result is that long-run availability of an additional acre-foot of irrigation water per acre (restricting the sample to observations where the price is less than $20 per acre-foot) adds $656 to the value of an acre of farmland, or about 16 percent of the average value in our sample of $4,177 per acre. If a typical farm receives, say, two acre-feet per acre, then access to water would account for 32 percent of the value of an acre, and so on. The estimate is mildly sensitive to the cutoff price for irrigation water, but most of our observations fall well below $20, due to implicit subsidies.

Table 2. Predicted Impacts of Various Climate-Change Scenarios

Model	Scenario	Time Period	Change in Temperature	Impact on Value per Acre	t-Value
PCM	B1	2020-2049	1.2	–155	(1.67)
PCM	A1	2020-2049	1.4	–189	(1.76)
HadCM3	B1	2020-2049	2.2	–347	(2.09)
HadCM3	A1	2020-2049	3.1	–564	(2.43)
PCM	B1	2070-2099	2.15	–336	(2.07)
PCM	A1	2070-2099	4.1	–845	(2.72)
HadCM3	B1	2070-2099	4.6	–997	(2.83)
HadCM3	A1	2070-2099	8.3	–2166	(3.12)

PCM: Parallel Climate Model HadCM3: U.K. Met Office Hadley Centre Climate Model
Source: Schlenker, Hanemann, and Fisher (2006b).

As hypothesized on the basis of both theory and previous empirical findings, population pressure plays a role in determining farmland value. The estimated coefficient is positive and significant. Of the soil variables, only percent clay is strongly significant, and negative. Higher clay percentages are undesirable as they imply drainage problems, especially on the west side of the Central Valley. Percent high-class soil has the expected positive sign, but is not statistically significant. Interestingly, these results are reversed in our study of farmland values east of the 100th meridian; percent best-soil class is strongly significant and percent clay is not.

Potential Impact of Climate Change: Preliminary Estimates

Here we provide some preliminary calculations of the potential impacts of climate change on the average value of farmland in California. More definitive results require more complete and accurate data on water rights, prices and deliveries, and how these will be affected under different change scenarios. Initially, climate scientists speculated that the increase in annual precipitation under most major climate scenarios would moderate the pressure on water resources. However, recent studies for California suggest instead a modest decrease in annual precipitation. More importantly, the runoff during the main growing season between April and September is expected to decrease dramatically, even for a given amount of precipitation. Relatively more precipitation will fall as rain, rather than snow, and runoff from a melting snowpack will occur earlier in the spring. Both changes will result in reduced availability of water when needed most, in the late spring and early summer.

What are the consequences of the changes in temperature and patterns of precipitation for the value of California farmland? We look at two climate-change scenarios developed by the Special Report on Emissions Scenarios for the Intergovernmental Panel on Climate Change (IPCC): B1, representing a low-emissions future characterized by rapid switches to non-fossil energy sources and greater energy efficiency, and A1, representing a world of rapid fossil-fuel intensive growth, with the introduction of new and more efficient technologies toward the end of the century.

Results for the two scenarios, using two different global climate models, are given in Table 2. The PCM, or Parallel Climate Model, is a low-sensitivity model developed in the United States by the National Center for Atmospheric Research and the U. S. Department of Energy. HadCM3, the U.K. Met Office Hadley Centre Climate Model, is a relatively high-sensitivity model, where sensitivity refers to the effect on global mean temperature resulting from a given change in the atmospheric concentration of greenhouse gases. The column "change in temperature" shows a projected impact on average annual temperature in California of one to three degrees Celsius toward the middle of the century, and two to eight degrees Celsius toward the end of the century. We translate these numbers to a projected change in degree days, which is then used with our regression equation (Table 1) to determine the impacts on farmland value per acre. This is shown in the column "impact on value per acre" in Table 2. Since the average per acre value of all observations in our sample is $4,177, the impact toward the end of the century in the "business as usual" A1 scenario, $2,166, represents a loss of more than half the value, with correspondingly lower but still substantial losses in the near term and even under the low-sensitivity and low-emissions scenarios.

We also calculate the impact on farmland value of projected changes in surface-water deliveries. Here we need to be very tentative, since we do not (yet) have information on how deliveries will be affected at a disaggregated level, that is, at the level of the individual farm or irrigation district. We do, however, have a very recent estimate of the impact on the ability of the major California water projects, the Central Valley Project and the State Water Project, to deliver water to agricultural users in the major growing area, the Central Valley south of the Delta. Due to the changes in the volume and timing of runoff, toward the end of the century deliveries fall by 15 to 30 percent in the lower temperature scenarios and by 40 to 50 percent in the medium and higher temperature scenarios.

Assuming these numbers apply across districts and farms, and an average pre-warming level of water use of approximately two acre-feet per acre, and given our estimate in Table 1 of a capitalized value of the long-run availability of an acre-foot per acre of $656, we can calculate the impacts toward the end of the century on the value of an acre of farmland under each of the scenarios and each of the models. Thus we associate a reduction in deliveries of 15 percent with PCM/B1, 30 percent with PCM/A1, 40 percent with HadCM3/B1, and 50 percent with HadCM3/A1.

These reductions in turn imply losses in value per acre of $197, $394, $525, and $656, respectively. The losses are to be added to those due to the changes in temperature and degree days. For example, under the A1 scenario in the HadCM3 model, the impact on value due to the changes in both degree days and water availability would be $2166 + $656, or $2,822 per acre, which represents a loss of just over two-thirds of the current value. This is of course a "worst case" outcome. On the other end of the range of outcomes is the impact associated with the B1 scenario and the PCM model: $336 due to the change in temperature/degree days, and $197 due to reduced water deliveries, for a total of $533 per acre, or about 13 percent of the current value.

It should be emphasized that none of these impacts are predictions of what California or the world will look like in, say 2085, the mid-point of the 2070-2099 period. Rather, they can be understood as estimates of impacts given a set of assumptions, such as, in the case of the A1 scenario, continued heavy use of fossil fuels and rapid growth over the next several decades. It may well be that the results of studies such as this one will have some influence on policymakers in the direction of greater reliance on alternative energy sources and improved energy efficiency, that is, in the direction of the B1 scenario.

For additional information, the author suggests the following sources:

Hayhoe, Katherine et al. "Emissions Pathways, Climate Change, and Impacts on California." *Proceedings of the National Academy of Science,* Vol. 101, No. 34 (August, 2004), pp. 12422-12427.

Schlenker, Wolfram, Hanemann, W. Michael, and Fisher, Anthony C. "Water Availability, Degree Days, and the Potential Impact of Climate Change on Irrigated Agriculture in California." *Climate Change,* forthcoming.

________. "The Impact of Global Warming on U.S. Agriculture: An Econometric Analysis of Optimal Growing Conditions." *Review of Economics and Statistics,* Vol. 88, No. 1 (February, 2006a), pp. 113-125.

________. "Will U.S. Agriculture Really Benefit from Global Warming? Accounting for Irrigation in the Hedonic Approach." *The American Economic Review,* Vol. 95, No. 1 (March, 2005), pp. 395-406. Ê

________. "Implications of Climate Change for Farmland Value: Preliminary Estimates for California." World Congress of Environmental and Resource Economists, Kyoto, Japan, July 3-7, 2006b.

Anthony Fisher is a professor in the Department of Agricultural and Resource Economics at UC Berkeley and a member of the Giannini Foundation of Agricultural Economics. He can be contacted by e-mail at fisher@are.berkeley.edu or by telephone at (510)642-7555.

After Methyl Bromide: The Economics of Strawberry Production with Alternative Fumigants

by

Rachael E. Goodhue, Steven A. Fennimore, Karen Klonsky, and Husein Ajwa

Results from a two-year study suggest that drip-applied chloropicrin, and 1,3-D may potentially be economically feasible alternatives to methyl bromide in commercial California strawberry production. Using virtually impermeable film instead of high-density polyethelyne when fumigating may improve economic feasibility, depending on the location and fumigant.

Methyl bromide, combined with chloropicrin, is commonly used as a pre-plant soil fumigant for many crops in California, including strawberries, grapes and almonds. Because methyl bromide is an ozone-depleting compound, the United States and other developed country signatories to the Montreal Protocol banned the use of methyl bromide, beginning in 2005, except for certain "critical uses" that receive annual exemptions to apply a specified amount when no alternative is technically or economically feasible. Commercial strawberry production in California received an exemption for 2005 and for 2006. The application process is underway for 2007.

One of the requirements for obtaining a critical use exemption is that there must be ongoing research efforts to find technically and economically feasible alternatives. In order to be economically feasible, alternatives must be feasible under the pesticide registration and use regulations facing producers. For California strawberry growers, two alternative fumigants that meet regulatory requirements are chloropicrin and 1,3-D (1,3-dichloropropene). While other compounds, most notably iodomethane, also demonstrate technical promise as alternatives, only chloropicrin and 1,3-D are currently registered for use in California. Metam sodium, while registered, is primarily used for weed control, as this product alone is not adequate to suppress pathogens. Therefore, metam sodium is most often used following an application of 1,3-D and/or chloropicrin. While organic strawberry production is growing, organic acreage is only four percent of total acreage: (1,300 of 30,000 acres in 2003). Because of the need for crop rotation in organic production, limited land availability, and high cost of land, it is unlikely that organic acreage will expand significantly as a share of total acreage in the medium term.

Fumigants are volatile organic compounds. Once applied, they volatilize, and enter the air. One way their rate of loss from soil can be reduced is by covering the ground with plastic at the time of application. Reducing the rate of loss keeps the fumigant in the ground longer, which increases, at least potentially, its ability to control pathogens, weeds, and other pests. This physical characteristic suggests that the technical efficacy of alternative fumigants may be improved when less permeable plastic is used, which may alter their economic feasibility. Impermeable films work well to retain fumigants applied through the drip system, which results in improved weed control with chloropicrin and 1,3-D. Due to differences in application techniques, under broadcast fumigation impermeable films do not regain fumigants better than standard films.

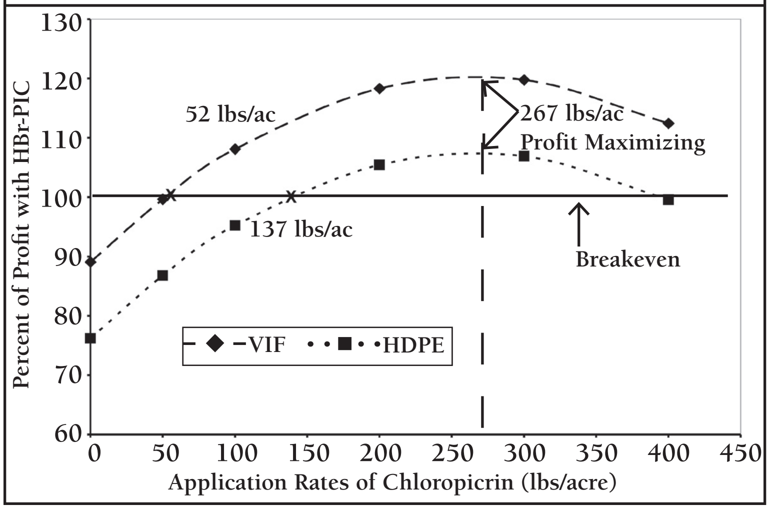
Using data from a USDA-funded project undertaken in cooperation with other UC and USDA researchers, we evaluate the profit-maximizing application rates for chloropicrin and 1,3-D drip-applied to strawberry beds prior to planting. We then compare these profits to profits from methyl bromide-chloropicrin fumigated fields. We also examine how profits are affected by using virtually impermeable film (VIF) to cover the beds, rather than the more permeable high-density polyethylene (HDPE) which is the most commonly used material.

Data and Research Methods

In 2002-03 and 2003-04, field trials were conducted in the Oxnard and Watsonville areas. Each year, in each location, weeding times and yields were measured for twelve treatments under two tarps, VIF and HDPE: The twelve treatments included Chloropicrin EC (PIC) and Inline (1,3-D and chloropicrin), each drip-applied at rates of 50, 100, 200, 300, and 400 lbs/acre; methyl bromide-chloropicrin (MBr-PIC) 67:33 shank-applied at a rate of 350 lbs/acre; and an untreated control. All application rates are reported as pounds per fumigated acre. Only the beds are fumigated, so the application rate per total acre is lower: about 30 percent lower for Watsonville, and about 25 percent lower for Oxnard.

Weeding time and yield information were combined with information regarding weeding costs per hour and other production costs from the UC cost and return

Figure 1. Estimated Profits as Percentage of MBr-PIC Profits: Chloropicrin with HDPE and VIF, Watsonville, 2003-04



studies for strawberries in each region; 2004 cost per pound or gallon information on alternatives collected from suppliers, growers, and other stakeholders; and fresh strawberry price information from the USDA. Profits per acre were calculated for each individual plot, and the resulting values were used to conduct a statistical analysis examining the effects of tarp choice and fumigant application rate on profits.

Estimated Per Acre Profits

Results suggest that at commercially popular application rates of 200–300 pounds per acre, PIC had higher expected profits per acre than methyl bromide in both locations and both years. Results for 1,3-D were not consistent across years and locations. Differences in chemical prices, application costs, yields, and weeding time affect the relative profitability of treatments. Using 2004 prices, MBr-PIC costs 17 percent more per pound than PIC, and 28 percent more per pound than 1,3-D. The cost of a broadcast application of MBr-PIC using HDPE is roughly $200 per acre more than using VIF and drip fumigation, and roughly $400 more per acre than using HDPE and drip fumigation.

Figure 1 illustrates our analysis. It graphs the profits by application rate estimated using the data for PIC in Watsonville in 2003-04. The profits for each application rate of PIC are reported as a percentage of the profits from applying MBr-PIC 67:33 at 350 pounds per acre. The dashed line reports profits when VIF is used. The dotted line reports profits when HDPE is used.

Notice that at each application rate, profits from using VIF are higher than profits from using HDPE. In the results reported here, we estimate a profit difference from using VIF that is required to be constant across application rates. Allowing the application rate to vary does not substantively affect our results in any way. At the profit-maximizing application rate of 267 pounds per acre, PIC is about 20 percent more profitable than MBr-PIC under VIF, and about eight percent more profitable under HDPE. For purposes of comparison, profits for the untreated control plot were 65 percent lower than profits from MBr-PIC.

The "breakeven" rates at which PIC profits equal MBr-PIC profits are marked on the graph. Although these rates are much lower than the profit-maximizing rates, it is important to interpret them with caution. As the application rate increases, the gain from each incremental pound of PIC applied falls, so that the low breakeven rates do not necessarily imply a huge difference in profitability between PIC and MBr-PIC. For example, profits for PIC applied under HDPE equal those for MBr-PIC at an application rate of 137 pounds per acre. Almost doubling the rate to 267 pounds per acre increases profits by eight percent, rather than almost doubling them.

Profit-Maximizing Application Rates

Our statistical approach allows us to estimate the application rate that results in the highest per-acre profit (the profit-maximizing application rate). For Oxnard, the profit-maximizing application rate for PIC is roughly 300 pounds per acre (Table 1). The data are much less informative regarding the profit-maximizing application rate for 1,3-D, and there is much less consistency across datasets. The 2003-04 data generate an estimated profit-maximizing application rate that is larger than the largest experimental rate and is 137 lbs/acre greater than the 2002–03 estimate. For Watsonville, the profit-maximizing application rate for PIC is roughly 260 pounds per acre (Table 2). The profit-maximizing application rate for 1,3-D is approximately 370 pounds.

Effect on Estimated Profit Per Acre of Using VIF

Overall, the results suggest that using VIF increases profits in the Oxnard area (Table 3). Estimates from the 2003-04 dataset have high levels of statistical significance, which means that there is a very low chance that using VIF will not increase profit. The analysis for Watsonville is much less conclusive. The 2002-03 data suggest that using VIF reduces profits, and that this reduction is statistically significant for1,3-D. In contrast, due to differences in yields and weeding times, the 2003-04 data suggest that using VIF increases profits, and that this increase is statistically significant for 1,3-D.

Caveats

Even for questions where our research found a clear answer, it is important to keep in mind that a number of caveats apply to our results. First, we do not consider the cost of purchasing drip irrigation equipment that is robust enough to withstand fumigation, although this may be offset in part by the reduced cost of using a single plastic tarp for fumigation and production, instead of the two plastic tarps used for broadcast fumigation and production. Second, prices and costs change over time. Because we used information from 2004 for the fumigants, changes in relative costs may affect the relative profitability of different treatments. Third, field trial conditions may not fully replicate commercial production conditions, and individual growers' costs may vary from those used here. Fourth, variability in soils and topography may alter the efficacy of the treatments we evaluated, relative to the efficacies demonstrated here. For example, it is much more difficult to achieve uniform drip application of fumigants on hilly fields. Fifth, very little is known about the implications for pathogen control of using alternatives for many years in a row. Sixth, this experiment used clear VIF. Because PIC photodegrades quickly when exposed to sunlight, it may have persisted longer and its performance may have been better, if colored VIF had been used to protect chloropicrin from photodegradation. Finally, another caveat may be the fragile nature of VIF itself. It is a three or five layer material, including one or two impermeable layers. Stretching can break the impermeable layer. Greater care must be used in the installation of VIF which increases labor and machine costs.

Implications and Unanswered Questions

Although subject to a number of significant caveats, our analysis suggests that PIC and 1,3-D are potentially economically viable alternatives to methyl bromide. Two important questions that will affect economic viability, and are as of yet unanswered, regard the effect on the price of strawberries if all growers move to alternatives, and the effect on pathogens of repeatedly using an alternative on the same field. Because yield profiles over time for the alternatives are different than the yield profile for methyl bromide, average prices received by growers may change, which will alter revenues. If alternatives are slightly less effective at controlling a given pathogen, there is the potential for this reduction in efficacy to have larger effects after repeated use.

Table 1. Estimated Profit-Maximizing Application Rates (lbs/acre): Oxnard

	2002-03	2003-04
PIC	276	317
1,3-D	282	419*

** Profit-maximizing point outside of data range*

Table 2. Estimated Profit-Maximizing Application Rates (lbs/acre): Watsonville

	2002-03	2003-04
PIC	259	267
1,3-D	353	381

Table 3. Estimated Gain from Using VIF Instead of HDPE (Dollars per Acre)

Year	2002-03		2003-04	
	Oxnard	Watsonville	Oxnard	Watsonville
PIC	$448	-$260	$1,136*	$1,170
1,3-D	$651	-$1,459**	$1,654**	$1,350**

** Significant at the 10% level   ** Significant at the 5% level*

The motivation for research on VIF and other emissions reduction methodologies is to reduce human exposure to fumigants, and improve fumigant performance on soil pests. VIF is just one possible method of accomplishing these goals. Increasing regulatory constraints means that a method to reduce fumigant emission must be found; otherwise, fumigant use will be drastically curtailed. At the same time fumigant emission reduction technology must not be so costly that growers can not afford to use it. California growers have not yet perceived sufficient benefit, either economically or in terms of relaxed fumigant application regulations, to use VIF on a wide scale. The data presented here suggest that there are economic benefits to the use of VIF. However, determination as to whether there are environmental benefits to the use of VIF need to be more thoroughly evaluated.

Rachael Goodhue is an associate professor and Karen Klonsky is a specialist in the Department of Agricultural and Resource Economics at UC Davis. They are members of the Giannini Foundation of Agricultural Economics. Steven Fennimore is an associate specialist and Husein Ajwa is a specialist in the Department of Plant Sciences, UC Davis. *This research was funded by the USDA-CSREES Methyl Bromide Alternatives Program (2002-51102-01924) and the California Strawberry Commission. The authors gratefully acknowledge the contributions of Coastal Berry, Mandalay Berry Farm and Seacrest Farms and the other researchers involved in this project.*

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To subscribe to **ARE Update** by mail contact:

Julie McNamara, Outreach Coordinator
Department of Agricultural and Resource Economics
University of California
One Shields Avenue, Davis, CA 95616
E-mail: julie@primal.ucdavis.edu
Phone: 530-752-5346

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Department of Agricultural and Resource Economics
UC Davis
One Shields Avenue
Davis CA 95616
3432