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OPTIMAL LAND, EQUIPMENT AND LABOR ALLOCATION UNDER ALTERNATIVE TILLAGE SYSTEMS IN SOUTH TEXAS

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Abstract

The paper presents results from a mixed integer, whole farm analysis that explicitly model machinery and full-time labor is best to analyze tillage studies. When decoupled farm payments are excluded, the economics of crop farming in the study area requires a large scale to be economically viable. Furthermore, the results highlight that crop, technology, and equipment selection is misleading if decoupled payments are included. The results show that if, at a given scale, there isn't enough time for additional acres of conventional crop/tillage systems, growers might be able to reduce fixed costs and increase returns/acre by adding residual amounts of reduced tillage crops..

Introduction

Cotton is the most important crop in the Texas Coastal Bend region. In South Texas as elsewhere, cotton growers have sought technology that will lower costs and/or increase productivity. For example, alternative tillage systems have been and continue to be the focus of economic analysis for potential improvements in economic efficiency (Cooke et al, 2003). The Texas Coastal Bend has mostly dryland production in a relatively dry climate. Therefore, part of the recognized potential for reduced tillage systems is in increasing productivity through soil moisture conservation. Soil erosion is not a major issue on the flat, clay soils of this region.

Beginning in 1998, a collaboration of growers, Extension, and Monsanto Corporation sponsored field trials comparing alternative tillage systems. The tillage systems examined included the status quo "conventional tillage" (which actually is a system representing a reduction in heavy tillage compared to the common practice in the 80s). Conventional tillage included a V-ripper (requiring a 300 hp tractor), field cultivator, hiboy applications of herbicide and insecticide, planter, fertilizer knife rig, and sweep cultivator (all with a 200 hp tractor). Cotton under this system also employed a shredder and stalk puller, both of which used a 94 hp tractor. A "reduced tillage" system in the study was basically the same as the conventional but substituted herbicide application for the V-ripper. A "no-till" system substituted herbicide applications for the field and sweep cultivators. Cotton and sorghum were grown in a 50:50 rotation using all three systems. Budgeting analysis for a given sized representative farm (2,500 acres in a cotton: sorghum rotation) indicated that the reduced tillage system was more profitable in some years, but that the conventional system was more profitable over a three year average.

Partial budgeting is adequate to assess the tradeoffs between changes in productivity and input costs. However, budgeting approaches fail to show how the most profitable choice of crop/tillage system might vary with increasing scale. The optimal crop mix would also likely be influenced by the pattern of acquisition of lumpy resources like full-time labor and equipment.

For this reason, a whole farm, mixed integer programming model was developed to answer questions like:

- What is the most profitable crop/tillage combination at different acreage sizes?
- What are the actual economies of scale (in dollars per acre) in row crop farming?
- How many acres are required to be economically viable from farming alone (i.e., without decoupled payments)?
- What is the best acreage size to minimize or optimize full-time labor?

Methods

A mathematical programming model was developed to reflect the general set of choices and tradeoffs faced by a farm manager. These include choices about tillage systems that potentially influence NRCS compliance (not a big issue in this study area) and thus eligibility for farm program payments. Other more basic choices include how to allocate land and "lumpy" capital resources (e.g., equipment, full-time labor) to the most profitable activity. The objective function (i.e., profit equation) for this model is presented below in Equation 1 where:

- i= crops (cotton, sorghum, and pasture as a default option)
- j= previously discussed tillage systems
- p=previous crop, to specify rotation constraints
- k=previously discussed capital items, plus default windmill & fencing for pasture
- t=time periods for labor constraints and Machine Trips parameter.

$$\begin{aligned}\text{Max Profits} = {} & S_i\, S_j\, S_p\, ((\text{GrossReturns}_{ijp} - \text{NonMachineryVariableCosts}_{ijp}) * \mathbf{X}_{\mathbf{ijp}}) \\ & + \text{DecoupledPayment} * \mathbf{ComplianceIndicator}_{\mathbf{ijp}} \\ & - S_i\, S_j\, S_k\, S_p\, S_t\, (\text{MachineryVariableCosts}_k * \text{MachineTrips}_{k,t,i,j} * \mathbf{X}_{\mathbf{ijp}}) \\ & - S_k\, (\text{MachineryFixedCosts}_k * \text{MachineTrips}_{k,t,i,j} * \mathbf{Buy}_{\mathbf{k}}) - \text{AnnualSalary} * \mathbf{Hire}.\end{aligned} \qquad [1]$$

The continuous variable $\mathbf{X}_{\mathbf{ijp}}$ represents acres of cropping/tillage activities, while the integer variables $\mathbf{Buy}_{\mathbf{k}}$ and **Hire** reflect purchases of lumpy resources. The binary variable $\mathbf{ComplianceIndicator}_{\mathbf{ijp}}$ is zero when the model solution violates an NRCS constraint on soil erosion, thus removing decoupled payments from the objective function. (In reality, non-compliance would also disqualify any loan deficiency payments as well, but these were not included for simplicity of calculation.) The parameter $\text{MachineTrips}_{k,t,i,j}$ is trips across one acre of a given crop/tillage combination with specified equipment. The AnnualSalary parameter is specified as \$20,000 per year for a full-time equipment operator. The remaining parameters in the objective function specify typical crop budget cost or return values. In summary, the objective function maximizes profits by choosing crop/tillage combinations, where farm income (net of non-machinery variable costs) is further reduced by the costs associated with acquiring machines or full-time labor.

Equation [1] was specified in conjunction with the following land, labor, machinery capacity, rotation, and NRCS compliance constraints:

$$S_i\, S_j\, S_p\, \mathbf{X}_{\mathbf{ijp}} \leq \text{Land Scalar} \qquad [2]$$

$$S_i\, S_j\, S_k\, S_p\, (\text{PerfRate}_k * \text{MachineTrips}_{k,t,i,j} * \mathbf{X}_{\mathbf{ijp}}) \leq S_k\, (\text{AvailableFieldHours}_k * \mathbf{HIRE}) \qquad [3]$$

$$S_i\, S_j\, S_k\, S_t\, (\text{PerfRate}_k * \text{MachineTrips}_{k,t,i,j} * \mathbf{X}_{\mathbf{ijp}}) \leq S_t\, (\text{CapacityParameter}_{k,t} * \mathbf{BUY}_{\mathbf{k}}) \qquad [4]$$

$$S_i\, \mathbf{X}_{\mathbf{ijp}} \leq \mathbf{PREP}_{\mathbf{jp}} \qquad [5a]$$

$$\mathbf{PREP}_{\mathbf{ip}} \leq S_i\, \mathbf{X}_{\mathbf{ijp}} \qquad [5b]$$

$$S_i\, S_j\, S_p\, \mathbf{X}^{*}_{\mathbf{ijp}} \leq \text{Land} * \mathbf{ComplianceIndicator}_{\mathbf{ijp}} \qquad [6]$$

For all $\mathbf{X}^{*}_{\mathbf{ijp}}$ for which the condition SOILLOSS(i,j)>TFACTOR(i)*TVALUE is true.

Equation [2] is a straightforward land constraint. The right hand side scalar was varied from 100 to 5,000 acres in one hundred acre increments for separate model solutions to generate a sensitivity analysis. Equation [3] constrains says that labor demand is less than or equal to labor supply. This constraint is built around by two key parameters. equipment performance rates (hours per acre) and days available for fieldwork. The budget performance rates were inflated by a factor (the $\log_{10}$ of acreage) that increased with land size to account for increasing logistics, travel time, etc. Hours available for fieldwork, by time period, were estimated at a 90% probability level for this study area by Bordovsky (1978). Hiring one machine driver acquires a supply of driver hours to satisfy the labor demands of specific crops.

Equation [4] represents a set of *k* equations (i.e., one for each capital item) constraining machine hours demand to be less than or equal to supply of available capacity of that given machine. As in the labor constraint, the machinery capacity parameter was also a function of the machinery performance rate multiplied by available hours. Buying one machine to give the maximum potential machinery capacity in each time period.

A conservation compliance parameter was formulated using revised universal soil loss (RUSL) equation estimates of soil erosion under each crop/tillage combo. If this soil loss to be less than the allowable amount using NRCS t-factors and t-values, then a 0/1 indicator variable was generated in equation [6] that eliminated government payments from the objective function.

Other assumptions involve continuous monoculture outcomes which were allowed in the rotation constraints [5a and 5b], but were assessed a yield penalty based on research by Matocha (2002). In addition, tractor purchases were linked by constraints to purchases of matching implements.

The model was written and solved in GAMS over a range of operation sizes. The XA solver was used for mixed integer programming with the optcr=0.01 setting.

Results and Discussion

Several points can be made regarding the results. The most obvious point is the obvious economies of scale in row crop farming. Figure 1 shows that the model selected the default pasture option from 100 through 1,400 acres. Beyond 1,500 acres the scale is large enough to sufficiently spread the fixed cost of one full time operator and an equipment complement (including all three tractor sizes). The crop mix is a 50:50 rotation of the conventional cotton and sorghum. As the farm scale increases from this point, the fixed costs are spread over more acres, reducing total costs and increasing net returns per acre. (Note: the net returns per acre shown in Table 1 and Figure 1 do not include decoupled payments, which are worth a constant $59/acre).

At 2,100 acres, there is not enough time to farm additional acres of the conventional rotation, so the optimal solution begins to include increasing amounts of continuous (i.e., rotated with itself) reduced tillage sorghum. This is apparent in Figure 1 as a slope change in the Total Revenue curve, caused by the addition of less profitable reduced tillage sorghum. However, the marginal additions of a labor-saving crop/tillage treatment do further reduce costs and thus increase returns per acre until the point at 2,600 acres when a second equipment operator is hired, and the crop mix reverts to the conventional rotation. This pattern is repeated again between 3,700 acres and 4,400 acres (Figure 1). Thus the impact of increasing economies of scale is evident. In addition, the model suggests an unconventional but useful and intuitive prescription for growers that don't have enough time for additional acres of conventional crop/tillage systems. Provided there is no additional investment requires, those growers might be able to reduce fixed costs and increase returns/acre by adding residual amounts of reduced tillage crops.

A final point is to emphasize that these results cannot be obtained using partial budgeting. Since tillage innovations are fundamentally about machinery and labor optimization, it is important to consider the scale of operation before making conclusions about what crop mix and tillage system is the most profitable.

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Table 1. Results from Land Sensitivity Analysis between 1,400 and 5,000 acres.

Acres	Tot. Returns	Tot. Costs	Net/acre	Mixed Integer Solution
1,400	21,000.00	16,960.09	2.886	pasture, 0 hires, fencing only
1,500	499,284.56	493,957.12	3.552	cv.cot:cv.sor, 1 hire, 1 equip. set
1,600	532,570.20	520,165.62	7.753	cv.cot:cv.sor, 1 hire, 1 equip. set
1,700	565,855.87	546,374.12	11.46	cv.cot:cv.sor, 1 hire, 1 equip. set
1,800	599,141.48	572,582.62	14.755	cv.cot:cv.sor, 1 hire, 1 equip. set
1,900	632,427.11	598,791.12	17.703	cv.cot:cv.sor, 1 hire, 1 equip. set
2,000	663,568.28	623,308.61	20.13	cv.cot and cv.sor, rt.sor, 1 hire, 1 e.s.
2,100	678,693.95	635,197.16	20.713	cv.cot and cv.sor, rt.sor, 1 hire, 1 e.s.
2,200	693,938.75	647,179.66	21.254	cv.cot and cv.sor, rt.sor, 1 hire, 1 e.s.
2,300	709,290.65	659,246.60	21.758	cv.cot and cv.sor, rt.sor, 1 hire, 1 e.s.
2,400	724,739.30	671,389.84	22.229	cv.cot and cv.sor, rt.sor, 1 hire, 1 e.s.
2,500	740,275.72	683,602.28	22.669	cv.cot and cv.sor, rt.sor, 1 hire, 1 e.s.
2,600	865,426.58	802,250.62	24.298	cv.cot:cv.sor, 2 hire, 1 equip. set
2,700	898,712.21	828,459.12	26.02	cv.cot:cv.sor, 2 hire, 1 equip. set
2,800	931,997.85	854,667.62	27.618	cv.cot:cv.sor, 2 hire, 1 equip. set
2,900	965,283.49	880,876.12	29.106	cv.cot:cv.sor, 2 hire, 1 equip. set
3,000	998,569.13	907,084.62	30.495	cv.cot:cv.sor, 2 hire, 1 equip. set
3,100	1,031,854.76	933,293.12	31.794	cv.cot:cv.sor, 2 hire, 1 equip. set
3,200	1,065,140.40	959,501.62	33.012	cv.cot:cv.sor, 2 hire, 1 equip. set
3,300	1,098,426.04	985,710.12	34.156	cv.cot:cv.sor, 2 hire, 1 equip. set
3,400	1,131,711.68	1,011,918.62	35.233	cv.cot:cv.sor, 2 hire, 1 equip. set
3,500	1,164,997.31	1,038,127.12	36.249	cv.cot:cv.sor, 2 hire, 1 equip. set
3,600	1,198,282.95	1,064,335.62	37.208	cv.cot:cv.sor, 2 hire, 1 equip. set
3,700	1,227,680.90	1,087,478.51	37.893	cv.cot and cv.sor, rt.sor, 2 hire, 1 e.s.
3,800	1,242,932.04	1,099,466.00	37.754	cv.cot and cv.sor, rt.sor, 2 hire, 1 e.s.
3,900	1,258,244.85	1,111,502.12	37.626	cv.cot and cv.sor, rt.sor, 2 hire, 1 e.s.
4,000	1,273,615.82	1,123,584.10	37.508	cv.cot and cv.sor, rt.sor, 2 hire, 1 e.s.
4,100	1,289,041.70	1,135,709.38	37.398	cv.cot and cv.sor, rt.sor, 2 hire, 1 e.s.
4,200	1,304,519.51	1,147,875.61	37.296	cv.cot and cv.sor, rt.sor, 2 hire, 1 e.s.
4,300	1,320,046.48	1,160,080.61	37.201	cv.cot and cv.sor, rt.sor, 2 hire, 1 e.s.
4,400	1,464,568.05	1,294,003.62	38.765	cv.cot:cv.sor, 3 hire, 1 equip. set
4,500	1,497,853.69	1,320,212.12	39.476	cv.cot:cv.sor, 3 hire, 1 equip. set
4,600	1,531,139.33	1,346,420.62	40.156	cv.cot:cv.sor, 3 hire, 1 equip. set
4,700	1,564,424.96	1,352,629.12	40.808	cv.cot:cv.sor, 3 hire, 1 equip. set
4,800	1,597,710.60	1,398,837.62	41.432	cv.cot:cv.sor, 3 hire, 1 equip. set
4,900	1,630,996.24	1,425,046.12	42.031	cv.cot:cv.sor, 3 hire, 1 equip. set
5,000	1,664,281.88	1,451,254.62	42.605	cv.cot:cv.sor, 3 hire, 1 equip. set

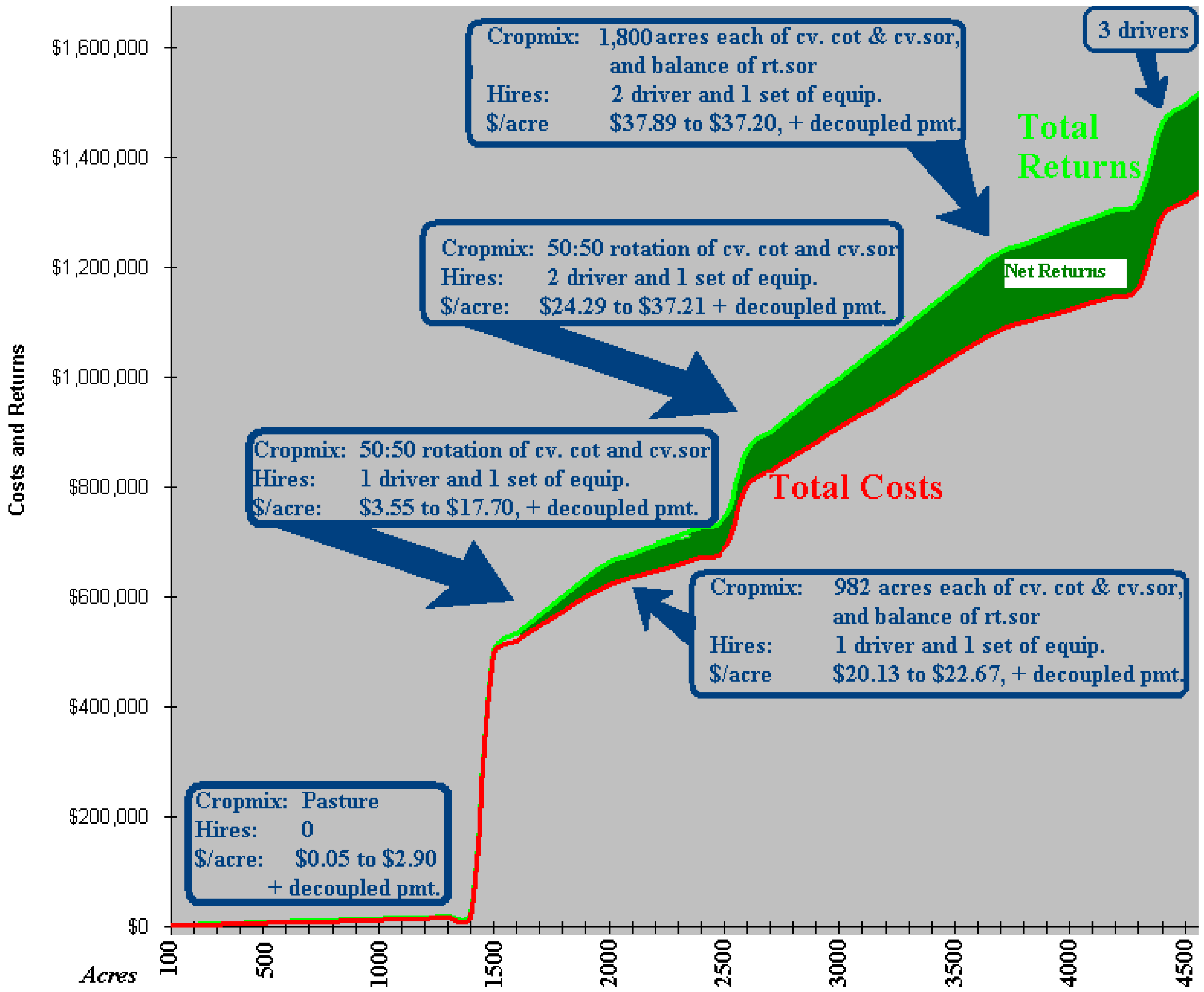

Figure 1. Optimal Solutions between 100 and 4,500 acres for Representative Farm.