

# Economic Evaluation of Methyl Bromide Alternatives for the Production of Strawberries in the Southeastern United States

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**SUMMARY.** Partial budget analysis was used to evaluate soil treatment alternatives to methyl bromide (MeBr) based on their cost-effectiveness in the production of strawberries (*Fragaria xananassa*). The analysis was conducted for two geographical areas: the piedmont and coastal plain area (including North Carolina and Georgia) and the mountain area of western North Carolina, based on 7 years of field test data. The fumigation alternatives evaluated were Telone-C35 (1,3-dichloropropene 61.1% + chloropicrin 34.7%), Telone II (1,3-dichloropropene 94%), chloropicrin (Chlor-o-pic 99% and TriClor EC), InLine (1,3-dichloropropene 60.8% + chloropicrin 33.3%), and metam sodium (Vapam or Sectagon 42, 42% sodium methylthiocarbamate). The MeBr formulation was 67% MeBr and 33% chloropicrin (Terr-O-Gas) with the exception of the earlier trials where a 98:2 ratio was used. In the piedmont and coastal plain area, the soil treated with chloropicrin showed the best results with an additional return of \$1670/acre relative to MeBr, followed by Telone-C35 with an additional return of \$277/acre. The projected return associated with shank-applied metam sodium was approximately equal to the estimated return a grower would receive when applying MeBr. Fumigating with drip-applied metam sodium, InLine, and Telone II as well as the nonfumigated soil treatment resulted in projected losses of \$2182, \$2233, \$4179, and \$6450 per acre, respectively, relative to MeBr. In the mountain area, all of the alternatives resulted in a projected increase in net returns relative to MeBr. The largest projected increase was \$1320/acre for the InLine treatment, while the added returns for the TriClor and Telone-C35 applications were estimated to be \$509 and \$339 per acre, respectively. The drip-applied metam sodium application resulted in an additional return of \$40/acre, and the added revenue for the nonfumigated soil treatment was \$24/acre more than MeBr treatment. Although technical issues currently associated with some of the alternatives may persist, results indicate that there are economically feasible fumigation alternatives to MeBr in the production of strawberries in the southeastern U.S.

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Methyl bromide (MeBr) is a highly effective broad-spectrum fumigant used to control insects, nematodes, weeds, and pathogens (Gullino et al., 2003; Martin, 2003; Ristaino and Thomas, 1997; Schneider et al., 2003). The United States uses about 38 million lb of MeBr (a.i.) each year for preplant soil fumigation, accounting for 70% to 75% of the total use [Osteen, 2000; Ristaino and Thomas, 1997; U.S. Department of Agriculture (USDA), 2005a]. Under the Montreal Protocol of 1991, MeBr was defined as a chemical that contributes to the depletion of the stratospheric ozone layer and a phase-out schedule was implemented with a targeted phase-out in 2005 [USDA, 2005a; U.S. Environmental Protection Agency (EPA), 2004]. As a result of the obligations imposed under the Montreal Protocol, importation and production of MeBr ceased in the U.S. beginning 1 Jan. 2005, except for emergency and critical use exemptions (EPA, 2004).

The phase-out of MeBr as a preplant soil fumigant may result in considerable financial losses for the U.S. farmers (Carpenter et al., 2000; Carter et al., 2005; Osteen, 2000; USDA, 2005b). There is no known single alternative fumigant, chemical, or other technology that can readily substitute for MeBr in efficacy, low cost, ease of use, availability, worker safety, and environmental safety below the ozone layer (USDA, 2005b). Possible alternatives include host plant resistance, biological control, different cultural practices, and alternative chemicals, either alone or in combination (Gullino et al., 2003; Manning and Fennimore, 2001; Martin, 2003; Rieger et al., 2001; Ristaino and Thomas, 1997; Schneider et al., 2003). The availability of the alternative control measures will generally be limited to a specific crop or use because specific crops have widely varying requirements associated with variations in the target pests, soil types, climates,

## Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
9.3540	gal/acre	L·ha <sup>-1</sup>	0.1069
2.5400	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha <sup>-1</sup>	0.8922
0.9464	qt	L	1.0567

and state and local regulations (USDA, 2005a). Chemical alternatives studied most intensively include products that have a long history of use such as 1,3-dichloropropene, metam sodium, chloropicrin and combinations of these [e.g., 61.1% 1,3-dichloropropene + 34.7% chloropicrin or Telone-C35 (Dow AgroSciences, Indianapolis) (Duniway, 2002; Martin, 2003; Schneider et al., 2003)].

Nearly 80% of preplant MeBr soil fumigation is used for strawberries, tomatoes (*Lycopersicon esculentum*), ornamentals and nursery crops, and peppers (*Capsicum annuum*) (USDA, 2005a). Therefore, strawberry growers present one of the major impact groups for the new MeBr regulations. For example, in the southeastern U.S. (Georgia, North Carolina, South Carolina, Tennessee, and Virginia), based on an economic impact analysis (Carpenter et al., 2000; Norman, 2005; Osteen, 2000; USDA, 2001) the revenue of small to mid-sized farms is expected to decrease due to the phase-out of MeBr if suitable replacements are not found.

Excluding Florida, which has large commercial operations, the strawberry industry in the southeastern U.S. is comprised primarily of small to mid-sized family farms (Safley et al., 2004). Therefore the focus of this research effort was on the production and direct marketing of strawberries and not the larger operations in Florida that utilize commercial distribution channels. The majority of the industry employs an annual plasticulture system that is dependent on MeBr as a soil fumigant. Fields are prepared in the early fall (September). Raised beds are formed 6 to 8 inches high, a single drip tape line is laid within the bed, the soil within the bed is fumigated, and the bed is covered with black polyethylene. Within 2 to 4 weeks strawberry transplants are field set, depending on the required plant-back interval for the individual fumigant, as double rows on each bed. Harvest commences in spring (April) for 6 to 8 weeks; and after the crop is destroyed in June, rotation crops are grown or the land is prepared for the next strawberry crop. In addition to significant weather-related problems that strawberry plasticulture in the southeastern U.S. can often encounter (e.g., frosts, freezes, hail, excess rain, tropical storms, and/or hurricanes), other deterrents to optimal production

include weed pressure and the black root rot complex caused primarily by the root rot pathogens belonging to the genera *Rhizoctonia* and *Pythium* (Abad et al., 1999, 2002; Ferguson et al., 2003).

A series of MeBr alternative trials were conducted in multiple sites in North Carolina and southern Georgia (Brannen and Louws, 2002; Brannen et al., 2003; Driver et al., 2001; Ferguson et al., 2001, 2002, 2003; Fernandez et al., 2000; Louws et al., 1998a, 1998b, 2000), and have documented the technical feasibility or limitations of alternative fumigants in the annual strawberry production system. The purpose of this report was to analyze the economic feasibility of the chemical alternatives to MeBr that can be substituted in the production of strawberries. The specific objectives were to:

- 1) Estimate the costs and returns associated with growing, harvesting, and marketing strawberries when applying the preplant fumigation with MeBr using the plasticulture production system, and

- 2) Evaluate the chemical alternatives to MeBr currently available to strawberry growers based on the impact on net returns.

## Methodology and assumptions

It was initially assumed that the success of a specific alternative fumigant would vary throughout the climatic regions in the southeastern U.S. Therefore, a series of trials were conducted in the coastal plain and piedmont regions of North Carolina and Georgia, and the mountain region of North Carolina. As expected, the average yields and pest pressures varied across these sites, affecting the outcomes of alternative soil treatments (Brannen and Louws, 2002; Brannen et al., 2003; Driver et al., 2001; Ferguson et al., 2001, 2002, 2003; Fernandez et al., 2000; Louws et al., 1998a, 1998b, 2000). Consequently, the economic evaluation was conducted for two separate geographic areas for which it was possible to assume uniform strawberry-growing conditions. The first area combines the piedmont and coastal plain regions of North Carolina and Georgia, while the second area represents the mountain region of western North Carolina. Experimental plots in Plymouth, Clayton, and Bunn, N.C.; and Vidalia, Ga., represented the piedmont and coastal plain area, and

trial plots in Fletcher and Leicester, N.C., represented the mountain area. The piedmont and coastal plain region of North Carolina and Georgia will be referred to as the piedmont and coastal plain area hereafter.

To accomplish the objectives of this study, a cost model for a plasticulture production system was first developed for a 5-acre strawberry planting using MeBr as the standard fumigation treatment (Safley et al., 2004). Production practices were based on customary management practices recommended by North Carolina State University extension and research horticultural specialists, and practiced by growers. Whereas the original cost model presented in Safley et al. (2004) synthesized the production practices and yields for the entire state of North Carolina, the base budgets for this study were adjusted to reflect the production techniques and average annual yields for the areas discussed above.

It was assumed that machinery and equipment were purchased new at 2001 purchase prices. The machinery and equipment used in this budget reflect machinery components that can be used for other farming enterprises in addition to growing strawberries on a typical diversified farm. Therefore, the total machinery expense was adjusted to reflect the portion of costs attributable to strawberry production enterprise based on assumptions about typical use of the machinery on an average farm. The fumigation and irrigation equipment were the exceptions because they were used solely for strawberry production. The overhead irrigation system was used primarily for frost and freeze protection. The drip irrigation system was used for managing soil moisture and fertilizer applications in the strawberry field.

Input prices were obtained from local dealers who regularly supply strawberry growers. Because land rental rates vary throughout the southeastern U.S., a land charge was not included in the budget. Hired employees were paid \$8.25/h while the owner/operator was compensated at a rate of \$16.39/h. These labor rates include workers' compensation, unemployment, FICA taxes, and other overhead expenses as well as the base wage rate, and were meant to be representative of the "true" costs of labor and not just the base wage rate.

The harvest season was assumed to last 6 weeks starting in the third week of April and continuing through May. The marketing process obviously bears a cost and varies considerably depending on the marketing system the producers use. In this study, it was assumed that all of the fruit would be sold at the farm with two-thirds of the strawberries sold through the pick-your-own (PYO) operation, and one-third sold at the fruit stand (Safley et al., 2004). A labor charge of \$1.15 per 4-qt basket was added to the cost of the prepick strawberries, while supervision labor was compensated at a rate of \$8.25/h. Supervision tasks included overseeing the pickers and checkout operations, as well as the general management of the direct market operations. It was assumed that growers received \$1.40/lb for prepicked strawberries and \$0.90/lb for PYO strawberries.

Fumigation treatments varied with respect to the number of years of data and the locations of the study plots (Table 1). The soil treatment alternatives evaluated in this study were

Telone-C35 (1,3-dichloropropene 61.1% + chloropicrin 34.7%), Telone II (1,3-dichloropropene 94%; Dow AgroSciences), chloropicrin (Chloro-pic 99% and TriClor EC; Hendrix and Dial, Greensboro, N.C.), InLine (1,3-dichloropropene 60.8% + chloropicrin 33.3%; Dow AgroSciences), and metam sodium [Vapam (Amvac, Newport Beach, Calif.) or Sectagon 42, 42% sodium methyldithiocarbamate (Tessenderlo Kerley Inc., Phoenix)]. The MeBr formulation was 67% MeBr and 33% chloropicrin (Terr-O-Gas; Great Lakes Chemical Corp., West Lafayette, Ind.). In addition, a nonfumigated alternative was evaluated to determine the economic necessity of fumigation in each region. Even though field studies were also conducted for iodomethane (Midas; Arvesta, San Francisco) and a combination of iodomethane and chloropicrin, these alternatives were not included in the economic analysis because of the lack of the product cost information for iodomethane.

MeBr (combined with chloropicrin) fumigation was considered the

standard for strawberry production practice on which the base budget was built. To compare yield data between years and across sites, all yield data were normalized to the average strawberry yield for the MeBr plots that were obtained in the same experiment in the same year. For example, if the MeBr yield in experiment 1, year 1, site 1 was 20,000 lb/acre, this was considered 100% yield. If alternative fumigant "A" had a yield of 23,000 lb/acre in the same experiment, this yield was considered 115%. In year 2, if the yield for MeBr was 25,000 lb/acre (100%) and the yield for alternative "A" was 20,000 lb/acre, this was considered an 80% yield. The yields for MeBr were averaged across all years and all sites (e.g., 22,500 lb/acre), and the average relative yield for the alternative was calculated (e.g., 97.5%). Then, the overall average relative yield for alternative "A" would be the product of the average MeBr yield and the average relative yield of the alternative (e.g., 22,500 lb/acre × 97.5% = 21,938 lb/acre). This approach circumvented yield variations due to year and site effects

**Table 1. Alternative soil treatments, application rates, experimental sites, and the number of sequential years the soil treatment was evaluated in strawberry production systems at each experimental site from 1996 to 2002.**

Site	Piedmont and coastal plain area sites						Mountain area sites		N <sup>v</sup>
	Bunn N.C.	Plymouth I <sup>z</sup> N.C.	Plymouth II N.C.	Clayton I <sup>w</sup> N.C.	Clayton II <sup>w</sup> N.C.	Vidalia Ga.	Fletcher N.C.	Leicester N.C.	
Sequential years of study	2	3	2	2	2	3	2	1-3	
Replications <sup>z</sup>	4	4	4	4	4	6	4	4	
<b>Soil treatments (fumigants) evaluated<sup>y</sup></b>									
	Rate/acre								
Nonfumigated	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	17
Methyl bromide (67:33)	300-400 lb <sup>u</sup>	Yes	Yes	Yes	Yes	Yes	Yes	Yes	17
Telone-C35	28-35 gal <sup>t</sup>	Yes	Yes	Yes	Yes	Yes	Yes	Yes	17
InLine	28 gal		Yes	Yes	Yes	Yes		Yes	7
Metam sodium (surface or shank)	75 gal		Yes	Yes	Yes	Yes			9
Metam sodium (drip applied)	75 gal			Yes				Yes	5
Chloropicrin (99%)	170 lb			Yes					2
Chloropicrin EC (96%)	120 lb							Yes	2
Telone II	22 gal			Yes					2

<sup>z</sup>All experiments were arranged as a randomized complete-block design with four or six replications.

<sup>w</sup>Methyl bromide [MeBr (67% MeBr and 33% chloropicrin)], Terr-O-Gas (Great Lakes Chemical Corp. West Lafayette, Ind.), Telone-C35 [61.1% 1,3-dichloropropene + 34.7% chloropicrin (Dow AgroSciences, Indianapolis, Ind)], and chloropicrin (Chloro-pic 99; Hendrix and Dial, Greensboro, N.C.) were shank-injected into raised beds 24-30 inches (61.0-76.2 cm) wide and covered with black polyethylene. Metam sodium [Vapam (Amvac, Newport Beach, Calif.) or Sectagon 42 (42% sodium methyldithiocarbamate; Tessenderlo Kerley Inc., Phoenix)] was surface applied or shank applied using five shanks on 6-inch (15.2 cm) centers on or into preformed raised beds and the beds were immediately rototilled (for effective distribution of the product throughout the bed profile) and covered with black polyethylene. InLine (1,3-dichloropropene 60.8% + chloropicrin 33.3%; Dow AgroSciences), metam sodium (Vapam; Amvac), and chloropicrin EC (TriClor EC; Hendrix and Dial) were applied through two drip tapes spaced at one-third and two-thirds of the bed width and after the beds had been formed and covered with black polyethylene.

<sup>x</sup>The MeBr formulation used was 98:2 (98% MeBr and 2% chloropicrin) and not 67:33 (67% MeBr and 33% chloropicrin).

<sup>y</sup>The metam sodium formulation used in these trials was Sectagon 42, not Vapam.

<sup>v</sup>Number of observations (n = number of years × number of sites per year) this treatment was tested from 1996-2002.

<sup>u</sup>1 lb/acre = 1.1209 kg·ha<sup>-1</sup>.

<sup>t</sup>1 gal/acre = 9.3540 L·ha<sup>-1</sup>.



and normalized all yield data relative to the MeBr treatment.

Partial budget analysis was used to evaluate the alternative soil treatments. Partial budget analysis is a standard technique to assess the economics of a change in a farm enterprise (Kay and Edwards, 1994) and is frequently used to estimate the impact of a variety of alternative production techniques when the change involves only part of the production system (Roberts and Swinton, 1996; Warmann, 1995; Wossink and Osmond, 2002).

The partial budget technique compares the negative effects of applying a new treatment relative to a base or standard treatment to the positive effects associated with the new treatment relative to the base or standard treatment. Therefore, it requires the consideration of both the returns of treatments and changes in the structure of the production costs. Aspects of costs and returns that do not change with the treatment relative to the base are not considered in this type of analysis. The typical partial budget analysis follows a seven-point format (Dalsted and Gutierrez, 1992), which includes:

- A. Negative effects:
- Added costs attributable to the new fumigant \$ \_\_\_\_\_
  - Reduced returns attributable to the new fumigant \$ \_\_\_\_\_
  - Total negative effects attributable to the new fumigant \$ \_\_\_\_\_
- B. Positive effects:
- Reduced costs attributable to the new fumigant \$ \_\_\_\_\_
  - Added returns attributable to the new fumigant \$ \_\_\_\_\_
  - Total positive effects attributable to the new fumigant \$ \_\_\_\_\_
- C. Total effects (additional/reduced revenue) \$ \_\_\_\_\_

## Results

The estimated costs per acre needed to produce, harvest, and market strawberries in the piedmont and coastal plain area using MeBr as the fumigant are listed in Table 2. The total harvest, marketing, and production costs were estimated to be \$13,556/acre. Expenses were separated into six production phases: 1) land preparation, 2) preplant operations, 3) transplant and postplant operations, 4) dormant period, 5) preharvest, and 6) harvest and postharvest operations. Preplant operations were the most expensive

set of procedures, costing an estimated \$4399/acre, while harvest and postharvest operations were the second most expensive phase, costing \$3528/acre. Preharvest operations were \$2138/acre and transplant and postplant operations totaled \$2035/acre. Overall materials accounted for \$6470/acre, labor costs made up \$5359/acre, and the costs linked to owning and operating the equipment totaled \$1727/acre.

The estimated fumigation costs varied with the soil treatment (Table 3). The projected fumigation costs associated with MeBr were the highest (\$1267/acre). In comparison, it cost \$1196/acre to fumigate with metam sodium (shank), \$1175/acre for chloropicrin, \$1107/acre for Telone-C35, \$1066/acre for TriClor, \$1059/acre for InLine, \$988/acre for Telone II, and \$904/acre for metam sodium (drip). The nonfumigated alternative was the least expensive soil treatment option with a cost estimate of \$767/acre, which included the estimates of equipment, material, and labor costs associated with laying the drip tape and plastic mulch. The estimated reduced fumigation costs per acre for each alternative relative to MeBr are listed in the last column of the table. The cost reduction ranged from a low of \$71.03/acre for metam sodium (shank) to a high of \$363.18/acre for metam sodium (drip). The nonfumigated treatment was \$500/acre lower than the cost of fumigating with MeBr.

The estimated differences in the weed pressure were obtained from the Plymouth experiments, and were assumed to hold constant for other locations. The predominant weeds at Plymouth were henbit (*Lamium amplex*), vetch (*Vicia* spp.), chickweed (*Stellaria media*), white clover (*Trifolium repens*), and cudweed (*Gnaphalium* spp.). Lesser weed species included grasses (*Lolium* spp. and *Poa* spp.), speardspurge (*Capsella bursa-patoris*), wild carrot (*Daucus carota*), carolina geranium (*Geranium carolinianum*), curly dock (*Rumex crispus*), broadleaf dock (*Rumex obtusifolius*), and corn spurry (*Spergula arvensis*). Weed pressure fell into three groups (Table 4). Not surprisingly, the nonfumigated treatment resulted in the highest number of planting holes per acre with weeds, while chloropicrin had the second highest number of holes

with weeds. The remaining fumigants had relatively similar levels of weed infestation. The differences in weed pressure resulted in corresponding differences in the costs of weeding associated with each treatment. Weeding costs were calculated assuming that it took an average of 11 s per hole to remove the weeds. This time estimate was based on random samples taken throughout the experiments. The cost of weeding for the nonfumigated treatment was \$524/acre and the weeding cost for chloropicrin was \$224/acre. The weeding costs for the remaining soil treatments ranged from \$145/acre for metam sodium (drip) to \$104/acre for metham sodium (shank). The additional costs of weeding relative to the MeBr treatment are also presented in the last column of Table 4. The nonfumigated soil treatment had the highest increase in the weeding cost relative to MeBr, \$398/acre and the chloropicrin soil treatment required an additional \$97/acre.

While strawberry production practices for the mountain area were assumed to be identical to those in the piedmont and coastal plain area, the projected annual yields were considerably lower. Based on 5 years of data, the projected strawberry yield associated with the MeBr soil treatment in the piedmont and coastal plain area was 26,673 lb/acre, compared to 11,101 lb/acre in the mountain area (Tables 5 and 6). Therefore, the harvest costs per acre were adjusted to account for the lower labor expenses and harvest-related materials in the mountain area.

The chloropicrin soil treatment had the highest projected yield in the piedmont and coastal plain area (28,377 lb/acre) (Table 5). Fumigating with Telone-C35, MeBr, and shank-applied metam sodium resulted in similar yields of 26,806 lb/acre, 26,673 lb/acre, and 26,604 lb/acre, respectively. Yields for the InLine and drip-applied metam sodium applications were 24,193 lb/acre and 24,103 lb/acre, while Telone II and the nonfumigated treatments had the lowest yields of 22,253 lb/acre and 20,010 lb/acre, respectively. Projected total harvest costs, including harvest materials and labor, and projected yield values associated with estimated yield levels for each alternative are presented in the table as well.

Strawberry yields were gener-

**Table 2. Estimated costs per acre needed to produce, harvest, and market strawberries in the piedmont and coastal plain areas of North Carolina and Georgia using the plasticulture production system and fumigating with methyl bromide (MeBr).**

Operation	Labor costs	Machinery costs	Material costs	Total costs
-----(\$/acre <sup>2</sup> ) -----				
Land preparation				
Treat old crop with paraquat	29.70	41.04	7.38	78.12
Remove and dispose plastic	158.40	68.80	0.00	227.20
Disking	9.90	21.08	0.00	30.98
Liming	0.00	0.00	26.00	26.00
Planting soybeans <sup>7</sup> for cover crop	24.75	89.13	39.33	153.21
<b>Total land preparation costs per acre</b>	<b>222.75</b>	<b>220.05</b>	<b>72.71</b>	<b>515.51</b>
Preplant operations				
Ordering plant material, fumigant, plastic mulch (10% deposit)	5.74	0.00	154.00	159.74
Rotovating cover crop	56.04	118.02	0.00	174.06
Pull greenhouse shade cloth	4.95	0.00	187.74	192.69
Set-up misting system	9.48	0.00	0.00	9.48
Plug supplies (tips, trays, soil)	10.31	0.00	1884.44	1894.75
Stick runner tips for plugs	315.81	0.00	0.00	315.81
Handling trays	24.76	0.00	0.00	24.76
Subsoiling	14.85	8.15	0.00	23.00
Disking (break up soil clods)	2.52	5.86	0.00	8.38
Moisten soil media	8.25	0.00	0.00	8.25
Irrigate and fertilize plugs (20N-8.8P-16.6K)	8.25	0.84	0.72	9.81
Spray for two-spotted spider mite <sup>8</sup> with hexakis	8.25	0.17	28.00	36.42
Assembling irrigation system	99.00	2.04	0.00	101.04
Irrigating for fumigation	0.83	7.61	0.00	8.44
Rotovating for fumigation	28.03	59.01	0.00	87.04
Preplant fertilization (ammonium nitrate, potassium sulfate, triple super phosphate) <sup>9</sup>	7.43	10.42	48.46	66.31
Preplant fumigation (67% MeBr + 33% chloropicrin)	39.34	288.06	939.50	1266.90
Seed annual ryegrass <sup>9</sup> in aisles	0.84	0.63	11.00	12.47
<b>Total preplant costs per acre</b>	<b>644.68</b>	<b>500.81</b>	<b>3253.86</b>	<b>4399.35</b>
Transplant and postplant				
Transplant plugs and replant	255.75	39.18	0.00	294.93
Irrigating plug establishment (three applications)	101.48	169.53	0.00	271.01
Drip irrigation (three 2-h applications)	4.95	30.96	0.00	35.91
Spray for two-spotted spider mite with bifenthrin	12.88	17.78	248.00	278.66
Tissue sample	2.06	0.00	4.00	6.06
Winterize drip system	16.50	0.00	0.00	16.50
Apply floating row covers	50.48	2.04	1079.00	1131.52
<b>Total transplant and postplant costs per acre</b>	<b>444.10</b>	<b>259.49</b>	<b>1331.00</b>	<b>2034.59</b>

Table 2 continued on next page.

ally much lower in the mountain area (Table 6). The highest yield was 12,235 lb/acre associated with the InLine treatment, followed by TriClor (11,497 lb/acre), Telone-C35 (11,297 lb/acre), MeBr (11,101 lb/acre), and the nonfumigated alternative (11,021 lb/acre). Fumigating with the drip-applied metam sodium produced the lowest yield (10,791 lb/acre). Similarly to the previous table, projected total harvest costs, harvest costs relative to MeBr, projected yield values, and yield values relative to MeBr associated with estimated yield levels for each alternative are also presented.

The positive and negative effects for each soil treatment are shown in Tables 7 and 8. The costs were calculated using the projected fumigation, weeding, and harvest costs associated with the alternative soil treatments presented in Tables 2 through 6. The returns were based on the projected yield values of the alternative soil treatments presented in Tables 5 and 6. In this analysis it was assumed that added (reduced) costs for the alternative treatments were incurred if one or more of the following conditions were true.

- The alternative treatment had

higher (lower) fumigation costs, including material, equipment, and labor costs.

- The alternative treatment resulted in higher (lower) yield, and therefore, higher (lower) yield-related labor and material costs.

- The alternative treatment was associated with higher (lower) weed pressure, and therefore, higher (lower) hand weeding costs.

Since MeBr was the standard or base treatment, there were no added costs or reduced returns for this fumigant, and the total effects are zero. The results of the partial budget analysis

Table 2. Continued from previous page.

Operation	Labor costs	Machinery costs	Material costs	Total costs
	-----(\$/acre <sup>z</sup> ) -----			
Dormant period				
Internet and weather service (annual fee)	0.00	0.00	83.88	83.88
Remove and reapply row covers	297.00	0.00	0.00	297.00
White-tail deer <sup>y</sup> control	24.75	0.00	96.25	121.00
Ordering containers, fertilizers, etc.	12.30	0.00	0.00	12.30
Remove row cover and dead foliage	379.50	0.00	0.00	379.50
Dormant spray (captan)	6.44	8.89	14.00	29.33
Scout for two-spotted spider mite	16.39	0.00	0.00	16.39
<b>Total dormant costs per acre</b>	<b>736.38</b>	<b>8.89</b>	<b>194.13</b>	<b>939.40</b>
Preharvest				
Pull plants through plastic	103.10	0.00	0.00	103.10
Pull weeds	126.31	0.00	0.00	126.31
Spray herbicide in aisles with paraquat + crop oil concentrate	6.44	8.89	10.15	25.48
Scout for two-spotted spider mite, clipper weevil <sup>y</sup> , and ants <sup>y</sup>	65.56	0.00	0.00	65.56
Spray for two-spotted spider mite with bifenthrin (two applications)	12.88	17.78	248.00	278.66
Connect drip system	49.50	0.00	0.00	49.50
Check overhead irrigation system	8.20	0.00	0.00	8.20
Inject mefenoxam (two applications)	32.78	27.36	210.00	270.14
Spray for clipper weevil with chlorpyrifos	6.44	8.89	11.60	26.93
Tissue sample (three samples)	6.18	0.00	12.00	18.18
Inject fertilizer (Sul-Po-Mg, boron, liquid nitrogen) <sup>x</sup>	16.39	13.68	2.95	33.02
Reapply row covers for freeze	198.00	0.00	0.00	198.00
Freeze protection-overhead irrigation (four applications)	52.44	399.98	0.00	452.42
Botrytis fruit rot <sup>w</sup> control with captan	6.44	9.71	14.00	30.15
Polination with honeybees <sup>y</sup>	0.00	0.00	70.00	70.00
Inject fertilizer (Sul-Po-Mg, liquid nitrogen) <sup>x</sup>	16.39	13.68	19.29	49.36
Botrytis fruit rot control with fenhexamide	6.44	9.71	51.56	67.71
Inject fertilizer (Sul-Po-Mg, calcium nitrate) <sup>x</sup>	16.39	13.68	2.48	32.55
Spray for two-spotted spider mite with abamectin	6.44	8.89	83.04	98.37
Botrytis fruit rot control with fenhexamide and powdery mildew <sup>v</sup> with myclobutanil	6.44	9.71	74.06	90.21
Inject fertilizer (potassium nitrate) <sup>x</sup>	16.39	13.68	14.54	44.61
<b>Total preharvest costs per acre</b>	<b>759.14</b>	<b>555.64</b>	<b>823.67</b>	<b>2138.45</b>
<b>Total production costs per acre</b>				<b>10,027.30</b>
Harvest and postharvest operations				
Picking supervision and fruit stand baskets	693.00	0.00	0.00	693.00
Prepick harvest expense	1704.30	0.00	518.70	2223.00
Drip irrigation (six applications = 18 h)	19.68	92.88	0.00	112.56
Spray for two-spotted spider mite with abamectin	6.44	8.89	83.04	98.37
Botrytis fruit rot control with captan	6.44	9.71	14.00	30.15
Tissue sample	2.06	0.00	4.00	6.06
Inject fertilizer (potassium nitrate and calcium nitrate) <sup>x</sup> (two applications)	32.78	27.36	26.73	86.87
Evaporative cooling—overhead irrigation (three applications)	24.60	22.83	0.00	47.43
Botrytis fruit rot control with fenhexamide and powdery mildew with myclobutanil (×2)	12.88	19.42	148.12	180.42
Disassemble irrigation system	49.50	1.03	0.00	50.53
<b>Total harvest and postharvest costs per acre</b>	<b>2551.68</b>	<b>182.12</b>	<b>794.59</b>	<b>3528.39</b>
<b>Total harvest and production costs per acre</b>	<b>5358.73</b>	<b>1727.00</b>	<b>6469.96</b>	<b>13,555.69</b>

<sup>z</sup>\$1.00/acre = \$2.4711/ha; 1 acre = 0.4047 ha.

<sup>y</sup>Soybean (*Glycine max*), two-spotted spider mite (*Tetranychus urticae*), annual rye grass (loium perenne), white-tail deer (*Odocoileus virginianus*), clipper weevil (*Anthonomus signatus*), red fire ant (*Solenopsis wagneri*), honeybee (*Apis mellifera*).

<sup>x</sup>Ammonium nitrate = 34N-0P-0K, potassium sulfate = 0N-0P-36.5K-1Mg-18S, triple super phosphate = 0N-22P-0K-12Ca-1S, Sul-Po-Mg = 0N-0P-17.8K-10.5Mg-21S, boron = 0N-0P-0K-20B, liquid nitrogen = 30N-0P-0K, calcium nitrate = 15N-0P-0K-19Ca-1Mg, potassium nitrate = 13N-0P-35.5K

<sup>w</sup>Botrytis fruit rot (*Botrytis cinerea*).

<sup>v</sup>Powdery mildew (*Sphaerotheca macularis*).

**Table 3. Estimated strawberry fumigation costs per acre for methyl bromide (MeBr) and selected alternative soil treatments and the fumigation costs of the alternative treatments compared to the fumigation costs associated with MeBr.**

MeBr and selected alternative soil treatments	Labor costs	Machinery costs	Materials costs	Total fumigation costs	Reduced fumigation costs relative to MeBr
----- (\$/acre <sup>z</sup> ) -----					
MeBr	39.34	288.06	939.50	1266.90	0.00
Metam sodium (shank)	68.84	417.53	709.50	1195.87	-71.03
Chloropicrin	39.34	288.06	847.50	1174.90	-92.00
Telone-C35	39.34	288.06	779.50	1106.90	-160.00
TriClor (drip)	0.00	6.72	1059.00	1065.72	-201.18
InLine (drip)	0.00	6.72	1052.00	1058.72	-208.18
Telone II	39.34	288.06	660.50	987.90	-279.00
Metam sodium (drip)	0.00	6.72	897.00	903.72	-363.18
Nonfumigated	39.34	288.06	439.50	766.90	-500.00

<sup>z</sup>\$1.00/acre = \$2.4711/ha.

**Table 4. The average number of strawberry planting holes with weeds, the estimated time required to pull the weeds, the estimated weeding cost per acre for methyl bromide (MeBr) and selected alternative soil treatments, and the difference in the weeding costs relative to MeBr based on fumigation trials in Plymouth, N.C.**

MeBr and selected alternative soil treatments	Avg no. of holes with weeds <sup>z</sup> (no.)	Avg percent of holes with weeds (%)	Estimated time required to pull weeds <sup>y</sup> (h/acre) <sup>w</sup>	Total estimated weeding costs <sup>x</sup> (\$/acre) <sup>w</sup>	Weeding costs relative to MeBr (\$/acre)
Nonfumigated	17,320	99	63.51	523.96	+397.65
Chloropicrin <sup>v</sup>	7400	42	27.13	223.82	+97.51
Metam sodium (drip)	4782	27	17.53	144.62	+18.31
Telone-C35	4634	27	17.00	140.25	+13.94
Telone II	4564	26	16.73	138.02	+11.71
InLine (drip)	4270	24	15.66	129.19	+2.88
MeBr	4176	24	15.31	126.31	0.00
Metam sodium (shank)	3452	20	12.66	104.44	-21.87

<sup>z</sup>Based on mean number of weeds per plot, counts taken in Feb. 2000, 2001, and 2003, assuming 17,400 holes/acre (42,996 holes/ha).

<sup>y</sup>Calculated assuming time for removal of weeds is 11 s/hole, based on random samples taken during weeding throughout the experiments. The time given was calculated as actual weeding time multiplied by 1.2 to capture additional time spent on the operation associated with preparation, rest, etc.

<sup>x</sup>Calculated based on a wage rate of \$8.25/h.

<sup>w</sup>1 h/acre = 2.4711 h-ha<sup>-1</sup>; \$1.00/acre = \$2.4711/ha.

<sup>v</sup>Weed pressure with TriClor alternative was assumed to be the same as with chloropicrin.

**Table 5. Average marketable strawberry yields for the years and locations the trials were conducted, the harvest-related costs per acre, including labor and materials, and gross returns for methyl bromide (MeBr) and selected alternative soil treatments and the difference in the harvest costs and yield values relative to MeBr for the piedmont and coastal plain area.**

MeBr and selected alternative marketable soil treatments	Avg marketable strawberry yields (lb/acre) <sup>z</sup>	Years the trials were conducted	Location of trial plots	Total estimated harvest costs	Harvest costs relative to MeBr	Gross returns	Gross returns relative to MeBr
----- (\$/acre <sup>y</sup> ) -----							
Chloropicrin	28,377	2000, 2002	Plymouth, N.C.	3058.00	+142.00	30,268.80	+1817.60
Telone-C35	26,806	1996-2002	Plymouth, Clayton, and Bunn, N.C.; Vidalia, Ga.	2927.00	+11.00	28,593.07	+141.87
MeBr	26,673	1996-2002	Plymouth, Clayton and Bunn, N.C.; Vidalia, Ga.	2916.00	0.00	28,451.20	0.00
Metam sodium (shank)	26,604	1996-2002	Plymouth and Clayton, N.C.	2910.25	-5.75	28,377.60	-73.60
InLine (drip)	24,193	2000, 2002	Plymouth and Clayton, N.C.; Vidalia, Ga.	2709.34	-206.66	25,805.87	-2645.33
Metam sodium (drip)	24,103	2000, 2002	Plymouth, N.C.	2701.84	-214.16	25,709.87	-2741.33
Telone II	22,253	2000, 2002	Plymouth, N.C.	2647.67	-268.33	23,736.53	-4714.67
Nonfumigated	20,010	1996-2002	Plymouth, Clayton, and Bunn, N.C.; Vidalia, Ga.	2360.75	-555.25	21,344.00	-7107.20

<sup>z</sup>1 lb/acre = 1.1209 kg-ha<sup>-1</sup>.

<sup>y</sup>\$1.00/acre = \$2.4711/ha.

Table 6. Average marketable strawberry yields for the years and locations the trials were conducted, the harvest-related costs per acre, including labor and materials, and gross returns for methyl bromide (MeBr) and selected alternative soil treatments and the difference in the harvest costs and yield values relative to MeBr for the mountain area.

MeBr and selected alternative marketable soil treatments	Avg marketable strawberry yields (lb/acre) <sup>z</sup>	Years the trials were conducted	Location of trial plots	Total estimated harvest costs	Harvest costs relative to MeBr	Gross returns	Gross returns relative to MeBr
InLine (drip)	12,235	2001, 2002	Leicester, N.C.	1713.00	+ 94.50	13,050.67	+1209.60
TriClor (drip)	11,497	2001, 2002	Leicester, N.C.	1635.17	+16.67	12,263.47	+422.40
Telone-C35	11,297	1997-99	Fletcher, N.C.	1634.83	+16.33	12,050.13	+209.07
MeBr	11,101	1997-2002	Fletcher and Leicester, N.C.	1618.50	0.00	11,841.07	0.00
Nonfumigated	11,021	1997-99	Fletcher and Leicester, N.C.	1611.83	-6.67	11,755.73	-85.34
Metam sodium (drip)	10,791	2001, 2002	Leicester, N.C.	1592.66	-25.84	11,510.40	-330.67

<sup>z</sup>1 lb/acre = 1.1209 kg·ha<sup>-1</sup>.

<sup>y</sup>\$1.00/acre = \$2.4711/ha.

Table 7. The total negative effects, added costs and reduced returns, the total positive effects, reduced costs and added returns, and the additional net returns incurred by substituting the selected alternative soil treatment for methyl bromide (MeBr) in the strawberry production system in the piedmont and coastal plain area.

MeBr and selected alternative soil treatments	Added costs of the alternative treatment	Reduced returns of the alternative treatment	Total negative effects of the alternative treatment	Reduced costs of the alternative treatment	Added returns of the alternative treatment	Total positive effects of the alternative treatment	Additional net returns of the alternative treatment
	----- (\$/acre) <sup>z</sup> -----						
Chloropicrin	239.51	0.00	239.51	92.00	1817.60	1909.60	+1670.09
Telone-C35	25.03	0.00	25.03	160.00	141.87	301.87	+276.84
Metam sodium (shank)	0.00	73.60	73.60	98.66	0.00	98.66	+25.06
MeBr	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Metam sodium (drip)	18.31	2741.33	2759.64	577.34	0.00	577.34	-2182.30
InLine (drip)	2.88	2645.33	2648.21	414.84	0.00	414.84	-2233.37
Telone II	11.71	4714.67	4726.38	547.33	0.00	547.33	-4179.05
Nonfumigated	397.65	7107.20	7504.85	1055.25	0.00	1055.25	-6449.60

<sup>z</sup>\$1.00/acre = \$2.4711/ha.

Table 8. The total negative effects, added costs and reduced returns, the total positive effects, reduced costs and added returns, and the additional net returns incurred by substituting the selected alternative soil treatment for methyl bromide (MeBr) in the strawberry production in the mountain area.

MeBr and selected alternative soil treatments	Added costs of the alternative treatment	Reduced returns of the alternative treatment	Total negative effects of the alternative treatment	Reduced costs of the alternative treatment	Added returns of the alternative treatment	Total positive effects of the alternative treatment	Additional net returns of the alternative treatment
	----- (\$/acre) <sup>z</sup> -----						
InLine	97.38	0.00	97.38	208.18	1,209.60	1417.78	+1320.40
TriClor	114.18	0.00	114.18	201.18	422.50	623.58	+509.40
Telone-C35	30.27	0.00	30.27	160.00	209.07	369.07	+338.80
Metam sodium (drip)	18.31	330.67	348.98	389.02	0.00	389.02	+40.04
Nonfumigated	397.65	85.33	482.98	506.67	0.00	506.67	+23.69
MeBr	0.00	0.00	0.00	0.00	0.00	0.00	0.00

<sup>z</sup>\$1.00/acre = \$2.4711/ha.



**Table 9. Estimated gross returns, costs incurred to fumigate, weed, harvest, produce, and market strawberries, total net returns for each soil treatment and the additional net returns per acre of the selected alternative soil treatments relative to methyl bromide (MeBr) for the piedmont and coastal plain area.**

MeBr and selected alternative soil treatments	Gross returns	Fumigation costs	Weeding costs	Harvest costs	Other production and marketing costs <sup>z</sup>	Total net returns <sup>y</sup>	Additional net returns relative to MeBr
	-----(\$/acre) <sup>x</sup> -----						
Chloropicrin	30,268.80	1174.90	223.82	3058.00	9246.48	16,565.60	+1670.09
Telone-C35	28,593.07	1106.90	140.25	2927.00	9246.48	15,172.44	+276.93
Metam sodium (shank)	28,377.60	1195.87	104.44	2910.25	9246.48	14,920.56	+25.05
MeBr	28,451.20	1266.90	126.31	2916.00	9246.48	14,895.51	0.00
Metam sodium (drip)	25,709.87	903.72	144.62	2701.84	9246.48	12,713.21	-2182.30
InLine (drip)	25,805.87	1058.72	129.19	2709.34	9246.48	12,662.14	-2233.37
Telone II	23,736.53	987.90	138.02	2647.67	9246.48	10,716.46	-4179.05
Nonfumigated	21,344.00	766.90	523.96	2360.75	9246.48	8845.91	-6449.60

<sup>x</sup>The production and marketing costs that did not change as a result of varying the soil treatments.

<sup>y</sup>Excluding land rental rates.

<sup>z</sup>\$1.00/acre = \$2.4711/ha.

**Table 10. Estimated gross returns, costs incurred to fumigate, weed, harvest, produce and market strawberries, total net returns for each soil treatment and the additional net returns per acre of the selected alternative soil treatments relative to methyl bromide (MeBr) for the mountain area.**

MeBr and selected alternative soil treatments	Gross returns	Fumigation costs	Weeding costs	Harvest costs	Other production and marketing costs <sup>z</sup>	Total net returns <sup>y</sup>	Additional net returns relative to MeBr
	-----(\$/acre) <sup>x</sup> -----						
InLine	13,050.67	1058.72	129.19	1713.00	9246.48	903.28	+1320.40
TriClor	12,263.47	1065.72	223.82	1635.17	9246.48	92.28	+509.40
Telone-C35	12,050.13	1106.90	140.25	1634.83	9246.48	-78.33	+338.79
Metam sodium (drip)	11,510.40	903.72	144.62	1592.66	9246.48	-377.08	+40.04
Nonfumigated	11,755.73	766.90	523.96	1611.83	9246.48	-393.44	+23.68
MeBr	11,841.07	1266.90	126.31	1618.50	9246.48	-417.12	0.00

<sup>x</sup>The production and marketing costs that did not change as a result of varying the soil treatments.

<sup>y</sup>Excluding land rental rates.

<sup>z</sup>\$1.00/acre = \$2.4711/ha.

are summarized in Table 9 for the piedmont and coastal plain area and in Table 10 for the mountain area.

In the piedmont and coastal plain area (Table 7), fumigation with chloropicrin was the most cost effective, resulting in an additional return of \$1670/acre relative to MeBr. Telone-C35 also brought about a positive return of \$277/acre, while the estimated return for shank-applied metam sodium was approximately equal to the return associated with MeBr (an additional return \$25/acre). Other soil treatment alternatives resulted in reduced returns relative to MeBr. The estimated return for metam sodium (drip) and InLine were similar, with projected losses of \$2182/acre and \$2233/acre relative to MeBr, and Telone II had an estimated loss of \$4179/acre. As expected, the projected return for the nonfumigated soil treatment resulted in the

largest loss return relative to MeBr (\$6450/acre).

In the mountain area (Table 8), all of the alternatives resulted in an increase in the projected returns compared to MeBr. The highest increase in returns was estimated for the InLine treatment (\$1320/acre), while additional returns were more modest for TriClor (\$509/acre) and Telone C-35 (\$339/acre). Projected returns for the metam sodium (drip) and nonfumigated treatments were very similar to the MeBr treatment with increases of \$40/acre and \$24/acre, respectively.

The estimated net returns for MeBr and the alternative soil treatments are presented in Tables 9 and 10. The net return for each soil treatment is the difference between the projected gross returns and the associated costs that changed as a result of applying different soil treatments plus the remain-

ing production and marketing costs that remained constant regardless of the soil treatment used. For example, in the piedmont and coastal plain area, the projected gross returns for the MeBr alternative were \$28,451.20/acre (Table 5), while the associated fumigation costs were \$1266.90/acre (Table 3), the weeding costs were 126.31/acre (Table 4), and the harvest costs were \$2916.00/acre (Table 5). Therefore the production and marketing costs that did not change as a result of varying the soil treatments were \$9246.48/acre, which was calculated by subtracting the fumigation, weeding, and harvest costs from the total production costs of \$13,555.69/acre (Table 2). This procedure yielded an estimated net return, less a land rental rate, of \$14,895.51/acre for the MeBr treatment. The net returns for the other soil treatment alternatives were calculated the same way.

The net returns were much higher in the piedmont and coastal plain area (Table 9) compared to the mountain area (Table 10) because of the significant difference in average marketable yields. In the piedmont and coastal plain area, fumigating with chloropicrin produced the highest projected net return (\$16,566/acre), followed by Telone-C35 (\$15,172/acre), shank-applied metam sodium (\$14,921/acre), drip-applied metam sodium (\$12,713/acre), InLine (\$12,662/acre), and Telone II (\$10,716/acre). The nonfumigated soil treatment resulted in the lowest net return estimate (\$8846/acre).

In the mountain area, the InLine treatment had the highest projected net return (\$903/acre) and the TriClor treatment had an estimated net return of \$92/acre. However, the remaining soil treatments, including MeBr, showed projected losses because the low yields did not generate enough gross revenues to cover the production costs.

## Conclusions

This paper contributes to the literature exploring the feasibility of MeBr alternatives used in the production of strawberries. This economic analysis explored the cost-effectiveness of the alternative soil treatments and their impact on net revenues using the partial budget methodology. Results indicate that there are economically feasible fumigation alternatives to MeBr in the production of strawberries in the southeastern U.S. However, the performance of the alternatives is not uniform throughout the region. Chloropicrin shows good potential for growing conditions similar to those of the piedmont and coastal plain area, with additional returns of \$1670/acre relative to MeBr. More modest improvements were projected for Telone-C35 and shank-applied metam sodium with additional returns of \$277/acre and \$25/acre, respectively. For growing conditions similar to those in the mountains of North Carolina, all of the alternatives showed an improvement in the projected net returns relative to MeBr. Fumigation with InLine showed the greatest potential with an additional return of \$1320/acre relative to MeBr.

Even though this analysis showed a negative return in the mountains using MeBr in the plasticulture sys-

tem, some growers find it profitable to produce strawberries. This budget should serve as a tool for growers to calculate the potential return on their investment and time based on a customized budget for their location and growing conditions. This study also highlights that growers should give careful consideration to their input costs and their fumigation options. Additional trials, particularly on-farm trials where growers practice beneficial crop rotation and cover crop practices, will help growers determine if fumigation is a necessary expense for their production system.

For the purposes of this analysis, all data were included, despite technical or environmental issues encountered. For example, the InLine treatments at the Plymouth, N.C., site in the 2001–02 production year failed to offer an advantage compared to the nonfumigated plot. This particular batch of product also failed at other experimental sites, suggesting that there was a problem with the formulation. However, it was not clear if the formulation was ineffective or if there were other undetermined issues. The experiments were designed to avoid problems associated with improper application or sub-optimal soil conditions. Values for all the years were included in this analysis, potentially representing a level of risk associated with the alternative. InLine performed best in the mountain production region and thus offers considerable promise as an economically viable alternative, and the economic returns a grower may expect with the InLine alternative in the piedmont and coastal plain area could be underestimated. Likewise, slight phytotoxicity was associated with the Telone-C35 treated plots in Plymouth in the 1998–99 and 1999–2000 experiments. This appeared to have been associated with water-saturated soils after the treatments were applied due to hurricane and heavy rain events, even with a plant-back time of over 21 d. Despite depressed yields in these data points, across years and sites, Telone-C35 offered a higher return than MeBr. Thus, a grower may expect higher returns on average if phytotoxicity is not encountered. Alternatively, plant-back issues and the potential for phytotoxicity, particularly in wet autumns, highlight technical issues currently associated with some of the alternatives.

In general, weed pressure was low at Plymouth. Although weed data were not collected in all locations, relative impacts of soil treatment would be similar; that is, no fumigation will always result in highest weed counts, while some fumigants are known to be less effective in controlling weeds. In the future, growers may need to vary their protocol to include additional herbicide treatments to reduce weed pressure if MeBr is not used.

These results are based on a study in progress. The availability of the updated information on yield estimates associated with possible fumigation alternatives may affect the above conclusions. Additionally, the availability of the cost information for iodomethane and analysis of its performance may add another feasible alternative. The audience of this article should also be aware that the results represent estimates only and are not a guarantee, since the performance of the fumigation alternatives investigated here varied in different locations based on particular local conditions.

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