on a 3-yr moving average.In Year 3, 565 acres were allocated to the production of program cotton and 283 acres were allotted to the production of doublecropped wheat and soybeans outside the program. The 565 acres were chosen because this was the size of the cotton base in Year 3. The model continued to produce program cotton up to its base limit in Years 4 through 7, with the rest of the available cropland used for doublecropped wheat and soybeans outside the program.

Results from the linear programming model, which evaluated other scenarios, were also incorporated into the mixed integer programming model. Since the results of the alternatives were not as profitable, it was possible that the mixed integer model would choose not to produce turfgrass. However, the results from the analysis were exactly the same as those reported in Table 5, and 100 acres being allocated to the production of turfgrass.

SUMMARY AND CONCLUSIONS

Given current typical market prices and production cycles for the three grasses, bermudagrass is the most profitable. Bermudagrass benefits from its relatively short production cycle and the resulting impact on cash flow. More than one crop of bermudagrass can be produced in the same amount of time it takes to grow one crop of either centipedegrass or zoysiagrass. Therefore, profits per unit of land for a fixed time resulting from production of multiple crops of bermudagrass are greater than profits that could be derived from production of one crop of the other grasses, despite price differentials favoring centipedegrass and zoysiagrass.

An analysis of production sensitivity to various prices for the grasses indicated that the above relationship holds over fairly wide price ranges for the grasses. With seasonality in bermudagrass considered, the price of bermudagrass had to be decreased to $0.60/sq yd before either of the other species became feasible. Without seasonality in the price of bermudagrass evaluated, its price must decline to $0.50/sq yd to make other grasses competitive. Evaluation of price sensitivity of the other grasses with seasonality in the price of bermudagrass included indicated that the centipedegrass price had to be raised to $1.50/sq yd above its base price of $1.22 and the zoysiagrass price had to be increased $0.80/sq yd above its typical level of $1.85 to initiate production. Thus, the competitive advantage of bermudagrass holds over a fairly wide range in prices for the respective grasses. Of course, demand and competitive conditions in particular markets may affect this relationship (i.e., the desire for premium-valued grasses on the part of individuals and landscapers in a high income community).

Results obtained from the linear programming model were incorporated into the mixed integer programming model to determine economical feasibility of turfgrass-sod production on a more conventional farming operation. In each case, all 100 acres available for turfgrass production were allocated to producing turfgrass-sod. These results suggest that it is economically feasible to incorporate turfgrass-sod production into an existing, more conventional, farming operation. This relationship held true even when the prices received for the different turfgrass-sod species were well below their typical levels.

Based on the costs and returns analysis, turfgrass-sod production may be a viable option for producers who are seeking alternatives to traditional farming enterprises. If producers choose to enter the turfgrass-sod production industry, the most profitable species of turfgrass for production seems to be bermudagrass. This relationship will probably hold true for as long as market conditions, production practices, and prices do not change drastically. Given current prices, markets seem sufficient to absorb additional production.

Production cycles for the three grasses are extremely important in influencing economic feasibility. New, more intensive production practices or introduction of new technologies to shorten production cycles could affect feasibility. For example, use of netting to permit earlier harvest of the grasses, especially for centipedegrass and somewhat for zoysiagrass, could cut several months off of the production cycle and limit problems related to slower root development and integrity of the squares or rolls in harvest and installation. These alternative technologies and practices would require additional economic analysis.

A shortcoming of the analysis is that markets were assumed to be present for the available turf at maturity and harvest. As noted, bermudagrass prices have shown a tendency to be seasonally sensitive to market supplies. Thus, producers may have to hold mature grass in inventory longer than that defined in the analysis. The present analysis somewhat addresses this issue through use of conservatively long production cycles. To the extent that this issue was not addressed in the analysis, defined net returns will be reduced. Adrian et al. (1992) indicate that turf operations exhibit substantial scale economies. Thus, larger turf farms will have greater ability to cope with downward price pressures and still maintain a profit.

For farmers considering turfgrass as an alternative enterprise, care must be taken to understand differences between markets for turfgrass and markets for traditional crops. While traditional crops generally have readily available markets, turfgrass outlets are not always available and tend to be sensitive to such economic factors as interest rates and the resulting impacts on construction and housing. Markets must be nurtured and developed. Turf producers may have to provide services such as transportation, handling, sprigging, etc. to attract buyers. Traditional crop farmers who wish to produce turf might develop relationships with larger, established turf farms and produce grass for them on a contractual basis. Thus, they can benefit from the market contacts and expertise of these operations and salespersons. Ideally, farmers growing turf on a contractual basis would understand their costs so as to more effectively bargain for contract terms and conditions.

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Profitability of Black Plastic Mulch for Limited Resource Farmers

Constance Ileko Mugalla, Curtis M. Jolly,* and Neil R. Martin, Jr.

Farmers and policymakers have recognized the need for alternative technologies for reducing costs and increasing profit for limited resource farmers. Plastic mulch has been evaluated as an alternative technology on experimental stations in the Southeast but its use has not yet gained wide acceptance among limited resource vegetable producers in the area. In this study, the economic feasibility of plastic mulch was evaluated as a profit enhancing technology for limited resource farmers. A farmer survey and farm simulation model were used in the evaluation of this technology. It was noted in the survey that most of the farmers in the research area were part-time and were above 50 years old. The average age was 60, with a minimum of 29 and maximum of 88. Plastic mulch resulted in increased output and farm revenue. The capital turnover ratio for production with plastic mulch was higher than for production without plastic mulch. Each hour of labor used with plastic mulch generated six times more net revenues than without plastic mulch. The total investment required for plastic mulch more than doubled, indicating that it might be difficult to encourage this age group of farmers to adopt the technology without easy credit arrangements. The diffusion of this technology may be difficult unless the alternative of renting vs. buying the necessary equipment is presented to this age group of farmers.

FARMERS IN THE SOUTHERN USA are constantly seeking ways of increasing their net revenues. Vegetable and small fruit production have been suggested as promising alternatives for limited resource Alabama and southern farmers (Colette and Wall, 1987; Adrian et al., 1989; Zwingli et al., 1987). The importance of vegetable crops in the southern states has increased in the last 30 years, as horticultural crop producers have increased their net benefits from farming by increasing yields and improving crop quality by the intensive use of chemical based inputs. The increased use of chemicals has, however, resulted in higher production costs and environmental concerns.

The cost of chemicals—including fertilizers—as a component of preharvest costs, varies from crop to crop. In Alabama, chemicals make up to 46% of the preharvest costs for tomatoes, while for okra, they form 73% of preharvest costs. These costs are derived from the purchase of inorganic fertilizers, pesticides, and herbicides. A high percentage value does not necessarily imply a high monetary value. For example, 46% of preharvest operating costs of tomatoes amounts to $430.90/acre, whereas 73% of preharvest operating costs for okra is approximately $150.90/acre.

Since labor and chemical costs are important components of vegetable production expenses, there is a need to adopt alternative technologies that reduce chemical use and environmental concerns, and at the same time increase returns to labor and nonfarm inputs, and net farm income. Fumigants such as methyl bromide are considered costly and hazardous to the environment and are targeted for replacement. Technologies which have been evaluated on experiment stations have been successful in reducing costs, but when applied to farmers' conditions, have resulted in increased per acre total costs even if average cost of production has been lowered. These technologies usually require initial investments that are beyond the means of the intended users, even though the returns to investments are sufficiently competitive. Most limited resource farmers in the study area have limited access to financial markets or are reluctant to accept the risk involved in the use of credit to purchase these technologies, even though they lower production costs.

According to Altieri et al. (1989), low-input farming techniques offer energy saving, cost effective alternatives for resource poor farmers. Crosson (1989) described low-input farming as a system that is structured to significantly

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reduce the need for off-farm plant focused inputs such as synthetic fertilizers, pesticides, and herbicides. This system encourages maximum use of crop rotation, organic fertilizers, minimum tillage, and other environmentally sound farming practices.

In this study, plastic mulch, a non-farm input, is evaluated as an alternative technology for increasing income for limited resource farmers. The effects of plastic mulch on investment costs and farm income are analyzed under different farming conditions.

Plasticulture involves the use of plastic mulch for controlling weeds, conserving moisture and increasing soil temperatures (Brown et al., 1991; Bhella and Kwolek, 1984; Bhella, 1988; Maiero et al.,1987; Vanderwerken and Wildox-Lee, 1988). The use of plastic mulch has also produced a cleaner and higher quality fruit (Brown et al., 1991). Khan et al. (1991) have shown that black plastic mulch has increased vegetable yields up to threefold for watermelons. Use of plastic mulch has been observed to promote early crop development (up to 4 wk earlier). For Alabama farmers, this means an early market price, which can be 50 to 100% above the average seasonal market price (Zwingli et al., 1987). There is a market risk associated with this technology. If all farmers aim for the same market there is likely to be a market surplus, which will result in low prices. It is, however, hoped that farmers will be able to adjust their production levels in order to prevent prices from falling too low and reducing income. It was also noted that the use of plastic mulch increased investment cost. This study examines the use of plastic mulch as an appropriate technology for limited resource Alabama farmers.

Table 1. Selected vegetables for the study, yield returns, and costs, 1992.

Vegetables	Yield/acre	Units	Gross revenue	Operating costs	Total costs	Net returns
			$/acre			
			No mulch			
S.† bell peppers‡	325	bu	2 437.50	461.32	1 942.84	494.66
S. cantaloupe	225	cwt	1 012.50	209.92	749.22	263.28
S. cucumbers	210	bu	1 815.00	266.68	1 374.83	440.17
S. okra	200	bu	2 405.00	204.62	2 147.18	257.82
S. tomatoes	750	box	4 875.00	922.49	4 108.59	766.41
S. watermelon	200	cwt	900.00	215.87	656.56	243.44
S. yellow squash	300	bu	2 490.00	307.19	1 556.58	933.42
S. zucchini squash	525	bu	2 829.75	360.37	2 017.18	817.82
			Mulch			
S. bell peppers	840	bu	6 720.00	2 301.03	4 980.02	1 739.98
S. cantaloupe	500	cwt	2 750.00	892.94	1 880.75	869.25
S. cucumbers	480	bu	4 500.00	952.87	2 669.80	1 830.20
S. okra	350	bu	4 550.00	923.08	3 476.19	1 073.81
F. okra	280	bu	3 520.00	179.04	2 347.82	1 172.18
S. tomatoes	2000	box	15 000.00	3 220.09	10 327.00	4 672.90
F. tomatoes	1600	box	10 400.00	2 198.60	8 073.96	2 326.04
S. watermelon	300	cwt	1 650.00	886.53	1 575.04	74.96
F. watermelon	240	cwt	4 237.50	206.09	737.23	342.77
S. yellow squash	450	bu	4 450.50	989.46	2 476.68	1 760.82
S. zucchini squash	750	bu	4 450.50	1 091.21	3 260.76	1 189.74
F. zucchini squash	600	bu	3 240.00	405.43	2 113.88	1 126.12

† S means Spring vegetables, F means Fall vegetables.

‡ Bell peppers, Capsicum anuum L., cantaloupe, Cucumis melo L.; cucumber, Cucumis sativus L.; okra, Abelmoschus esculentus (L.) Moench; tomato, Lycopersicon esculentum (Mill.); watermelon, Citrullus lanatus (Thunb.) Matsum. and Nakai var. lanatus; yellow squash, Cucurbita pepo var. melopepo (L.) Alef; zucchini squash, Cucurbita pepo L.

METHODOLOGY

Forty vegetable farmers from 14 counties in east-central Alabama, within a 90 mi radius of the Auburn University Experimental Station, were surveyed in the Fall of 1990. Information on their farm and family characteristics, cultural practices, farm income, and market outlet for vegetables was solicited. Farmers' willingness to participate in on-farm, farmer managed trials was noted. The number of farmers already using black plastic mulch was recorded.

From the 40 farmers, eight were selected to participate in on-farm trials. Farmer participation was monitored during the Spring of 1992. Records were kept on farm practices and the use of plastic on a 0.25 acre plot. Results from two farmers who followed all recommended practices, as outlined by the Alabama Commercial Vegetable Farm Demonstration Committee, and who kept good records, were used as a basis for simulating a number of farm situations for farmers in the research area. Information collected on the surveyed farms was used in the planning to make sure that the simulation results would answer questions of the research area farmers. The data collected from farmers' fields were supplemented by data from the Auburn and Tuskegee University Experimental Stations. The farm simulation models were designed to evaluate the profitability of the technology under actual farm conditions.

The following linear programming model was developed to simulate production outcomes based on typical farm situations:

$$\text{Maximize } Z = \sum_{j=1}^{a} c_j x_j \qquad [1]$$

Subject to:

$$b_i \geq \sum_{j=1}^{a} a_{ij} x_j \qquad [2]$$

and

$$x_j \ldots x_n \geq 0 \qquad [3]$$

where:

c_j = the income above variable cost derived from the production of spring and fall vegetables

x_j = the level of the jth activity, spring and winter vegetables, with or without plastic mulch, where j = 1 to n

b_i = the supply of the ith resource in the production of x_j, where i = 1 to m

a_{ij} = the amounts of the jth resource required by one unit of the jth activity. The a_{ij} values are the technical coefficients, or input-output coefficients.

The objective was to maximize income above variable costs for selected vegetables. In this study, 20 different vegetables, usually produced by farmers during spring and fall, were considered. The list of vegetables and the costs and returns are seen in Table 1.

RESULTS

Survey Results

All farmers considered their farm operation commercial. Commercial small-scale farmers made up to 14% of all

Table 2. Selected statistics of 39 commercial vegetable farm operators and farms in east-central Alabama, 1992.

Item	Unit	Mean	Minimum	Maximum	STD
Years of farming	years	29.2	2	75.0	20.9
Years of producing vegetables	years	19.6	0	60.0	16.2
Age of operator	years	60.0	29	88.0	15.4
Level of education	years	10.0	0	18.0	4.0
Number of workers	no.	6.0	1	51.0	8.1
Full-time hired	no.	0.1	0	4.0	0.1
Part-timed hired	no.	0.4	0	4.5	0.7
Number of hours worked full time per day in a year	hours	3.0	0	15.0	4.6

Table 3. Summary of different scenarios analyzed in linear programming, 1992.

Scenario	Base acres	Borrowing limit	Price	Crop limit	Purchased equipment	Buy labor	Prod. season	Family labor
				acres				
Base	5	1 000	Normal	2	No	Yes	Spring/fall	Full
Scenario 1	5	1 000	Normal	2	No	Yes	Spring/fall	Full
Scenario 2	5	1 000	Normal	2	No	No	Spring/fall	Full
Scenario 3	5	25 000	Normal	2	No	Yes	Spring/fall	Full
Scenario 4	5	25 000	Normal	2	No	Yes	Spring/fall	Full
Scenario 5	5	25 000	80%	2	No	Yes	Spring/fall	Full
Scenario 6	5	25 000	Normal	2	Yes	Yes	Spring/fall	Full

farmers interviewed, and 17% of those classified as small scale had pick and pay operations (Table 2). Some of the large scale farm units were also partnerships and made up 5.1% of the total farm operations, while 7.7% of the farms were classified as large scale cooperatives. About 33.3% of the operators were part-time, and 64.1% full time.

The average age of all farmers was 60, with a minimum age of 29 and a maximum age of 88 (Table 2). Farmers over the age of 65 made up 49.2% of those interviewed, and only 7.7% were less than 35 yr of age. A total of 61.5% had more than 15 yr experience in farming with 48.7% having more than 40 yr of experience producing vegetables. Since most of the farmers are over 60 yr old, their desire for money income may be less than younger farmers and they are more risk averse; therefore, the adoption of plastic mulch technology is less desirable (Shields et al., 1993). The average level of education was 10 yr of schooling, with seven of the 39 farmers having 12 or more years of schooling. Low levels of education often mean greater resistance in technology adoption. The ethnic composition of the farmers was 82.1% white, and 17.9% black. Occupations included full time farmers (64.1%), some of whom were retired from other professions: teachers 10.0%, mechanics 5.0%, and the rest were factory workers, janitors, or businessmen. Most of the farms were family operated, and 87.2% had no full-time employees. An average of six individuals worked on a farm, with 56.4% of farms being operated by less than five individuals, while 10.3% were operated by more than 10 individuals.

Although 46% of the farmers felt that amounts of chemicals used by other farmers exceeded required amounts, only three of the 39 believed that these chemicals were harmful to man, animals, and the environment. About 39% of these farmers indicated that they had adopted measures to reduce chemical use, while 46% had not taken any measure. Most farmers thought that both the quantity and quality of vegetables would be reduced if chemical use was lowered. Less than 5.0% had used plastic mulch on their fields. The number of hours worked full time per day ranged from 3.0 to 15.0 h with a standard deviation of 4.6.

A variety of farm activities, such as production of field crops, fruits, nuts, vegetables, and livestock were carried out on the farms. Among farmers who grew vegetables, most produced spring and fall season crops. The most common vegetables produced were tomatoes, cucumbers, squash, watermelons, beans, and collard greens.

Farm sizes varied from 1 to about 1000 acres and vegetable farms ranged in size from less than 1 to 300 acres. Only 41% of the farms were over 10 acres and 38.5% had less than 5 acres. Irrigation was practiced on about 50% of the farms, while only 20% of those irrigated 100% of their crops.

Simulation Model

A number of representative farm situations were simulated (Table 3). The first model represented basic conditions existing on a representative farm in the research area. The farm was 5 acres and produced a number of vegetables that were sold at local markets and roadside stands. The farm family was constituted of five members who worked on the farm during the spring, summer, and fall. Family labor was constrained by the number of family members, but there was no limit placed on hired labor. A 2 acre limit was placed on each vegetable crop since farmers diversified to minimize risk. This constraint is dictated by market conditions in the area. The farm produced vegetables without the use of plastic mulch with limited financial resources. This farm situation is, therefore, considered the basic farm solution and is used for comparative analyses.

Basic Solution without Plastic Mulch

For the basic solution, the equipment is rented and the farmer uses $1000 of borrowed capital and $10 000 of his own funds to cover operating costs. The basic solution seen in Table 4 shows production of 2 acres of spring okra, 2 acres of spring tomatoes, and 1 acre of spring yellow squash. This farm solution generated gross income of $17 050, which required a total investment of $14 065 with 4409 h of family labor and 115 h of hired labor. All land was used and the shadow price of an acre of spring land was $1853. Shadow price is the marginal value product of the last input brought into production. This is the rental value that can be assigned to each unit of resource brought into production by a profit maximizing firm. The reduced cost or penalty of an acre of spring okra was $83 and that of spring tomatoes was $1327. The reduced cost represents the amount by which the objective function would fall if 1 acre of spring okra and 1 acre of spring tomato were to be forced into solution. The reduced cost of output and the shadow prices of resources are interpreted in a similar way (Hazell and Norton, 1986). The net benefit per hour of labor was $0.65, indicating that each hour of labor used in vegetable production, without the use of plastic on the example farm, generated $0.65 of net benefits.

Table 4. Base solution, scenario 1 and 2, vegetables produced, labor used, and shadow prices for simulated 5 acre farms in Alabama, 1992.

Scenarios†	Vegetables‡	Limit land	Production	Family labor	Hired labor	Shadow prices
Basic	S. okra (N)§	2.0	2.0			83
	S. tomatoes (N)	2.0	2.0	4409	115	1327
	S. yellow squash (N)	2.0	1.0			
S. land		5.0	5.0			1853
Scenario 1	S. cucumber (M)	2.0	0.11			
	S. okra (M)	2.0	2.0			
	S. okra (N)	2.0	1.8	3141	0	
	S. tomatoes (M)	2.0	1.09			
	F. tomatoes (M)	2.0	0.12			
	F. okra (M)	2.0	2.0			1194
S. land		5.0	5.0			640
F. land			2.12			552

† Basic scenario: 5 acres, no plastic;
Scenario 1, 5 acres, plastic, equipment rented, capital $1000.
‡ S, spring; F, fall.
§ N, no mulch; M, mulch.

Scenario 1: Basic Farm Situation with Plastic Mulch

A similar farm situation as the example farm was simulated with the adoption of plastic mulch technology. The description of the farm situation is seen in Table 3. The farm solution produced 0.11 acre of cucumbers, 2 acres of okra, 1.09 acres of tomatoes, all using plastic in spring. Fall vegetable production included 0.12 acre of tomatoes, 2 acres of okra with mulch, and 1.2 acres of nonmulched okra (Table 4). All 5 acres of land were placed in production, requiring 3141 h of family labor and total investment of $27 738, resulting in a capital turnover of 1.42. Capital was the most limiting factor for fall vegetables. The penalty for bringing in additional acre of spring okra with mulch into the farm solution was $49 and that of fall okra was $1194. Spring land was the most limiting constraint. An additional acre of spring land would generate $640 and that of fall $552 (Table 4). The partial budget showed that the use of plastic mulch resulted in an increase in net economic value of $7548.04. The benefit cost index was 0.20 (Table 5).

This induced technology innovation generated higher levels of output, with modest increases in labor use, but total investment requirement almost doubled.

Sensitivity Analysis

To evaluate the sensitivity of the analysis, a number of parameters such as credit availability, production costs, and price of vegetables were altered. Each of these scenarios are examined.

Scenario 2: Credit Limit Increased to $25 000

Since credit is the major constraint for small farmers, farm investment credit was extended to $25 000. In this scenario, only famliy labor was used (see Table 3). The spring mulched vegetables in solution were 0.23 acre of okra, 1.3 acres of tomatoes, 2 acres of yellow squash, and fall mulched vegetables were 1.3 acres of tomatoes, and 0.9 acre of okra (Table 6). The nonmulched enterprise in solution is 1.4 acres of okra. June and September labor had shadow prices of $33 and $25, respectively. These shadow prices indicate that additional labor in these two periods is very valuable to the farm. The solution showed some increase in the objective function, but the number of vegetables produced was still at an upper limit of 2 acres per enterprise. Total revenue increased to $49 222 at a total cost of $34 793. Total amount of hired labor used was 4613 h, producing a net benefit to labor ratio of $3.13. September labor was the most constraining factor for fall vegetables. The partial budget analysis showed a positive net change in revenue of $11 610.57 and a net benefit cost index of 0.26.

Scenario 3: Family Labor is Supplemented by Hired Labor and the Capital Investment Limit is Expanded by $25 000

Since all famliy labor was exhausted in the previous scenario, family labor was supplemented by hired labor. The optimal solution generated gross revenues of $67 656 at an annual total cost of $48 579. All production was under mulch. Spring vegetables were 2 acres of okra, 2 acres of tomatoes, 1 acre of yellow squash, and fall vegetables were 2 acres of tomatoes and 1 acre of okra. Fall vegetable production increased by only 1 acre. The farm used 5631 h of family labor, plus 798 h of hired labor. Investment capital was the most limiting constraint. The net benefit to labor used was $2.96. The increase in revenue was due to the doubling of tomato production in spring and fall, which had been previously constrained by June labor. Labor costs significantly increased production costs, however. Mulched tomatoes in this solution replaced mulched spring cucumbers, nonmulched tomatoes in the spring, and mulched okra in the fall. The partial budget analysis showed a net economic gain of $16 088.54 and a benefit cost index of 0.24.

Scenario 4: Production Costs Increased by 20%

Production cost was increased by 20% to determine the sensitivity of the profitability of plastic mulch to changes in

Table 5. Partial budget and benefit-cost index for six simulated scenarios of a 5 acre farm in Alabama, 1992.

Partial budget	Base solution	1	2	3	4	5	6
Added revenue	0	34 233.00	45 709.50	67 657.50	65 203.20	62 699.00	71 177.50
Reduced cost	0	10 203.20	11 216.68	14 068.04	14 068.04	14 068.04	14 068.04
Net positive effect	0	44 436.20	56 926.18	81 717.54	79 721.24	76 760.04	85 245.54
Added cost	0	24 167.12	31 787.30	48 579.00	46 025.53	43 929.34	50 926.82
Reduced revenue	0	12 721.00	13 528.31	17 050.00	17 050.10	17 050.00	17 050.00
Net negative effect	0	36 888.12	45 315.61	65 629.00	63 074.53	60 979.34	67 976.82
Change in net economic value	0	7 548.08	+11 610.57	+16 088.54	+16 196.71	+15 780.70	+17 268.72
Benefit-cost index†	0	0.20	0.26	0.24	0.26	0.26	0.25

† Index calculated via formula by Estes et al. (1985), $\text{Benefit - Cost index} = \frac{\text{Net positive effect}}{\text{Net negative effect}} - 1$

Table 6. Vegetables produced, labor used, and shadow prices for simulated 5 acre farms in Alabama, 1992.

Scenarios†	Vegetables‡	Limit land	Production	Family labor	Hired labor	Shadow prices
Scenario 2	S. okra (M)§	2.0	0.23			
	S. okra (N)	2.0	1.40	4613	0	
	S. tomatoes (M)	2.0	1.30			
	S. yellow squash (M)	2.0	2.00			498
	F. tomatoes (M)	2.0	1.30			
	F. okra (M)	2.0	0.90			
S. land		5.0	4.93			1276
F. land		5.0	2.20			306
June labor						33
September labor						25
Scenario 3	S. okra (M)	2.0	2.0			23
	S. tomatoes (M)	2.0	1.09			
	S. yellow squash (M)	2.0	1.0	5631	798	
	F. tomatoes (M)	2.0	2.0			
	F. okra (M)	1.0	1.0			
S. land		5.0	5.0			3914
F. land		5.0	3.0			1795
Scenario 4	S. okra (M)	2.0	1.18			
	S. tomatoes (M)	2.0	1.82			
	S. yellow squash (M)	2.0	2.00	5514	0	19
	F. tomatoes (M)	2.0	1.87			
	F. okra (M)	2.0	1.31			
S. land		5.0	5.00			3257
F. land		5.0	3.18			1566
Scenario 5	S. okra (M)	2.0	1.18			
	S. tomatoes (M)	2.0	1.82			
	S. yellow squash (M)	2.0	2.00	5268	369	23
	F. tomatoes (M)	2.0	1.50			
	F. okra (M)	2.0	1.69			
S. land		5.0	5.00			2478
F. land		5.0	3.19			1217
Scenario 6	S. okra (M)	2.0	2.0			114
	S. tomatoes (M)	2.0	2.0			1581
	S. yellow squash (M)	2.0	1.0	5631	798	
	F. tomatoes (M)	2.0	2.0			991
	F. okra (M)	2.0	1.0			
S. land						4212
F. land						1995

† Scenario 2: 5 acres, equipment rented, credit limit $25000.
Scenario 3: Family labor is supplemented by hired labor, equipment rented, capital $25000.
Scenario 4: Vegetable production cost increased 20%, equipment rented, credit limit $25000.
Scenario 5: Decrease in vegetable prices by 20%, mulch equipment rented, $25000 capitol available.
Scenario 6: Labor cost reduced by 20%, mulch equipment purchased.
‡ S, spring; F, fall.
§ N, no mulch; M, mulch.

production costs. The effect of increasing production costs by 20% led to lower returns to land, family labor, and management. The vegetables in solution were all mulched. Spring crops in solution were 1.18 acres of okra, 1.82 acres of tomatoes, and 2 acres of yellow squash. Fall crops were 1.87 acres of tomatoes and 1.31 acres of okra. This solution resulted in less hired labor being used than in the basic farm situation with plastic mulch. Land was the most limiting factor and an additional unit of spring land would yield $3257 and fall land $1566. Investment was the most limiting factor for fall vegetables. There was an increase in production of yellow squash, which required less operating capital and reduction in the acreage of tomatoes produced. Tomato production demanded larger amounts of operating capital. The net effects of an increase in production cost were due to a reallocation of resources and a reduction in returns to management. Other factors, such as the purchase of more inputs and reduction in the price of outputs, could have similar impacts on output and resource use. Net benefit to an hour of labor used was $3.50. The net economic value due to the use of plastic mulch was $16 196.71 with a benefit cost index of 0.26.

Scenario 5: A Decrease in Vegetable Prices by 20%, Mulch Equipment is Rented

Vegetable prices fluctuate a great deal and a 10% increase or decrease in price could mean success or failure to marginal farmers. Vegetable prices were decreased by 20% to determine how sensitive the use of plastic mulch was to price changes. Only mulched vegetables came into solution. Spring crops included 1.18 acres of okra, 1.82 acres of tomatoes, and 2 acres of yellow squash. Fall crops included 1.5 acres of tomatoes and 1.69 acres of okra. Land was again the most limiting factor. The shadow price of spring land was $2478 and that of fall land was $1217. Total revenue generated was $62 777 at a total cost of $43 893. The net returns to each hour of labor used was $3.45. The change from no plastic use to plastic mulch resulted in net revenues of $15 780.70 with a benefit cost index of 0.26.

Scenario 6: Labor Costs are Reduced by 20% and Plastic Mulch Equipment is Purchased

The main purpose of this scenario is to test the sensitivity of equipment purchase on the outcome of adopting plastic mulch technology and, at the same time, to see how income would change if labor costs are reduced. The main change in solution is income reduction. Total revenue was $67 656 and total cost $48 579.

Spring mulched vegetables in solution included 2 acres of okra, 2 acres of tomatoes, and 1 acre of yellow squash. Fall vegetables were 2 acres of fall tomatoes and 1 acre of fall okra. In spite of the reduction in labor costs, there was only a small increase in labor use. All spring land available was used. Capital was again the most limiting factor. The reduction of labor cost resulted in the increased shadow price of a unit of land. An additional unit of land would yield $4212 in spring and $1995 in fall.

Labor use generated $2.97 for every hour applied in production. This scenario shows that the net benefit to labor is lowered when equipment is purchased instead of rented. The change to plastic mulch produced additional net revenues of $17 268.72 and a benefit cost index of 0.25.

DISCUSSION

The survey showed that most of the farmers in the area were well experienced in vegetable production. In the evaluation of technology adoption for a group of users, the age of the individuals will help reflect how quickly they adopt the technology. Older farmers tend to be more conservative and are less willing to invest in high cost technologies than younger ones. Survey results showed that farmers were not aware of the potential damages of chemicals to the environment and they did not think that they were using too great an amount of chemicals. In fact, they felt that lowering the amount of chemicals would lower the quantity and quality of vegetables. Hence, arguments geared at encouraging them to lower chemical use would have to demonstrate that alternative technologies are profitable. The cost required for adopting plastic mulch technology for vegetable production is fairly substantial and may be beyond the means of limited resource farmers who are close to retirement. The change from no plastic to plastic mulch resulted in increased net income. Farmers may be willing to adopt new technologies, but credit must be available to them.

The linear programming results showed that the use of plastic generated higher gross and net revenues, but had higher capital cost requirements. The total costs with plastic mulch almost doubled that without plastic mulch. This situation must be noted by researchers and extension agents who encourage the use of plastic mulch, since most of the vegetable farmers in the area are 60 yr old or more, may have less desire for money, and are unwilling to accept credit risks. In spite of the high capital requirements, the net benefit to cost index was positive with the change from no mulch to plastic mulch. The total cost also increased with output with the use of plastic mulch because of additional financial requirement for the harvest and marketing of the added output resulting from the use of plastic mulch.

It must be noted that a number of farm situations included both mulched and nonmulched vegetables. Though the enterprise budget for a single activity may show higher net revenues for mulched vegetables, the most profitable farm situation may be a combination of both mulched and nonmulched crops.

The solutions did not change substantially when equipment was purchased instead of rented, though income declined. With rented equipment becoming available, more farmers may adopt this technology.

SUMMARY AND CONCLUSION

Plastic mulch required a higher investment for the purchased equipment situation and operating costs increased when equipment was rented. Use of plastic mulch resulted in substantial increases in output and total revenues, and improved capital turnover ratios. These changes were due to changes in technology and management. Each unit of labor generated higher net returns when plastic mulch was used. The increases in technology and management resulted in higher total costs. Plastic mulch technology increased farm income substantially for the scenario where equipment was purchased. The increased costs placed an added risk burden on farmers, who, at the upper end of their farm life cycle, are more risk averse.

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Measuring Sustainable Cotton Production Using Total Factor Productivity

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Continuous cotton (*Gossypium hirsutum* L.) production was examined using data from Alabama's long-term Old Rotation experiment (c. 1896). Index values were used to examine trends in productivity and sustainability for 95 yr. Treatments studied were those receiving (i) no N fertilizers and no winter legumes for 95 yr, (ii) only winter legumes as a source of N, and (iii) chemical fertilizer N. Three sets of index numbers were calculated from all inputs and outputs involved in the production systems: (i) total factor productivity (TFP), which accounts for all direct production inputs, but which does not consider production externalities; (ii) productivity relative to a base plot; and (iii) total social factor productivity (TSFP), which accounts for all direct production inputs as well as externalities of soil erosion and pesticide use. Viewed from the 95-yr perspective of the Old Rotation experiment, all three treatments fulfill at least one criterion required for a system to be considered sustainable. Output per unit of input is higher in 1991 than in 1896, even when externalities are valued. None of the systems showed a linear trend in output or TFP over the life of the experiment; productivity cycles are present in all three systems, despite a positive overall trend. An average annual rate of TSFP growth of 1.8%/yr was attained. Accounting for erosion and pesticide externalities reduced the annual productivity growth rate by 0.2%/yr. The system that has neither an organic nor a chemical source of added N was less productive and less sustainable than the two other systems, with a 0.3%/yr TSFP growth rate. The plots using organic and chemical sources of N had similar productivity impacts. Valuing soil erosion and pesticide externalities had only a modest effect on measured productivity. The most dramatic single event to affect the productivity of cotton farming was the introduction of the mechanical cotton picker. The impact of this technology was powerful enough to offset the effect of many other changes in the system.

DEFINING SUSTAINABLE agriculture or sustainable land management has been a difficult challenge for those attempting to work in this area. Nevertheless, most who have written about sustainable agriculture/sustainable land management generally agree that a sustainable system should maintain or enhance agricultural production (productivity), reduce the level of production risk for the farmer (security), protect natural resources (protection), be economically viable (viability), and be socially acceptable (acceptability) (Novak and Goodman, 1994; Pfeffer, 1992; Taylor, 1990). With these five fundamental areas that sustainable system must address, we can begin to devise ways of measuring a cropping system to see if it is truly sustainable.

Cotton production has had a major impact on the economy of the southeastern USA for almost 200 yr. The fact that it continues to be produced as an economically viable crop gives us an idea of cotton's viability and acceptability in a sustainable production system. Yet the historical record of cotton production's destruction of natural resources (soil erosion in the southern Piedmont, stream sedimentation, deforestation, etc.) leaves doubt as its sustainability as a protector of the natural resource base (Trimble, 1974). Pesticide use since the boll weevil (*Anthonomus grandis* Boheman) entered the Cotton Belt in the early 1900s has added to concerns about sustainability, especially since some of the early insecticides included arsenicals and DDT, which are no longer allowed by EPA because of their health or environmental hazards.

Productivity is also difficult to assess because it involves more than just yield per acre. Alabama's cotton acreage is approximately 10% of what it was during peak production in 1914, yet statewide yields are five times higher. The price growers receive has fluctuated over the past 100 yr. These trends make evaluating sustainability very difficult.

Records from long-term, agronomic research experiments where actual inputs and yields are known are extremely valuable for assessing productivity. Production indexes have been suggested as appropriate measures of change (Binswanger, 1978; Lu et al., 1979). If all quantifiable inputs and outputs are known or can be reasonably estimated from historical records, then a TFP index can be calculated. If externalities such as the cost to society from exposure to pesticides or the negative effects of sedimentation from soil erosion can be factored into TFP, then a TSFP index can be defined and used to evaluate long-term sustainability of a production system.

One advantage of using indexes is the ease with which they can be developed and compared. The movement of a TFP index over time addresses the question of the sustainability of cotton production. Total factor productivity can be a more informative productivity indicator than partial measures such as output per unit of land or output per unit of labor. The appeal of TFP is that it can be interpreted as "output per unit of input." This index number formula adjusts for the effect of changing input prices, so that changes in TFP can be attributed to a change in production efficiency, rather than changing market prices; a doubling of TFP implies that twice as much output is derived from each "unit" of input. The Tornquist approximation to the Divisia index was used in our analysis. The Divisia index number formulation has appealing theoretical properties, including consistency with

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Abbreviations: TFP, total factor productivity; TSFP, total social factor productivity.