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Feasible Fumigant-Herbicide System Alternatives to Methyl Bromide for Bell Pepper Producers

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With the current methyl bromide (MeBr) system for producing Georgia's peppers being phased out, alternative fumigant and herbicide systems for producers are analyzed. Using stochastic dominance analyses, two alternatives exceeding MeBr's yield and financial efficiency were identified. A programming model, incorporating simulation-optimization techniques, generated optimal production and financial plans. Results indicate potential economic viability under alternative systems vis-à-vis the traditional MeBr production system. The Telone II and Chloropicrin combination with Metham potassium may offer a viable substitute for MeBr.

Key Words: fumigant, herbicide, methyl bromide, multi-period programming, optimization, simulation, stochastic dominance

On September 16, 1987, 24 nations ratified the Montreal Protocol on Substances that Deplete the Ozone Layer. A component of this international agreement identified substances causing significant damage to the ozone layer. Methyl bromide (MeBr) was one such substance considered a major toxic contributor to ozone depletion, and thus was recommended for an accelerated phase-out originally set in 2005.

MeBr's contribution to agriculture and its integral role in facilitating international trade have led to a general agreement that there should be allowances for "critical," "quarantine," and "pre-shipment" uses. The Protocol states that a use of MeBr should qualify as "critical" only if the nominating party determines that its lack of availability would result in a significant market disruption, and there are no technically and economically feasible alternatives available. These potential alternatives should be acceptable from the standpoint of environment and health and be suitable to the crops and circumstances of the nomination (United Nations Environment

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Programme, 2000). The phase-out schedule, for developed nations including the United States, adheres to a 100% reduction by the year 2005, but allows for emergency uses after 2005.

Currently MeBr serves as an agricultural fumigant primarily used to control weeds, nematodes, soil-borne pests, and diseases. It has been widely adopted by U.S. agricultural producers because of its ease of use, affordable cost, and effectiveness in most climates. However, with the imposed ban on its use, research efforts have focused on identifying alternative fumigants which would at least equal, if not exceed, MeBr's technical efficacy and financial efficiency.

California and Florida have conducted significant research examining alternatives and the economic impact resulting from the phase-out. The majority of these experiments have focused on strawberries and tomatoes, the major crops of interest in Florida and California, thus leaving some void in information on the feasibility of input substitution strategies for other vegetable crops (U.S. Department of Agriculture/Economic Research Service, 2001). In Georgia, vegetables are the second most valuable crop, with a farm-gate value of $901 million (Boatright and McKissick, 2003). Georgia ranks third nationally in acreage of fresh market vegetables planted. Vegetable growers in Georgia argue that eliminating MeBr will reduce yields and increase production costs (Seabrook, 2005). During the past several years, Georgia producers have been pressed for time to identify technically and economically feasible alternative production systems as a replacement for MeBr.

Unlike California, researchers and scientists in Georgia and Florida have had to deal with another issue in their search for alternative fumigation-herbicide systems. Yellow and purple nutsedge are common weeds that thrive in the southeastern United States due to its humid climate. In order to control for nutsedge, it is necessary to apply a combination of plastic mulch, fumigants, and herbicides to crops such as tomato and pepper (Gilreath and Santos, 2004). A list of fumigants such as metham sodium (MNa), chloropicrin (teargas) (Pic), anhydrous ammonia (AHN4), and 1,3-dichloropropene (1,3-D) have been tested in combination with the herbicides napropamide, metolachlor, and pebulate, and analyzed in comparison to MeBr (Gilreath, Noling, and Santos, 2004). While these tests focused on identifying comparable yield structures[1] among alternative chemicals, the financial feasibility of these substitutes was not a priority.

This study addresses the financial feasibility of available fumigation-herbicide alternatives both from risky and risk-free operating situations by employing two analytical tools, stochastic dominance and simulation-optimization techniques, respectively. Specifically, the second-degree stochastic dominance analysis is first applied to consider the riskiness of the alternative fumigant-herbicide systems and to identify the most risk-efficient method. Data limitations to capture the riskiness

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[1] Comparing yield structures involves analyzing not just the overall yield level but also the relative proportions of the different pepper grades that command different market prices. For example, the proportion of jumbo peppers assigned the fancy pepper grade is compared with the proportion of the regular US 1 & 2 pepper grade since the former commands a much higher price.

of newly established alternative production systems on an annual basis have resulted in the formulation of a multi-period linear programming framework that is used to analyze the comparative yield efficiency and financial feasibility of three alternative fumigation-herbicide systems under a risk-free operating environment. These three alternatives are based on field trials conducted by University of Georgia scientists in Tifton, Georgia, during 2002–2003 relative to a base treatment system involving MeBr.

Stochastic Dominance Analysis

Stochastic dominance (SD) analysis is a risk-efficiency criterion for determining the risk-efficient set of alternatives available to producers when faced with uncertain outcomes. It allows for a ranking of alternatives based on producers' risk preferences. Researchers have developed multiple variations of stochastic dominance, but its two basic criteria are first- and second-degree stochastic dominance. We employ second-degree stochastic dominance (SDSD) analysis, which eliminates dominated or inefficient distributions from the first-degree stochastic dominance set (Huang and Litzenberger, 1988). This is accomplished by adding the assumption of risk aversion to the decision-making process with respect to agents' preferences. (For more detailed discussion of SDSD, interested readers are referred to Huang and Litzenberger.)

Risk-averse agents seeking to maximize utility will never prefer a dominated distribution. Therefore, a second-degree stochastically efficient set of alternatives will be comprised of only nondominated distributions, and any further reduction of this set will require additional assumptions concerning risk preferences (Anderson, Dillon, and Hardaker, 1977).

The existence of crossings of distribution plots could, however, cause second-degree stochastic dominance failure or the inability to determine the dominance rankings of the distributions being analyzed. Hammond (1974) has proposed an approach to deal with the crossings problem. He contends that the rankings of alternatives in this case will depend on the decision maker's risk aversion coefficient. Thus, in this analysis, two scenarios of high and low risk aversion are considered to capture any variations in the rankings of alternatives.

Four variables are separately considered in the stochastic dominance analysis:

1. An aggregate yield measure that disregards the pepper grade components of total yield.
2. A jumbo (fancy pepper grade) yield measure which commands a higher price than the regular US 1 & 2 pepper grade.
3. A gross revenue measure where the grade components of total yield are weighted by the grades' respective prices.
4. A net return per acre measure derived from the extrapolated experimental yields and the corresponding variable and fixed costs for each acre of pepper farm operations.

For variables 3 and 4, the experimental yields are extrapolated to acre-scale revenues given the fact that experimental plots are 0.001 of an acre.

The yield data used in this study were obtained from field trials conducted in 2002 and 2003 at the University of Georgia (UGA) Center for Agribusiness and Economic Development's experimental plots in Tifton, Georgia. The Center's scientists determined a set of fumigants and herbicides to be tested based on current and past literature (Culpepper and Langston, 2000). These field experiments addressed major pest control concerns of Georgia bell pepper producers, and aimed to identify an effective control for nutsedge, a weed that cannot be controlled with black plastic mulching. The experiments analyzed two herbicide systems (no herbicide control and the Command-Devrinol-Dual Magnum prescription), along with three fumigant options on 6' × 35' experimental plots. Results of these field trials determined the fumigants' overall ability to control nutsedge growth. Culpepper and Langston report that the herbicide system contributed to nutsedge control by increasing the containment (growth suppression) rate from 24% to 27%.

The three alternative fumigant systems considered are C35 + KPAM, Telone II + Chloropicrin, and C35 + Chloropicrin, and each were separately combined with a commonly prescribed herbicide system consisting of Clomazone (Command), Napropamide (Devrinol), and s-metolachlor (Dual Magnum). KPAM serves as an abbreviated term for metham potassium, C35 identifies a Telone II and Chloropicrin combination, and Telone II represents 1,3-Dichloropropene.

In this study, stochastic dominance analysis was conducted using yield and cost records for two production cycles of six experimental plots developed by the UGA-Tifton scientists for each of the four fumigation-herbicide systems. A bell pepper enterprise budget model prepared by the UGA Agricultural Economics Extension team was used to calculate values for gross and net returns, which are two of the four variables considered in the stochastic dominance analysis.

The Multi-Period Programming Model

The financial and production decisions of a representative Georgia pepper producer are analyzed using simulation-optimization techniques in a mathematical programming framework. The producer's goal is to optimize his or her expected utility of accumulated net worth over a specified planning horizon. The choice between using a nonlinear risk and a linear risk-free programming model is constrained by data limitations. Nonlinear risk programming models require the construction of a variance-covariance matrix to account for risk. In this matrix, several years of historical cost and returns data, among other data requirements, will be needed for the newly identified alternative fumigant-herbicide systems. In view of the lack of more longitudinal, annual data on these new production methods, a risk programming model could not be developed at this time.[2]

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[2] In contrast, the stochastic dominance analysis performed in this study utilized experimental data that allowed for the measurement of risk from a cross-sectional (experimental plots) point of view, instead of the time-series perspective required for a multi-period nonlinear risk programming analysis. Variables in the programming model are

The risk-neutral linear programming (LP) model employed in this study accounts for the net changes in final wealth regardless of the producer's risk considerations (Gwinn, Barry, and Ellinger, 1992; Barry and Willmann, 1976; Escalante and Barry, 2001). The programming problem in matrix format is constructed as:

$$\text{(1)} \qquad \begin{aligned} &\text{Max } \mathbf{Z} = \mathbf{CX} \\ &\text{s.t.: } \mathbf{AX} \;\#\; b, \\ &\qquad \mathbf{X} \;\$\; 0, \end{aligned}$$

where **Z** is a matrix of the total objective value, **C** is a column vector representing the contribution of each unit of **X** to the objective function, **A** is the use of the items in the *i*th constraint by one unit of x_j, and b is the upper limit imposed by each constraint (McCarl and Spreen, 1994). The final inequality imposes a nonnegativity constraint on the decision variables. Major components of equation (1) are described below, with a full discussion provided in Byrd (2005).

The model operates under a five-year planning horizon in its determination of the producer's optimal net accumulation of wealth (net income over this period). The final accumulation of net worth is calculated by accruing the values of farmland, equipment, and cash balance at the end of the planning horizon less all financing charges contracted over the same period. The model's constraints establish limits on land availability, machinery requirements, off-farm investments, consumption, and borrowing levels. In order to capture the timing of certain cash flows within each year, the model has two subperiods in its cash transfer equations

The model's empirical properties resemble previous multi-period programming models (Barry and Willmann, 1976; Gwinn, Barry, and Ellinger, 1992) that define a large matrix of activities and constraints where submatrices along the main diagonal elements correspond to the time periods and off-diagonal elements provide information on transfers among the model's activities. The major activities include production and marketing, land, and machinery investments, related borrowing alternatives, farmland leasing under cash-rent conditions, short-term borrowing, off-farm investments, liquidity management, consumption, and taxation. Specifically, the model allows the expansion of production area by either entering into a one-year renewable cash leasing contract or purchasing additional acreage of farmland. Machinery requirements in each production year can be satisfied through already owned equipment and, if necessary, the purchase of new machinery. Labor requirements can be supplied by family members and hired farm laborers. The model assigns a credit facility for each of the operator's financing needs. Aside from equity

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calculated on a production year basis. While the risk component of most decision variables can be defined using available historical annual data, the untested new methyl bromide alternative fumigation methods do not have historical data that can provide estimates of their riskiness. In light of the production-year perspective of this multi-period programming model, the cross-sectional observations for the returns for these new methods cannot be used to substitute for the required time-series data.

funds that may be used when the operator generates a cash flow surplus, land acquisition, equipment purchases, and working capital requirements may be financed by long-, intermediate-, and short-term credit facilities, respectively. Withdrawals for family living expenditures are evenly divided and disbursed in each of the two subperiods. The operator also derives off-farm income by investing in nonfarm assets. The cash transfer equations take up the investment as an outflow in the first subperiod and recover the same amount along with gains from investment in the second subperiod.

The final goal of optimizing a producer's net worth is predicated and begins with the analysis of a base-case representative farm model. The base model accounts for the activity measures and financial conditions of a typical producer's operations. Adjustments to components of the base model reveal variations in the profitability and cost structure of the producer's operations. This analysis involves iteratively running the base-case farm model by introducing adjustments in the production system as defined by the fumigants and herbicides employed as chemical controls on the farm. More specifically, the production system using MeBr and an accompanying menu of herbicides is chosen to serve as the base case. The other three alternative fumigation systems, using the same herbicide system as that in the MeBr system, are then tested against this base case. In each iterative run of the base model, yields and input costs applicable to each alternative system are used.

The Representative Georgia Pepper Farm

The simulation-optimization analysis is applied to a representative Georgia pepper operation whose conditions define the initial resource, financial, and operating levels of the base model. The financial attributes were constructed according to the average financial operating conditions of approximately 50 farm operations registered with the Georgia Farm Business Farm Management Association in 2001. The initial operation size is 362 acres, of which 300 acres are owned by the producer and 62 acres are rented.

The producer's pre-operating balance sheet declares a total farm asset value of \$1,843,234, which includes \$468,900 worth of machinery and equipment and farmland value of \$645,000. The producer's assets were financed by current (\$241,688), intermediate (\$422,010), and long-term (\$350,099) debts as well as the operation's equity funds (\$829,437). Based on these figures, the producer's debt-to-asset ratio is 0.55. The producer's annual living expenditures in the pre-operating year amount to \$31,729, excluding income taxes. That year, the producer generated a net farm income of \$20,171 plus a net nonfarm income of \$13,180, both before taxes.

Average yields and costs were calculated from the production records for two cycles for the six experimental plots (for each fumigant-herbicide system). These cost-returns data were then used as inputs in each version of the multi-period programming model.

Results

The results of the two analytical methods are presented in tables 1, 2, and 3. The effect of risk aversion on producers' preferred rankings of alternative production systems (as suggested by Hammond, 1974) is considered in the stochastic dominance analysis. In this approach, two scenarios are modeled by setting the risk-aversion coefficients at 0.00004 and 0.004 to represent conditions of low and high risk aversion, respectively.[3]

Stochastic Dominance Rankings and Risk Aversion

Based on total experimental yields (table 1), the C35 + KPAM is the most preferred production system under both low and high levels of risk aversion. This system produced the highest mean yield of 36.33 lbs. per plot, but has a high relative variability with a coefficient of variation (CV) of 0.4737, ranking second among the four production systems. MeBr, despite its low relative variability (CV) of 0.4582, could not overtake C35 + KPAM in the overall rankings due to its mean yield of only 32.67 lbs. per plot. C35 + PIC and T2 + PIC are in third and fourth place, respectively, in the low risk-aversion category, and in fourth and third place, respectively, in the high risk-aversion category. While C35 + PIC has the least volatile yield results, its mean yield of 32.33 lbs. per plot is too low to enable it to dominate C35 + KPAM in the preference rankings.

The preference ordering based on jumbo grade alone reveals the vulnerability of the MeBr system vis-à-vis the three other systems. MeBr's mean jumbo yield of 10.22 lbs. per plot is eclipsed by the top two jumbo yields of 15.00 and 12.56 lbs. per plot delivered by the C35 + KPAM and T2 + PIC systems, respectively. The preference rankings are identical in both the low and high risk-aversion categories (table 1).

The gross revenue rankings introduce the price component[4] to serve as weights for the different pepper grades, and thus capture variations in the pepper grade compositions in the four production systems. Consistent with the total and jumbo yield rankings, C35 + KPAM dominates the other three production systems in the gross revenue rankings with its mean of $14,821 per acre (highest mean) despite its highly variable revenue structure (CV of 0.4472). MeBr's second-place rank in terms of total yield is pulled down in the gross revenue rankings due to lower proportion of jumbo yield relative to this pepper grade's proportion to total yield in the other fumigation methods, which commands a higher price than the US 1 & 2 pepper grade. MeBr is ranked third by the less risk-averse decision maker, while the more risk-averse producer considers it the least preferred system. C35 + PIC, which

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[3] These values are within the acceptable range determined by Babcock, Choi, and Feinerman (1993).

[4] Annual average prices for jumbo and US 1 & 2 peppers in 2003 were used in this analysis under the assumption that this year represented a normal or representative year for producers relative to the abnormally high market prices in 2004 resulting from production shrinkage from hurricanes.

Table 1. Descriptive Statistics and Results of Second-Degree Stochastic Dominance (SDSD) Analysis Under Different Levels of Risk Aversion

	Production Systems			
Measures/Rankings	MeBr	C35+KPAM	T2+PIC	C35+PIC
A. Based on Total Yield:				
Mean Yield (lbs./0.001 acre)	32.67	36.33	31.33	32.33
Standard Deviation	14.97	17.21	14.96	12.56
Coefficient of Variation	0.4582	0.4737	0.4774	0.3884
SDSD Rank, Low Risk Aversion	2	1	4	3
SDSD Rank, High Risk Aversion	2	1	3	4
B. Based on Jumbo (Fancy Pepper Grade) Yield:				
Mean Yield (lbs./0.001 acre)	10.22	15.00	12.56	10.56
Standard Deviation	3.03	3.85	2.79	4.22
Coefficient of Variation	0.2966	0.2565	0.2221	0.3994
SDSD Rank, Low Risk Aversion	4	1	2	3
SDSD Rank, High Risk Aversion	4	1	2	3
C. Based on Gross Revenues:				
Mean Revenues ($/acre)[a]	12,980.63	14,821.43	12,741.59	12,894.44
Standard Deviation	5,623.67	6,628.20	5,635.27	4,566.92
Coefficient of Variation	0.4332	0.4472	0.4423	0.3542
SDSD Rank, Low Risk Aversion	3	1	4	2
SDSD Rank, High Risk Aversion	4	1	3	2
D. Based on Net Returns:				
Fumigation Cost per Carton[b] ($)	0.35	0.61	0.47	0.87
Variable Cost per Carton[b] ($)	9.64	9.61	9.90	10.22
Fixed Cost per Acre ($)	860	920	879	954
Mean Net Returns ($/acre)[a]	5,579.21	6,694.25	5,851.59	3,910.07
Standard Deviation	5,623.67	6,628.20	5,635.27	4,566.92
Coefficient of Variation	1.0080	0.9901	0.9630	1.1680
SDSD Rank, Low Risk Aversion	3	1	2	4
SDSD Rank, High Risk Aversion	3	2	1	4

[a] Gross revenues and net returns were derived from enterprise budgets prepared for an acre of pepper farm operation. For purposes of this analysis, the yield results obtained from the 0.001 experimental plots were therefore extrapolated into one-acre operations to generate the gross revenue and net return estimates.

[b] A carton is approximately equivalent to 28 lbs. of peppers.

consistently ranks third (or fourth) in both total and jumbo yields, has the least variable gross revenue structure (CV of 0.3542) and ranks second under both categories of risk aversion (table 1).

Rankings based on net returns expand the perspective on gross revenue analysis by introducing the effect of cost. Table 1 provides supplemental information on the applicable production costs to better understand the derivation of net returns.

Producers argue that MeBr's advantage of cost efficiency is difficult to match. The summary in table 1 supports this argument, with MeBr requiring the least fumigation cost per carton and fixed cost per acre. However, C35 + KPAM and T2 + PIC closely match MeBr's cost efficiency. Specifically, C35 + KPAM has a probably insignificant lower variable cost per carton of $9.61 versus MeBr's $9.64. Among the three alternative systems, T2 + PIC's fumigation cost per carton of $0.47 comes closest to MeBr's $0.35.

Considering both gross revenue and cost structures, the net return rankings favor C35 + KPAM and T2 + PIC over MeBr. C35 + KPAM's ranking is not surprising, considering its consistently high placement in all previous rankings (total yield, jumbo yield, and gross revenues). T2 + PIC, which ranks in the last two places in the gross revenue rankings, is the most preferred system by the more risk-averse producer, mainly owing to this system's CV of 0.9630 (the lowest among the four systems). C35 + PIC, the most expensive production system based on the cost summary in table 1, is the least preferred system under both categories of risk aversion, and this cost disadvantage pulls down its second place finish in the gross revenue rankings.

Optimal Production Plans

The LP model [equation (1)] delivers solutions to the optimization problem for each period throughout the five-year time horizon. Additions and/or reductions to both the producer's assets and liabilities dictate adjustments to the final value of accumulated net worth. These adjustments can be made through increases or decreases in the model's decision variables representing land purchases, cash-rented acreage, new equipment purchases, off-farm investments, and incremental short-, intermediate-, and long-term debt.

Each optimization of the four production systems began with an identical set of assumptions concerning specific attributes of the representative farm. For example, beginning land values and cash rent levels, equipment costs, family consumption, off-farm income and yields on off-farm investments, depreciation schedules, and interest on credit facilities were constant values at initial time $T(0)$ for all systems. Variables including per acre variable production costs, gross returns, overhead costs, and net margins, along with farm wage rates, were forecasted to increase due to inflation.

Conveying the LP solutions for the production variables as five-year averages, the summary in table 2 indicates that MeBr and C35 + KPAM systems yield similar preferred solutions relative to the other two systems. The more detailed yearly programming solutions in table 3 reveal some trends in production and financing decisions made under the different production systems.

Farm Size Solutions and Farmland Control Arrangements

An upper-limit constraint on total production of 1,000 acres per system has been imposed on the farm size solutions reported in tables 2 and 3. Given this constraint,

Table 2. Programming Solutions and Financial Ratios, Five-Year Averages

	Production Systems			
Activity Measures/Ratios	MeBr	C35 + KPAM	C35 + PIC	T2 + PIC
Farm Size (acres)	1,000	1,000	886	887
Incremental Land Purchases (acres)	435	435	300	300
Acres Rented	565	565	586	587
Incremental Equipment Purchases ($)	$0	$0	$22,416	$32,276
Off-Farm Investments ($)	$1,528,000	$1,520,800	$393,840	$393,840
Tenure Ratio	0.4530	0.4350	0.3386	0.3382
Current Ratio	310.7210	331.5987	62.9012	100.6090
Debt-to-Asset Ratio	0.0089	0.0084	0.0253	0.0266
Off-Farm Investment-Total Assets Ratio	0.0325	0.0303	0.0219	0.0223

both MeBr and C35 + KPAM produced the maximum of 1,000 acres each year (table 2). The yearly results in table 3, however, indicate different patterns of land purchase and renting decisions under these two systems, especially during the first two years of the planning period. For instance, the MeBr solutions prescribe a purchase of seven acres more and a renting of seven acres less than the solutions prescribed for C35 + KPAM in year *T*(1), but purchased less and rented more land in year *T*(2).[5] It is expected that relaxing the constraint on farm size would result in even larger acreage solutions under MeBr and C35 + KPAM, although intuitively producers would tend to plant more under the C35 + KPAM system given its established dominance over the MeBr system in both gross and net returns.

The average C35 + PIC and T2 + PIC solutions of 886 and 887 acres, respectively, are below the imposed farm size constraint (table 2). Notably, the prescribed average farm size solution for MeBr is larger than the C35 + PIC and T2 + PIC systems, although each of them has dominated the MeBr system in terms of gross revenues and net returns, respectively, as shown in the stochastic dominance analysis results in table 1. A closer examination of the cost structures of these three systems, however, indicates that MeBr entails the lowest fumigation, variable, and fixed costs (table 1). In the programming model, the timing of cash disbursements, which is captured in the cash transfer equations, is an important consideration in prescribing solutions that maintain acceptable liquidity conditions. In this case, lower amounts of advances for production costs in subperiod 1 of the cash transfer equation are more preferred, even if larger revenues are realized later in subperiod 2.

Cash renting has also been more opted as a strategy to increase farm size under the C35 + PIC and T2 + PIC systems. Over the planning period, the C35 + PIC system

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[5] Note that the solutions for land purchase activity measures are incremental measures that express the additional acres purchased in excess of the initial endowment of 300 acres. The values for acres rented do not accumulate during the planning period. Producers rent land for a period of one year, and at the beginning of the next period must again decide how much acreage to devote to renting. This figure is then carried over and added to purchases made during the next period, with this process being repeated over the life of the planning period.

Table 3. Optimal Production and Financing Plans, Yearly Programming Solutions

	Time Periods				
Production System/Activity Measures	*T*(1)	*T*(2)	*T*(3)	*T*(4)	*T*(5)
Methyl Bromide (MeBr):					
Acres Purchased	55	93	0	11	7
Acres Rented	645	552	552	541	534
Equipment Purchased	$0	$0	$0	$0	$0
Off-Farm Investments	$0	$1,873,500	$1,876,100	$1,921,200	$1,969,200
Tenure Ratio	0.3550	0.4480	0.4480	0.4590	0.4660
Current Ratio	75.6536	190.9730	315.2278	430.3238	550.4611
Debt-to-Asset Ratio	0.0505	0.0170	0.0086	0.0045	0.0032
C35-Metham Potassium (C35 + KPAM):					
Acres Purchased	48	102	0	10	7
Acres Rented	652	550	550	540	533
Equipment Purchased	$0	$0	$0	$0	$0
Off-Farm Investments	$0	$1,837,500	$1,876,100	$1,921,200	$1,969,200
Tenure Ratio	0.3480	0.4500	0.4550	0.4600	0.4670
Current Ratio	80.4174	202.6952	336.0724	459.7462	588.7872
Debt-to-Asset Ratio	0.0479	0.0160	0.0081	0.0042	0.0030
1,3-Dichloropropene-Chloropicrin (T2 + PIC):					
Acres Purchased	0	0	0	0	0
Acres Rented	649	538	612	590	544
Equipment Purchased	$0	$0	$109,040	$52,341	$0
Off-Farm Investments	$0	$0	$0	$0	$1,969,200
Tenure Ratio	0.3161	0.3580	0.3289	0.3371	0.3555
Current Ratio	62.2190	81.4923	78.8442	74.3274	194.0709
Debt-to-Asset Ratio	0.0607	0.0399	0.0336	0.0264	0.0093
C35-Chloropicrin (C35 + PIC):					
Acres Purchased	0	0	0	0	0
Acres Rented	649	605	592	563	522
Equipment Purchased	$0	$0	$77,461	$34,620	$0
Off-Farm Investments	$0	$0	$0	$0	$1,969,200
Tenure Ratio	0.3161	0.3315	0.3363	0.3476	0.3650
Current Ratio	4.1892	63.3410	81.3502	79.3299	79.0014
Debt-to-Asset Ratio	0.0598	0.0363	0.0318	0.0243	0.0086

required cash renting of an average of 586 acres per year, while T2 + PIC's average cash rented acres was 587 acres. No land purchases were prescribed for either of these systems over the entire period. The farm size solutions for these systems were nearly identical (table 2).

These preferences for different farmland control strategies are reflected in the tenure (proportion of owned land to total tillable acres) ratios reported in table 2. The five-year average ratios for MeBr and C35 + KPAM (0.4530 and 0.4350, respectively) are higher than those obtained for the other two production systems. As suggested by these results, given the scale and size of production solutions prescribed for the MeBr and C35 + KPAM systems, the returns and cash flow available to producers under these systems are more favorable and encourage more investments in farmland relative to the other two systems.

Off-Farm Investment Solutions

Discrepancies among solutions for the financial decision variables were pronounced between the MeBr and C35 + KPAM production systems versus C35 + PIC and T2 + PIC. Each of the four farm models began with an initial allocation of off-farm investments totaling $100,000. The former two systems realized off-farm investments of approximately $1.5 million per year over five years (table 2). In contrast, production systems C35 + PIC and T2 + PIC were prescribed equal solutions of $393,840 invested in off-farm activities per year when averaged over the planning period.

The ratio of off-farm investments to total assets reveals that more money is allocated outside of the primary revenue-generating activities of the farm for MeBr and C35 + KPAM where off-farm investments represent about 3% of all assets. A slightly lower proportion (about 2%) is obtained for the other two systems (table 2).

The larger farm size solutions prescribed for the C35 + KPAM and MeBr systems and their relatively high average net returns from production (table 1) allow them to generate more excess funds that can be set aside for off-farm investments. Off-farm investment decisions in the model are evaluated against the returns structure of the competing farm production investment alternative. In the model, off-farm yields are assumed to be lower than the net returns that can be generated from farm production. Apparently, the model has initially optimized the more lucrative farm investment solutions (through the prescribed acreage solutions) and only considered investing excess cash generated in off-farm activities. In all four systems analyzed, excess cash to be allocated for other investments can easily be accumulated given the large acreage solutions prescribed by the model and the net returns levels reported for each production system in table 1. As C35 + KPAM dominates the rest in terms of generating net returns, this system is expected to invest more in off-farm activities upon relaxation of the farm size constraint.

Liquidity and Solvency Solutions

In terms of liquidity, all current ratio results are highly favorable (table 2) as the farm relies less on short-term credit to finance operating capital requirements and, at the same time, accumulates off-farm investments that increase total current assets. C35 + KPAM with a current ratio of 331.59 had the highest liquidity. MeBr was also highly liquid with a ratio of 310.72. The ratios for all four systems were well above the critical value (around 2.0 times as established by some analysts for certain enterprises), indicating each had the ability to quickly pay off short-term debts.

Leverage positions, as measured by the debt-to-asset ratio, are likewise favorable under all production systems. Debt-to-asset ratios ranged from less than 1% (0.008 for C35 + KPAM) to a high of approximately 0.027 for T2 + PIC.

These results indicate less reliance on external funds to cover capital and operating funding requirements. They suggest that external financing is considered more costly than internally generated funds which can be reinvested into the business to cover cash flow requirements. The cost of borrowing used in this analysis is set at 8% to coincide with the prevailing rates at the time when the Federal Open Market Committee has been increasing the federal funds rate. Again, large acreage solutions prescribed by the model, coupled with the high levels of average net returns per acre, allow the accumulation of excess cash that more than adequately covers operating and all other cash requirements. This financial self-reliance significantly reduces the need to avail of large short-, medium- or long-term loans to supplement internally generated funds in covering all funding requirements. Apparently, the small amounts of external funds (loans) reflected in the programming solutions were incurred to strategically finance cash flow gaps resulting from the timing of certain fund disbursements and inflows.

Summary and Conclusions

The current MeBr system—which has proven to be a reliable, affordable, and effective fumigant—is slated to be phased out under the Montreal Protocol. Seeking alternative environmental and economically feasible systems, a two-year UGA field experiment has identified three production systems as possible replacements. These three systems involve combinations of three fumigant chemicals and a commonly prescribed herbicide system that have effectively controlled pests and generated equal or higher yields than the MeBr system.

This study extends the technical efficiency analysis by utilizing stochastic dominance techniques to compare the production and financial efficiencies of MeBr and alternative production systems. The analytical framework also accounts for the effect of producers' risk attitudes on the efficiency rankings of the four systems. Results of our analyses indicate that under conditions of both low and high risk aversion, only the C35 + KPAM system outperforms the MeBr system in total yields, although all three alternative systems dominated the MeBr system in jumbo pepper production. Considering gross revenue, with price premiums for the preferred pepper grades, along with all operating costs for calculating net returns, C35 + KPAM was the only system that consistently outperformed MeBr in terms of both gross and net returns. Notably, another alternative system, T2 + PIC, dominated the MeBr system in net returns. The C35 + PIC system produced the least favored risk-return profile for both the less and highly risk-averse decision maker. The net-return dominance of C35 + KPAM and T2 + PIC systems over the MeBr system can be attributed to both their comparable production cost structure with MeBr and their more favorable yield structure. Both the C35 + KPAM and T2 + PIC production systems have the ability to produce a larger proportion of the premium-priced jumbo peppers.

The cost-return estimates under the four production systems were further analyzed using simulation-optimization techniques under a multi-period programming framework. Results indicate similar optimal production and financing plans for MeBr and C35+KPAM systems. Under these systems, optimal farm size solutions are prescribed at the maximum acreage limit set, with greater reliance on land ownership than cash renting. The larger farm size solutions, enhanced by capability of all four systems to generate high-level net returns per acre, have resulted in the accumulation of more excess funds, some portions of which have been allocated to off-farm investments to diversify the farm's asset portfolio. These same factors, coupled with the more costly nature of external financing assumed in the analysis, produced programming solutions that reflect less reliance on external funds to cover capital and operating funding requirements.

Our results suggest that economically viable alternatives may exist for Georgia pepper producers to replace MeBr. However, the successful adoption of these alternatives has yet to be determined and could depend on the alternatives' consistency, efficiency, and reliability across different farm conditions and over longer periods of time. Producers have relied on the MeBr's ability to eradicate diseases and pests over a wide range of environmental conditions and growing conditions. Only actual on-farm use of the suggested fumigants can ascertain whether, like MeBr, the alternatives are equally flexible and adaptable to different farm conditions (such as irrigation levels, soil conditions, diseases, or pests not captured by the experiments). Moreover, producers have already established the consistency of yields under MeBr over time. Although environmentally friendly alternatives have been found to be equally or more financially efficient in experimental trials, there is not enough evidence that they can deliver consistent yields at comparable costs over long-run varying environmental conditions.

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