infiltration." *Soil Sci. Soc. Amer. J.* 56(September-December 1992):1614-1620.

Burt, O.R. "Farm Level Economics of Soil Conservation in the Palouse Area of the Northwest." *Amer. J. Agr. Econ*. 63(February 1981):83-92.

Givan, W. and D. Shurley. *Crop Enterprise Cost Analysis*, Cooperative Extension Service, Agricultural and applied Economics, The University of Georgia, College of Agricultural and Environmental Economics, 1997.

Goetz, R.U. "Diversification in Agricultural Production: A Dynamic Model of Optimal Cropping to Manage Soil Erosion." *Amer. J. Agr. Econ*. 79(May 1997):341-356.

Krause, M.A. and B.J. Roy. "Optimal Adoption Strategies for No-Till Technology in Michigan." *Rev. of Agr. Econ*. 17(September 1995):299-310

McConnell, K. "An Economic Model of Soil Conservation." *Amer. J. Agr. Econ.* 65(February 1983):83-89.

Miranowski, J. " Impacts of Productivity Loss on Crop Production and Management in a Dynamic Model." *Amer. J. Agr. Econ*. 66(February 1984):61-71.

Mitchell, C.C. and J.A. Entry " Soil C, N and Crop Yields in Alabama's Long Term 'Old Rotation' Cotton Experiment." *Soil and Tillage Res.* 1282(1998), Forthcoming.

Walker, D. J. "A Damage Function to Evaluate Erosion Control Economics." *Amer. J. Agr. Econ*. 64(November 1982):690-698.