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Methyl Bromide: Progress and Problems Identifying Alternatives, Volume II[1]

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Every other year, methyl bromide production and importation is reduced. In 2001, it was reduced an additional 25% as a result of the EPA regulatory implementation of the U.S. Clean Air Act and provisions of the Montreal Protocol Agreement. This additional reduction means that now methyl bromide manufacturers can produce only 50% of the levels produced in 1991. As has been repeatedly the case, methyl bromide prices ($2.60 lb 67/33) have increased in response to regulatory action and reduced supply. Not only has availability been reduced, but market competition among the different end users is intensifying and redefining how remaining methyl bromide supplies are allocated. Future pricing of methyl bromide will be driven by market demand, whereas availability will determined to large extent by previous sales and contractual agreement established between grower and distributor. Finally being caught in the squeeze, Florida growers are only now beginning to realize unfilled need of methyl bromide quantities, and are beginning to trial various alternatives in earnest.

Each year, extensive field research continues to explore new products, application technologies, and treatment regimes to serve as alternatives to soil fumigant uses of methyl bromide. Each year, the USDA-ARS has provided funding in the sum of $243,750 to conduct small-plot research and field-scale demonstration / validation studies at multiple sites with the major crop producing regions of Florida. Significant funding for ongoing research efforts has also been derived on an annual basis from other state, federal, university, agribusiness, and commodity groups such as the Florida Tomato Committee, the Florida Fruit and Vegetable Association, the Florida Strawberry Growers Association, and the U.S. Environmental Protection Agency. The authors and research personnel of the University of Florida involved in these projects would like to express sincere appreciation for the continuing support provided, because without this support, the research activities and the information in this article would not have been possible. As with the previous article of spring 2000, we will try to address some of the current research on alternative management tactics, both chemical and nonchemical, which can have an impact on soilborne pest and disease control and changes in crop productivity in the post methyl bromide era.

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Florida Strawberry Research

Alternative research efforts at University of Florida research and education centers in Dover, Quincy, and Gainesville were initiated in 1995 and have continued to the present. The primary focus of this research has been to evaluate cultural and chemical alternatives to methyl bromide soil fumigation within Florida strawberry production. The early studies at Dover, conducted by Dr. Craig Chandler, clearly demonstrated that strawberry productivity in Florida could be substantially (50-70%) reduced by growing plants in soil that had not been fumigated prior to planting, <u>even</u> in the absence of lethal pathogens. These studies also demonstrated no differences in resistance or tolerance to soil borne nematode and disease pathogens among six commercially important strawberry cultivars, two plant propagation sites (Florida, Canada), or two plant types (plug vs. bareroot). Following these studies, field research efforts began to focus on chemical alternatives to control nematodes, disease, and other sublethal microoganisms. The results of these chemical trials clearly demonstrated significant increases in strawberry yields over that of the untreated control, and equivalent to if not higher than that of methyl bromide following use of Chloropicrin (300 lb/a), Telone C17 (35 gal/a), and in some trials, with Chloropicrin (300 lb/a) plus Metham sodium (75 gal/a), or metham sodium (75 gal/a) plus Telone II (12 gal/a). In some of the trials, strawberry yield responses were proportional to the amount of chloropicrin actually applied, strongly suggesting the importance of other undefined soil pathogens as primary yield determining factors and of using a fumigant with excellent fungicidal activity. It was also determined that because chloropicrin is such a poor nematicide, another fumigant which could broaden the spectrum of soil pest control activity to include nematodes was needed. As a result, Telone C17 or Telone C35 was determined to be the most promising, currently registered, alternative fumigant to that of methyl bromide for Florida strawberry. There was also grower concern that to much chloropicrin in itself would confer an undesirable increase in vegetative growth response, and as a result, provided further confirmation to target Telone C17 and Telone C35 for evaluation in advanced trials.

Since 1997, thirteen USDA funded large scale field demonstration trials have been performed in the Plant City area comparing Telone C-17 (35 gal/a) or Telone C-35 (26 gal/a) applied in-row or broadcast, in combination with the herbicide Devrinol (4 lb /a) to that of methyl bromide (67/33; 350 lb/a) for weed, disease, and nematode control and for strawberry yield response. The Telone treated area in these field trials ranged from approximately one- third to one acre in size. Grower fumigation and bedding equipment was used for all in-row applications of Telone C17 or Telone C35. Devrinol (4 lb a.i./a), when it was used for weed control, was applied as a surface spray prior to soil fumigation and incorporated 2 to 4 inches deep with a rolling cultivator. Most fields had no previous history of severe pest pressures. At three of the grower sites, Telone C17 or Telone C35 has been repeatedly evaluated in the same field location for the past 3 years to examine long term impacts of repeated Telone use.

At none of the field demonstration sites during the period 1997 to 1999 were substantial differences in the incidence of dead or decline plants per row ever observed between in-row applications of Telone C17 and methyl bromide. In all cases, the numbers of dead and decline plants marginally increased during the course of the season but no significant trends was ever observed between treatments. It is interesting to note that in many of the trials, plant mortality due to strawberry anthracnose was numerically higher in the methyl bromide compared to Telone treated field areas. In general, no differences in weed control was observed at any time between the Telone C17 plus Devrinol and methyl bromide treatment. In a number of years and site locations, the average number of small plants were significantly higher per unit length of strawberry row in the Telone C17 + Devrinol treated fields compared to that of methyl bromide. The cause for the marginally smaller plant sizes are not known, but in some cases may be linked to herbicide induced stunting as has been previously observed with Tillam on tomato. Overall, strawberry plant growth of the Telone C17 or Telone C35 plus Devrinol in-row treatments were near equivalent to that of methyl bromide yield, particularly at seasons end in March. At a number of sites, yield records were incomplete or not provided by grower cooperators so a more comprehensive assessment of yield impacts is not possible. In general however, it would appear that yield differences, when they occurred were always relatively small between the Telone C17 plus Devrinol and methyl bromide treatments, even when small but significant differences in plant sizes were observed between treatments.

The Telone label requirement for a full spray suit, rubber gloves, boots, and a full face respirator by all personnel in the field at the time of application prompted a new research focus in 1999 towards evaluation of broadcast, rather than in-row, treatments of Telone C35 (26 gal/a) applied prior to bedding to minimize personnel protective equipment requirements. Seven field demonstration trials evaluating broadcast applications of Telone C35 were conducted during the period 1999 to 2001. In these trials, broadcast applications were made utilizing either a deep placement Yetter coulter system (courtesy of Mirusso Fumigation & Equipment, Delray Beach, FL), or with a 12 inch, forward swept chisel plow followed by a rolling operation to provide for a seal of surface soil (courtesy Hy-Yield Bromine, Plant City, FL). Devrinol (4 lb a.i./a), when it was used for weed control, was applied as a surface spray prior to soil fumigation and incorporated 2 to 4 inches deep with a rolling cultivator.

At none of the three demonstration sites in 1999 or four sites in 2001 were substantial differences in the incidence of dead or decline plants ever observed between broadcast treatments of Telone C35 and methyl bromide. At two sites during 2000-2001, where a herbicide was not applied prebedding, weed densities were 2 to 4 times higher with broadcast or in-row applications of Telone C35 compared to that of methyl bromide (Figure 1). Differences in weed densities between treatments were preserved season long even though preplant glyphosate and or hand weeding operations were performed prior to and after planting. At three of the demonstration sites, significant differences in plant size were observed between Telone C35 and methyl bromide. At one these sites, phytotoxic levels of Devrinol (6 lb a.i./a) presumably caused severe early season plant stunting which persisted season long and caused significant yield loss (30%) (Figure 2).

Based on the overall results of the seven large scale field demonstration trials conducted during the period 1999-2001, strawberry plant growth and vigor with broadcast treatments of Telone C35 (26 gal/a) were generally observed again to be near equivalent to that of methyl bromide. Again, yield records were incomplete or not provided by grower cooperators so a more comprehensive assessment of yield impacts is not possible. Based on what this author observed during the course of the growing season in these trials, strawberry yields will not be significantly reduced with either Telone C17 or Telone C35, applied either broadcast or in-row, as long as a supplemental preplant herbicide is applied and incorporated properly, and a sufficient waiting period before bedding or transplanting is observed after fumigant application. It should also be recognized that not all strawberry trials utilized the more advanced Yetter Coulter application system for broadcast or in-row applications of Telone, and so it is reasonable to believe that yield responses can be improved further than what was observed in some of these trials. With methyl bromide, Florida strawberry growers have not had to consider use of a preplant incorporated herbicide for weed control and it is only now that they are becoming aware of some of the problems which can occur when herbicides like Devrinol are not applied or incorporated properly. It should also be recognized that the herbicide arsenal for strawberry is small, and other weed management chemicals or tactics are wanting.

What is not clear at this time, is whether any U.S. EPA regulatory change in requirement for personal protective equipment (boots, gloves, respirators, etc.) or whether any reduction in buffer zones, which currently restrict application of Telone products within 300 feet of any occupied dwelling, will occur in the near future in Florida. Dow Agrosciences has submitted new field volatility and worker exposure data including the results of Florida air monitoring studies to the U.S. EPA which shows greater than a 95 percent reduction in worker exposure potential to concentrations of airborne Telone vapors following use of the Yetter in-row or broadcast application system. The California

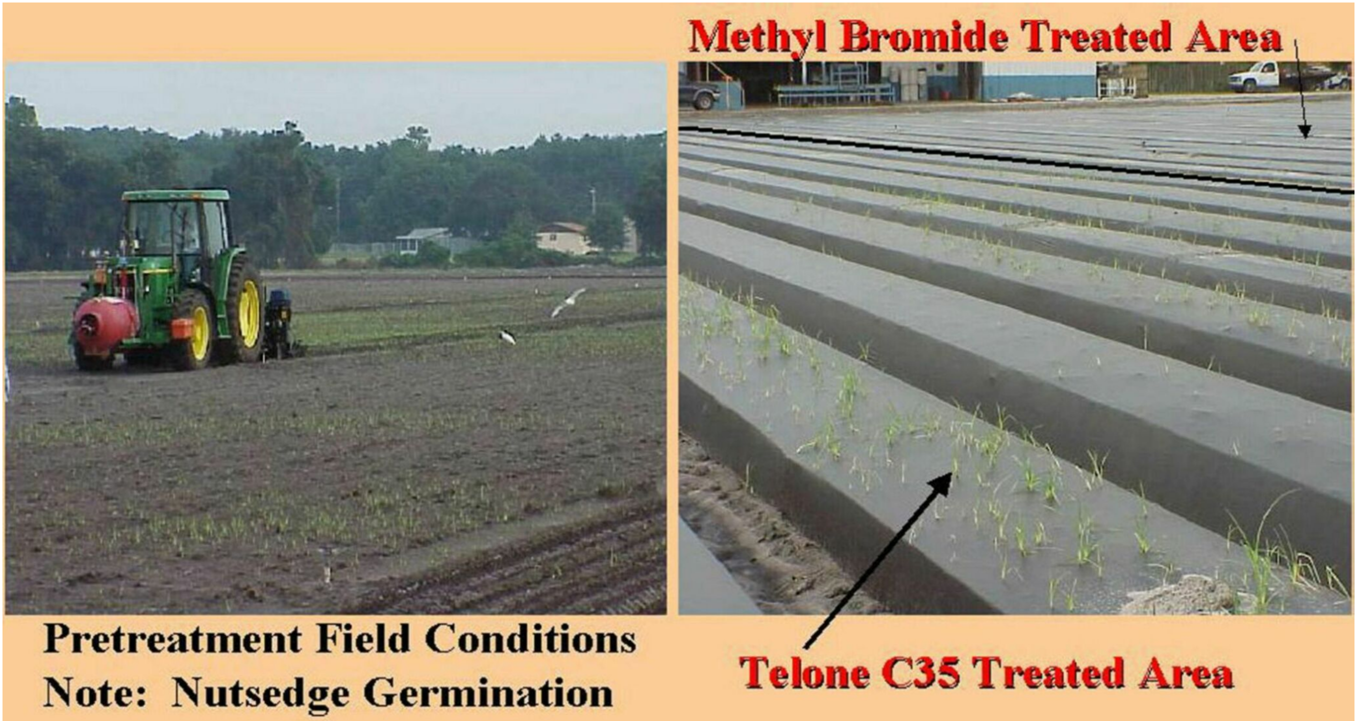

Figure 1. Differences in weed control between areas treated with methyl bromide chloropicrin (67/33; 350 lb/a) and broadcast applications of Telone C35 (26 gal/a) where a pre-emergent herbicide was not applied. Fall 2000, Plant City, FL.

Figure 2. Illustration of Devrinol (6 lb a.i./a) crop injury on strawberry. Fall 2000. Plant City, FL.

Environmental Protection Agency has already reviewed this new data package and subsequently have reduced their buffer zone restrictions to 100 feet for all Telone applications. This is encouraging news, and hopefully Florida will acquire regulatory relief in terms of buffer zone and personal protective equipment restrictions as well. However, if acceptable regulatory changes in personal protective equipment and or buffer zone restrictions do not occur in Florida, Florida strawberry growers will either have to move to new production sites in which buffers are not at issue, or accept significant yield penalties following use of other pest and crop management tactics. Another possible scenario may be that the Florida Strawberry industry may be the first affected agricultural industry to file for a Critical Agricultural Use exemption with the U.S. EPA and governing agency of the Montreal Protocol to allow continued use of methyl bromide after the 2005 phaseout date.

USDA IR-4 Sponsored Strawberry Field Research Trials

Another major facet to field research efforts to develop methyl bromide alternatives in strawberry include the USDA IR-4 sponsored research projects in California and Florida. Each year since 1999, two field experiments have been conducted in grower fields to evaluate soilborne pest and disease control and differences in strawberry yield to a number of federally registered and nonregistered alternative fumigants. Depending upon spectrum of pest control efficacy, most of the fumigants included in these studies were evaluated individually or in combination with other herbicides and fumigants in hopes of achieving the same broad spectrum activity as that of methyl bromide. Some of the fumigants which have been evaluated include: methyl iodide + chloropicrin, Enzone (carbon disulfide), Metham sodium (Vapam), Basamid, Telone C35, and Methyl bromide + Chloropicrin (67/33) compared with an untreated control. In general, the results from this work indicates the metham sodium (Vapam) treatments, applied either preplant incorporated or chemigationally via the drip system, to be ineffective for nematode control. There was some indication however, that Vapam had the activity to perform as a bed-top herbicide component in combination treatments where the herbicide or methyl bromide alternative product could not be relied upon to provide effective weed control.

In general, strawberry yields with either methyl iodide + chloropicrin or Telone C35, applied alone or in combination with another fumigant, have consistently produced strawberry yields which were equivalent to that of methyl bromide in California and Florida trials. Significant strawberry plant phytotoxicity was observed with post plant applications of Enzone (carbon disulfide). Similar to the above results, California IR-4 trials have also demonstrated that fumigant treatment combinations which included Telone C35 EC (InLine®) to be equally as effective as methyl bromide for pest control efficacy and strawberry yield response. The USDA IR-4 funded field research project is now continuing in its third year at field research locations in Plant City and Bradenton under the direction of Dr. Jim Gilreath, GCREC, Bradenton, FL.

Field Demonstrations

Tomato and Pepper

Since the spring 2000 cropping season, more than 20 USDA funded large scale field demonstration trials have been performed in east, west, and southwest Florida tomato and pepper fields. Much of the previous field demonstration research have focused on in-row applications of Telone C17 or Telone C35. Given the impracticality of the Telone label requirements for personal protective equipment of workers in the field during application, new efforts have focused on evaluations of broadcast applications of Telone at least five days in advance of bedding. The prinicipal objective for these new trials were to compare either Telone II (15-18 gal/a), Telone C-17 (35 gal/a) or Telone C-35 (26 gal/a) applied broadcast or in-row, in combination with the herbicides Tillam (2-4 lb/a), Devrinol (2-4 lb /a) and or Treflan (0.3 - 0.75 lb/a) to that of methyl bromide (67/33; 350 lb/a) for weed, disease, and nematode control and for tomato and pepper yield response. Another principal objective was to determine whether the newly developed Yetter deep placement coulter injection system for Telone products could improve pest control efficacy and crop yield response compared to the results of previous studies using broadcast application systems which relied upon predisking, simple straight or forward swept injection chisels, followed by a rolling operation to seal surface soil of chisel traces. In a number of the broadcast Telone trials, an additional application of chloropicrin (100-200 lb/a) was included as a separate soil injected treatment at the time of bedding. All studies were conducted in grower fields with plot sizes ranging from 1 to 13 acres.

Nematode control has generally been good to excellent with all broadcast treatments of Telone products. The superiority of the broadcast Yetter coulter rig was clearly demonstrated in some of the west coast trials in which Telone C35 provided better root-knot nematode control than that of methyl bromide, presumably due to the deeper 12 inch placement of Telone C35 into previously undisturbed soil.

In general, disease control was always improved, but not always to the level of methyl bromide, with the addition of chloropicrin either in the formulation with Telone or as a separate treatment prior to bedding. The increase in disease incidence and plant mortality when broadcast application of any of the Telone products was not followed by additional chloropicrin to the bed, suggests that chloropicrin escape from untarped soil can significantly reduce overall disease control. This conclusion is further supported by the results of trials performed in pepper and tomato in east coast trials conducted by Dr. Dan Chellemi, (USDA ARS Horticulture Lab, Ft. Pierce). In the east coast trials, reduced efficacy by not covering chloropicrin treated soil with a tarp was observed principally during the fall, when conditions appeared to be more favorable for soilborne diseases such as Pythium and damping-off. In west coast studies, reduced efficacy was observed during the spring when hot and dryer soil conditions prevailed which presumably favored more rapid escape of Chloropicrin, particularly within the surface soil horizon. Overall, it would appear that the cropping season itself may not be as important as prevailing environmental conditions, and that additional chloropicrin in the bed at the time of bedding will in many cases improve disease control efficacy. It should also be noted that with a loss of disease control, broadcast application of Telone C35 without additional chloropicrin applied at bedding also resulted in reduced fruit production in some trials.

Previous tomato studies in demonstration trial format have showed less than ideal performance of Tillam when the spectrum of weed species present in the field was broad, and when Tillam was applied alone for weed control. In those studies, various grasses, black nightshade, ragweed, pigweed, and purslane were oftentimes not effectively controlled. As a result of these previous findings, new research efforts targeted the evaluation and performance of various herbicides applied either alone, or in tank mix combinations for overall weed control in both tomato and pepper. For example, tank mixing Devrinol or Treflan with Tillam typically broadened the weed control spectrum in most cases, improving control of some weeds not controlled by Tillam alone. Treflan was especially effective against crabgrass, and provide improved pigweed control in at least one location. In east coast trials, Chellemi observed that combinations of the three herbicides, Tillam, Devrinol, and Treflan usually improved the spectrum of weed control efficacy in tomato, such that it was equivalent to that of methyl bromide.

Other significant results which derive from recent grower field demonstration trials include the effects of timing of Tillam applications in tomato. Previous research has repeatedly demonstrated that Tillam can provide effective nutsegdge control comparable to that of methyl bromide, but has also demonstrated that if not applied and incorporated properly could severely stunt tomato plant growth, and reduce crop yields. In recent trials on the east coast, Chellemi reported that Tillam applications made after broadcast application of Telone and at the time of bedding frequently resulted in injury to the tomato crop. In west coast research trials, tomato growth, fruit production, or weed control efficacy did not appear to affected by time of Tillam application, even when applied at the time of bedding. The east coast trials may simply demonstrate the difficulty of incorporating Tillam in very wet soils with a single pass of a field cultivator. Further research is continuing conducted in tomato regarding the issue of Tillam timing, but since it is not possible to predict or ensure optimal soil conditions at the time of bedding, it may be prudent to consider application of Tillam 7 to 10 days in advance of bedding to minimize the risk of Tillam injury on tomato.

Long Term Studies

Tomato

A three year study was conducted at the Gulf Coast Research and Education Center in Bradenton, FL during the fall of 1998, 1999 and 2000 and the spring of 1999, 2000 and 2001. A principal objective of this study was to examine long term impacts of repeated use of select chemical and nonchemical treatment regimes and cropping systems on pest population abundance and multicrop productivity. In this study, standard methyl bromide soil fumigation was compared to the best chemical alternative, Telone C17 (a mixture of 1,3-dichloroporopene (1,3-D) and chloropicrin) used in combination with Tillam (pebulate), and the best nonchemical alternative, soil solarization, for soilborne pest control and crop response in both fall tomatoes and spring double-cropped cucumbers over multiple years on the same site. Tillam was applied broadcast, preplant incorporated at 4 lb.a.i./acre, then 35 gal/acre of Telone C17 (a mixture of 1,3-D + chloropicrin (83/17%)) was applied through three chisels to the soil in 8 inch tall raised beds during the summer of 1998, 1999 and 2000. Methyl bromide + chloropicrin (350 lbs/acre of 67/33%) was applied at the same time and in a similar fashion. Solarization proceeded for 7 weeks during the summer of 1998 and for 8 weeks during 1999 and 2000. Seven days prior to transplanting tomato, all solarization and nontreated control plots were sprayed with paraquat (0.5 lb./acre) to dessicate existing weed cover. Six week-old >Solamar= tomato plants were transplanted in mid September of each year. Tomato plants and weeds were sprayed twice with paraquat after the last tomato harvest in the fall and before planting spring cucumbers.

Nutsedge populations varied from year to year, but the relative differences remained fairly similar. Both fumigants and soil solarization reduced nutsedge compared to the nontreated throughout the season and there were no statistically significant differences in the number of nutsedge plants between either fumigant or between the fumigants and soil solarization, due in large part to the early desication of nutsedge in solarization plots.

The soil in the test area had a low population of root knot nematodes at the beginning of the experiment in 1998, but this increased greatly in the nontreated control plots in 1999 and declined significantly in 2000. Root-knot populations remained low and fairly stable over the three years during the tomato crop with methyl bromide and Telone C17. There was an increase in rootknot nematode population from 1998 to 1999 with soil solarization, but the population declined slightly during 2000. The most severe galling of tomato roots was observed with soil solarization and the nontreated control in each of the three years. Methyl bromide resulted in no gall formation during the first year, but gall formation increased over the next two years. Galling on plants grown in soil treated with Telone C17 was intermediate during the first year, similar to methyl bromide during the second year and the least of all the treatments during the third year. Both fumigants were superior to either soil solarization or the nontreated control in reduction of the incidence of Fusarium wilt of tomato. Soil solarization reduced the incidence compared with the nontreated control in each of the three years, but the level of infestation in the second year was over 20% which would be commercially unacceptable and by the third year the level had increased to greater than 50% and resulted in many dead plants by the time of harvest, thereby reducing yields significantly.

Tomato production generally declined each of the three years from the levels in the first year. The most extra large and total marketable tomatoes were produced with methyl bromide and Telone C17 + Tillam in 1998. There was no difference in tomato production among alternatives in 1999. During 2000, tomato production was comparable with methyl bromide and Telone C17 + Tillam, but solarization reduced yields to a level intermediate between that of the fumigants and the nontreated control.

Nutsedge populations in the spring cucumber crop varied from year to year, apparently affected by the prolonged drought through which Florida suffered from the spring of 2000 to summer of 2001. The number of nutsedge plants increased greatly from 1999 to 2000 but declined in 2001. In the spring of 2000, there was more nutsedge in Telone C17 + Tillam plots than was present in methyl bromide or solarization plots and there was a trend for this again in spring 2001, although this difference was not significant in 2001.

Rootknot nematode populations were the highest in the nontreated control during the first spring cucumber crop and declined after that, possibly due to the effects of the prolonged drought. Methyl bromide and Telone C17 reduced root-knot populations equally well in all three years of the spring cucumbers. There was little difference in the numbers of root-knot juveniles recovered from any of the treatments in spring 2001 (year 3). This is a significant finding for those growers producing more than a single crop on the same plastic.

Cucumber production declined each year in the nontreated control plots, but remained fairly constant with methyl bromide and Telone C17 + Tillam. Yield fluctuated quite a lot with soil solarization, ranging from the lowest producer in 1999 to comparable to the fumigants in 2000 then dropping back to a point intermediate between fumigants and the nontreated control.

Chemigation Research

Since 1994, various soil applied fumigant alternatives, either alone or in combination, have been field evaluated in Florida vegetable production systems for their potential to replace methyl bromide while maintaining pest control efficacy and crop yield. Significant advancements have been made in the commercial development of soil application technologies for some fumigants such as Telone® products applied via standard shank or chisel injection with the broadcast or in-row Yeatter Coulter system. Problems continue to plague us here in Florida with crop and pest control response variability for those soil fumigants applied either preplant and or post plant via drip irrigation delivery systems (chemigation). Most Florida vegetable soils are classified as fine sands with low water holding capacity and high hydraulic conductivity, which allows water to easily, and in some cases the chemicals in them, to rapidly percolate through soil. As a result, recent field research efforts have focused on evaluations of the spatial distribution of drip irrigation water colored with a blue dye when applied through one or two drip tubes. Dow AgroSciences, particularly the assistance of Dr. Joe Eger, should be acknowledge for thoughtful insight of experimental methodology, design, and support of preliminary research. Various irrigation run times and total water volumes were evaluated in hopes of increasing our understanding of the dynamic of water movement in soil so to achieve a broader based, environmentally sound, use recommendation for chemigated compounds.

During the past year, drip irrigation field research trials have been conducted at various locations around the state by University of Florida research faculty in collaboration with Dow AgroSciences and grower cooperators. At each site, soil type was a fine sand, with beds formed, covered with plastic mulch, and new drip tape installed in accordance with normal grower practices. At sites in Plant City, the experiments were conducted at the end of the strawberry growing season, with existing plants positioned in two rows within the bed, and new drip tubing installed before treatment initiation. At all sites, drip tubing used was either T-Tape®, Netafim®, or Queen Gil®. Emitter spacing for the different tubes varied from 4 to 18 inches, delivering from 0.281 to 1.2 gallons per minute per 100 linear feet of row. Depth distribution of drip irrigation water for irrigation run times of 1 to 12 hours was evaluated using a water soluble blue marking dye such as Signal® or TerraMark®. One and two drip tubes per bed were evaluated in most trials. For a single tube per bed, the tube was positioned on the bed top center, while the two tubes were centrally positioned 10-12 inches apart in 2 rows down the middle of the mulched covered row.

Width, depth, and overall bed area of soil covered by the drip water were evaluated by digging cross-sections across the beds to the depth of the wetting front. For all trials, with single drip tubes, cross sections and measurements of drip water dispersion were made across the bed at points on the emitters and equidistant between emitters. In all cases, cross sectional observations were made at two random locations per replicate plot for each treatment. To measure the spatial distribution of drip water, a 36 to 48 inch square plexiglass sheet, scored at 1 inch intervals in both directions, was held against the bed face to be measured and the bed and water distribution pattern measured or outlined with an erasable felt pen (Figure 3). In many trials, mapped grid coordinates were then field recorded and later entered into the computer to analyze depth, width, and size of treated or dye stained areas relative to bed size, irrigation run time, water volume, drip tube number, and other treatment regimes.

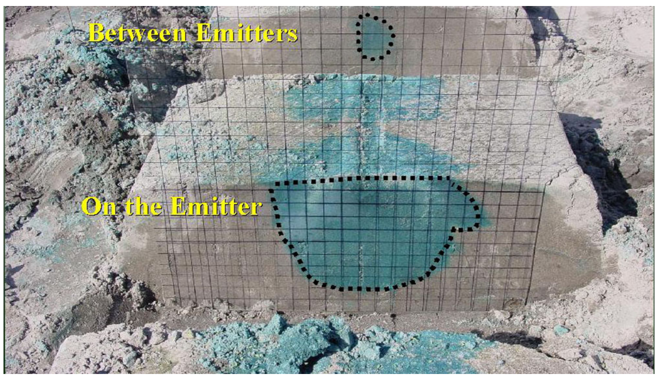

Figure 3. Grid evaluation method for measuring width, depth, and area of drip water movement using a blue dye introduced into the irrigation water stream.

For measurements taken on the drip emitter and a single drip tube per bed, the depth, width, and cross-sectional bed area wetted by drip irrigation water increased linearly with irrigation run time from 1 to 12 hours at all field experimental sites (Figure 4). As with patterns measured with a single tape on the emitters, increases in width, depth and area were generally linear when measurements were taken at points midway between drip emitters. At some of the sites, the presence of a shallow compacted traffic layer severely restricted downward penetration of drip water, and resulted in the flooding of row middles after irrigation run times of longer than 4 hours (Figure 5). The use of two drip tubes per bed only expedited the time in which flooding occurred within the field. In general, convergence of the wetting fronts midway between emitters was a much slower process as distance increased between emitters. For preplant soil fumigation purposes therefore, where maximum bed coverage along the entire bed is important, emitters which are too widely spaced along the row are likely to compromise overall treatment efficacy with any chemigated, soil fumigant compound.

Figure 4. Illustration of the incremental radial expansion of the wetted zone in a raised plant bed after pulsing the injection of a blue, water soluble, dye through a drip irrigation system over a 10 hour injection period. Each ring represents approximately 2 hours irrigation run time.

The relation between drip irrigation run time and depth, width, and cross sectional bed area wetted by drip irrigation water were very different between experimental sites and could not be directly compared due to variations in irrigation run time, line operating pressure, drip tube flow rate (high, medium, low), in addition to differences in tube numbers per bed and emitter spacing. However, average depth, width, and cross sectional bed area wetted by drip irrigation water was determined to increase as a curvilinear function of total water volume applied, and the functional relationship was remarkably similar for many of the experimental sites (Figure 6). For the irrigation run times and total water volumes evaluated in these studies, there was little indication that one drip tube manufacturer was any different from another when equal volumes of irrigation water were compared. For a given water volume, the use of two tapes per bed always increased spatial distribution of irrigation water simply because of the spacing between drip tubes and the increased number of emission points along the bed. In the overall analysis of the relationship between total irrigation water volume and spatial distribution of the wetted zone, it appears that most bed wetting occurs in the time to deliver the first 300 gallons of water expressed per 100 linear feet of row. If a maximum depth of 16-20 inches from the top of the bed is assumed, then irrigation run times required to deliver water volumes of 100 to 200 gallons per 100 linear feet of row should not be exceeded so as to contain the wetting front within the future rooting zone of the plant (Figure 7).

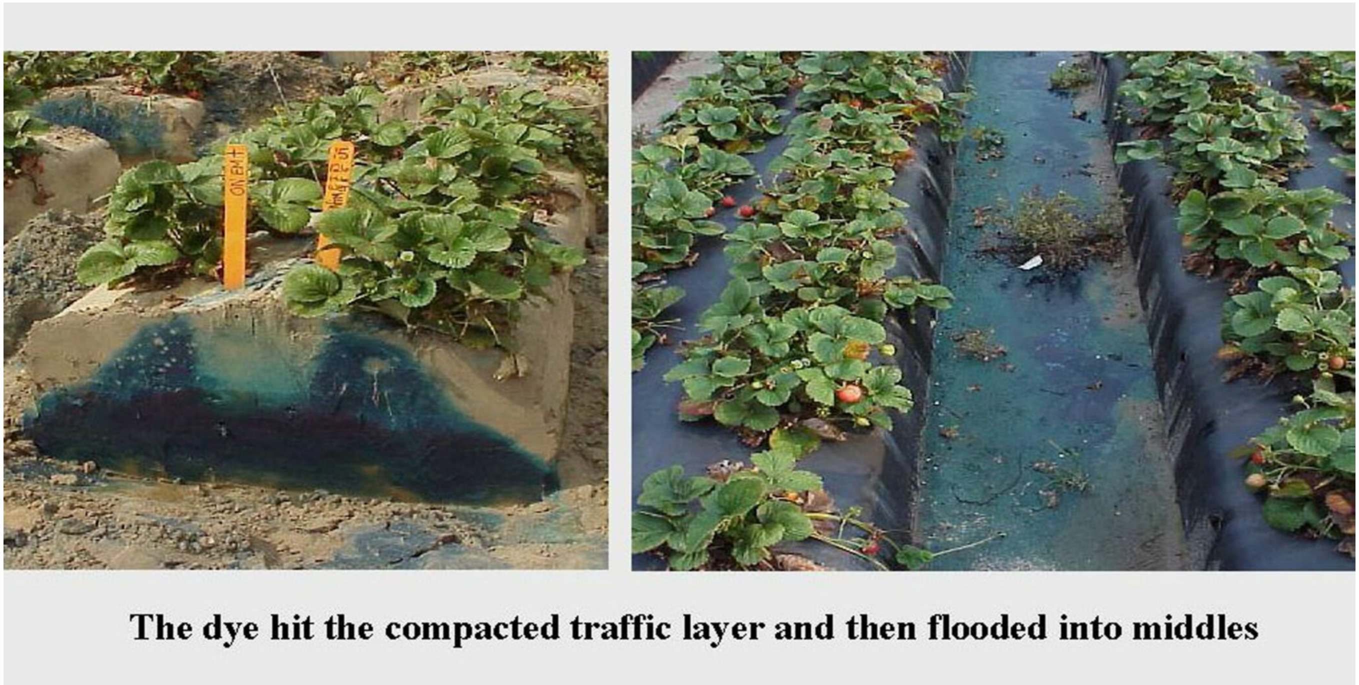

Figure 5. Illustration of how the presence of a shallow compacted traffic layer restricts downward movement of drip water flow, resulting in the flooding of row middles.

Further reductions in irrigation run times or water volumes could be achieved if significant radial movement of fumigant gases occurs after drip application when new soil air passages redevelop. A recent field trial with InLine®, an emulsifiable concentrate of Telone C35 at the University of Florida in Gainesville has demonstrated that the fuming effect may be as much as 5 to 10 inches further than movement of the blue dye in both directions. The range of gas movement was dependent upon fumigant concentration in irrigation water between 500 and 1500 ppm, the higher the concentration the greater the radial movement. This suggests even less irrigation water, and quite possible a single drip tube per bed, may be required to achieve soil pest control efficacy due to the evolution and movement of fumigant gases from the wetted zone after fumigant application.

Even though our knowledge and understanding of the dynamics of drip water movement in soil increases, this does not mean that growers, armed with this information, will achieve immediate success without cost or change. For example, recent USDA sponsored field trials have shown that flaws in irrigation system design could significantly compromise treatment efficacy of any water soluble compound, such as Telone EC or metham sodium. The principal problem involves delivery uniformity throughout the entire field. In one field trial, significant drops in drip line water pressure from one end of the field to the other, established a gradient of diminishing volume of water output and hence of treated soil volume. If preplant samples for comparisons of nematicidal efficacy along the row had been taken, they surely would have shown a decline in efficacy down the row which corresponded to reduce drip flow rate. The experiment clearly demonstrated that use of pressure regulators across the entire field with adequate water flow sizing requirements are a must for uniformity.

The proximity of the plant to the drip tube has also been demonstrated to be very important in terms of defining pest control efficacy and plant growth response with a chemigated fumigant. In two separate experiments conducted a number of years ago, it was observed that metham sodium application rates as low as 10-15 gallons per treated acre could be effectively used for both tomato and pepper crop destruction purposes if established plants were within two inches of individual drip emitters. Identical

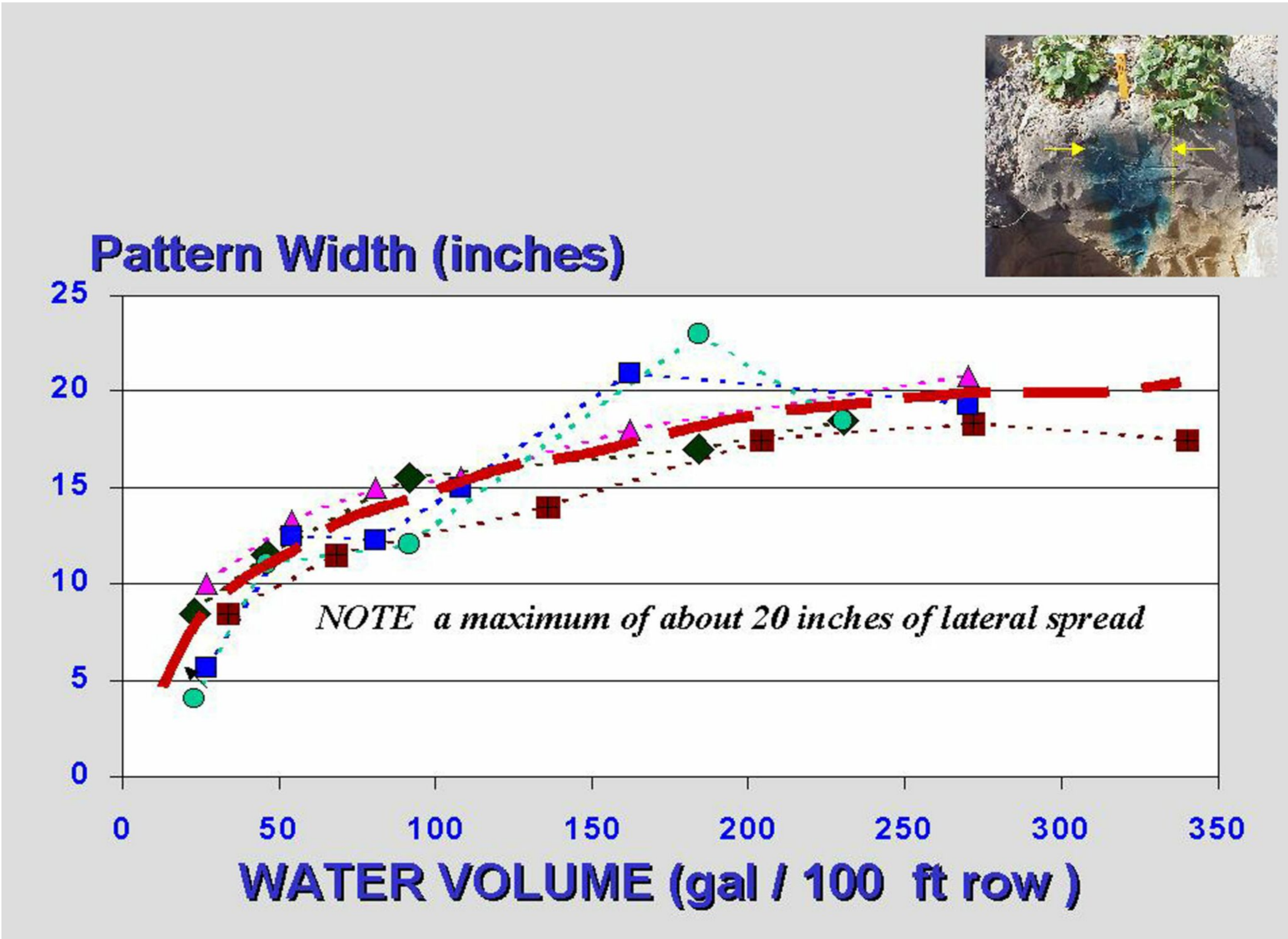

Figure 6. Relation between irrigation volume and average width of dye pattern on the drip emitters for Plant City, FL drip studies.

studies with plants positioned 6 to 8 inches from the drip line required 20-30 gallons per treated acre to achieve the same level of plant mortality. Presumably, a two-fold increase in application rate was needed to compensate for the additional distance required to contact the primary root zone of the plant. The problem is even further amplified when one considers typical production practice of laying the drip tape on one side of the bed and planting the crop offset of center on the opposite side of a 32 to 36 inch wide raised bed (Figure 8). Ideally the tape would be placed in the center of the bed and the crop planted offset of the tape. Bed widths may also need to be evaluated as narrower beds could be more uniformly covered than wider 34-36 inch wide beds. Given the sandy nature of Florida soils, narrower bed widths, drip tubes with closer drip emitter spacing (likely in the range of 8-12 inches), and planting practices which place plants closer to the drip tube may need to be adopted to more effectively utilize the drip tape for chemigational purposes.

General Conclusions of Chemigation Research:

- Regardless of drip tube manufacture, irrigation run time, tube flow rate, emitter spacing, or total volume water applied, it was virtually impossible to wet more than 50-60% of the bed with a single drip tube per bed.

- In the sandy soils of Florida and not accounting for any fuming action, two drip tubes will likely be required to treat upwards of 85-95% of the entire mulch covered bed with any chemigational alternative to methyl bromide.

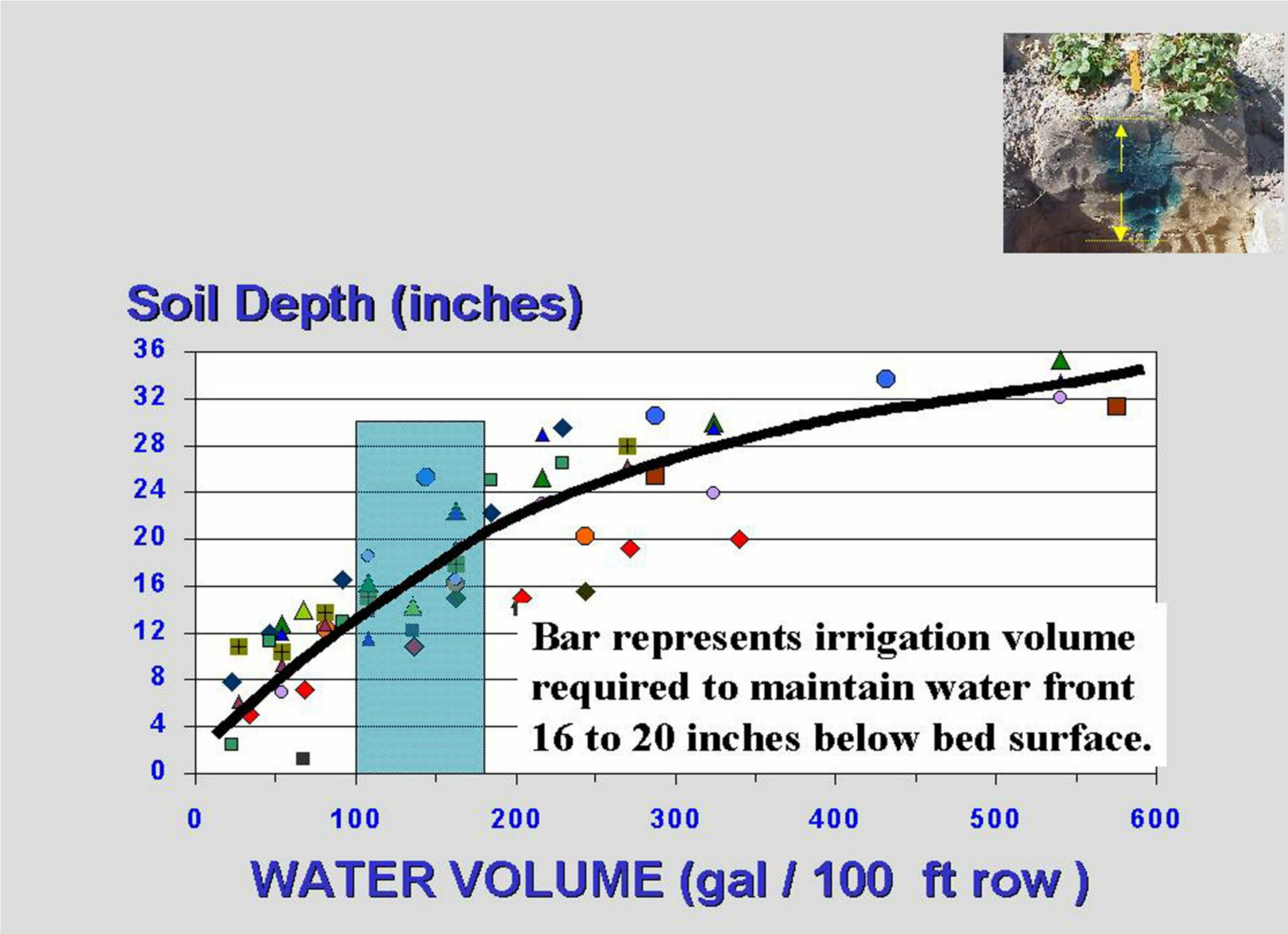

Figure 7. Relation between irrigation volume and average penetration of dye movement without regard to number os tapes, emitter spacing, location or manufacturer.

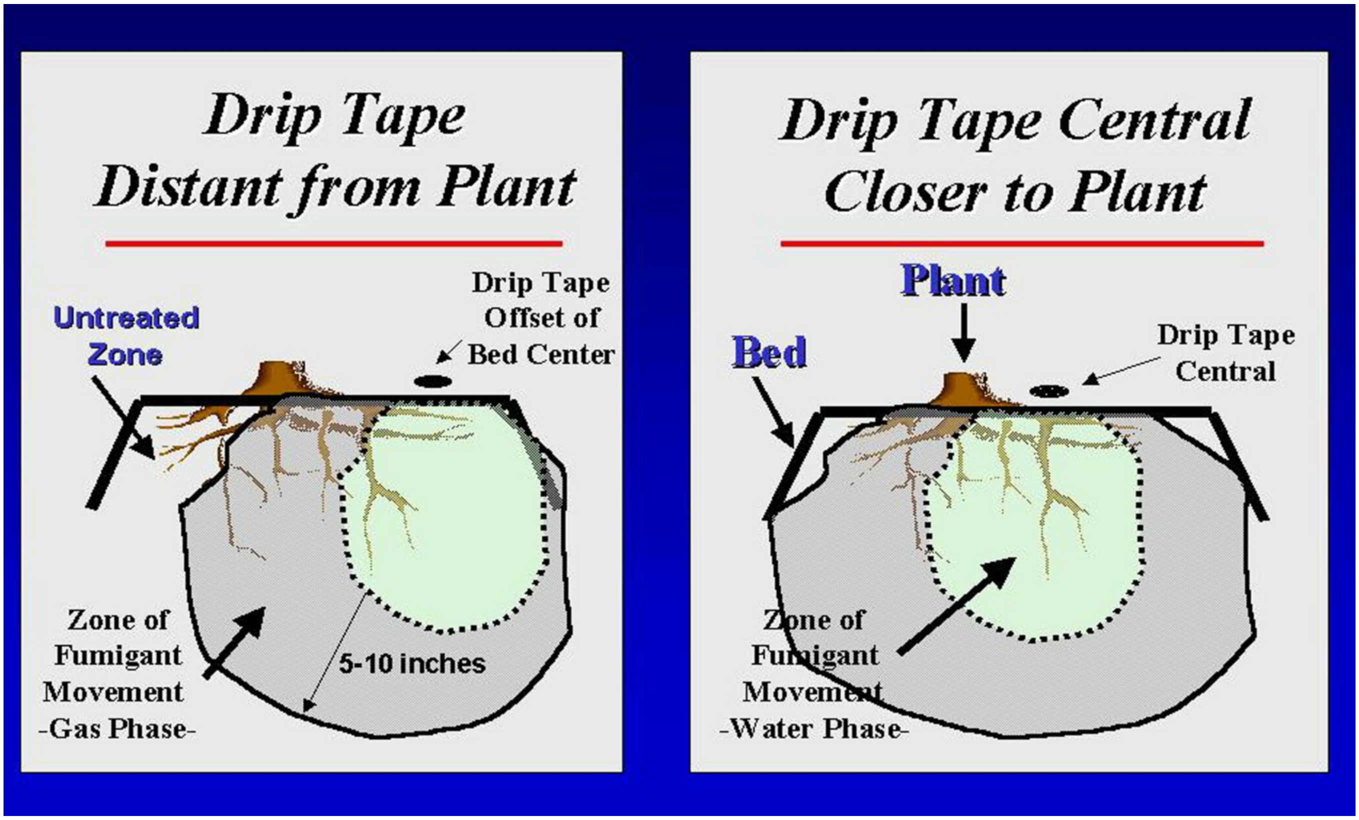

Figure 8. Importance of central drip tape placement to mixiimize bed coverage with chemigated Telone EC.

- For the sandy soils of Florida, most bed wetting seems to occur in the time to deliver the first 300 gallons of water expressed per 100 linear row feet, and that lesser volumes (100-200 gallons / 100 linear feet of row) should be considered if depth of penetration of the wetting front is an important consideration .

- Soils and grower production practices markedly differ, and these differences in soil type, compaction, depth to restrictive layers can all effect water movement and the final distribution of chemicals within, which enforces the need by growers to conduct their own dye studies to optimize the utility of the drip irrigation system for chemigational purposes.

- It would appear that irrigation injection schedules previously utilized to evaluate drip applied fumigants (such as Vapam®) in Florida field research efforts have significantly underestimated irrigation run times or water volume requirements for maximizing bed coverage, and therefore in all likelihood, soil pest control efficacy.

- Finally, the effect of applying large volumes of water to the raised bed on plant nutrition and fertility programs needs to be furthered researched. Surely some readjustment in the fertility program must be developed to minimize leaching impacts from use of the drip system for preplant soil fumigation.

Methyl Bromide Formulations and Application Rate

Previous research has demonstrated that methyl bromide (Mbr) is the component with principal nematicidal activity and chloropicrin (Pic) is only weakly nematicidal. Given the changes which have occurred in cost, availability and formulation of methyl bromide, field demonstration and microplot experiments were conducted to evaluate differences in pest control efficacy and tomato yield response to reduced application rates of three formulations of methyl bromide and chloropicrin. During spring 2001, two experiments were conducted to evaluate three formulations of methyl bromide and chloropicrin and three application rates. The different formulations included 1) 98% methyl bromide and 2% chloropicrin; 2) 75% methyl bromide / 25% chloropicrin, and 3) 50% methyl bromide / 50% chloropicrin. Application rates of 50, 75, and 100% of the maximum broadcast equivalent were evaluated within each formulation. All formulations and application rates were evaluated for control of the southern root-knot nematode (*Meloidogyne incognita*) and yellow nutsedge (*Cyperus esculentus*), and resultant impacts on Florida 47' tomato plant growth, development, and yield . In general, the results of these microplot trials clearly showed :

••••••••• ab•All formulations and application rates of methyl bromide and chloropicrin provided significant control of nematode and nutsedge compared to the untreated control.

••••••••• ab•Incremental loss of nematode and nutsedge control with reduced methyl bromide and chloropicrin rate.

• ab•Compared to a formulation of 98% methyl bromide and 2% chloropicrin, nematode and nutsedge control decreased with increased chloropicrin content of the methyl bromide formulation.

These results appear to validate field observations of increased severity and incidence of weed and nematode problems associated with the change in methyl bromide formulation from 98/2 to 67/33, and with reduced rates of methyl bromide field application. It also suggests a further erosion of nematode and weed control if chloropicrin content of methyl bromide formulations is increased further from the current 67/33 formulation to a formulation composed of 50% methyl bromide and 50% chloropicrin. The degree to which this increase is actually related to a change in formulation is not known. In addition to a formulation change, some growers have also tended towards reduced application rates from previous standards. With increased cost and possibly reduced availability, growers will likely want to reduce rates, and once again, the expectation of increased pest incidence, severity, and of reduced yields should also be expected. In this regard, Florida strawberry growers may want to consider use of those plastic mulches which reduce the amounts of methyl bromide which escape from soil and as a way to distribute reduced availability within existing acreage in the future if the regulatory status of Telone remains unchanged.

Virtually impermeable Plastic Mulches (VIF)

Plastic mulches are used are used in Florida raised bed vegetable culture not only for horticultural reasons, but are mandatorily used to allow more effective use of methyl bromide by reducing the rates in which the fumigant volatilizes from soil. The permeability or ability of a particular gas to flow through a given mulch is directly related to the thickness and chemical composition of the mulch, as well as ambient temperature, tarp integrity, and of the dosage and formulation of the fumigant applied. The most commonly used plastic mulches in Florida are low-density polyethylene mulches (LDPE). Over the years, improvements in LDPE production technologies have resulted in the availability of mulches of reduced thickness while maintaining good tensile strength. A variety of thicknesses are available, generally ranging from 0.6 to 1.25 mil. In general, most of the LDPE mulches are not particularly effective in retarding outflow of most fumigant gases from soil.

Because permeability decreases as the density of the plastic increases, high-density polyethylene (HDPE) mulches are much less permeable to methyl bromide than LDPE tarps. Virtually impermeable films (VIF), allows very little methyl bromide (or other gases) to pass through them. Compared to LDPE tarps, certain VIF films are over 20,000 times less permeable to methyl bromide. Historically however, VIF films have had problems with tensile strength such that they tend to tear easily and do not stretch well.

Preliminary research, some of which was conducted in both north and south Florida, showed that methyl bromide application rates could be reduced as much as 50 percent without serious compromise to pest control or crop yield if an appropriate, less permeable, VIF type plastic mulch was used. During the past two years, over fourteen USDA funded field demonstration trials have been conducted to evaluate and validate the feasibility of using VIF mulch films to reduce methyl bromide field application rates and to compare crop yield and pest control efficacy. Large scale grower field demonstration trials were conducted in west central (Parrish & Plant City, FL) and south Florida (Immokalee) to compare possible methyl bromide and chloropicrin (67/33) rate reductions of 25 to 50% compared with a full grower standard rate using the standard low density polyethylene plastic mulch. In all of these trials, differences in plant growth, including comparisons of plant size, height, vigor, consistency, mortality, and nematode and disease incidence and severity were evaluated on a periodic basis during the growing season. Assessments of any differences in crop yield between the two treatments was the responsibility of individual grower cooperators.

In general, the results of the 14 grower field demonstration trials have indicated no significant loss of pest control efficacy or of crop yield (tomato, pepper, cantaloupe, or strawberry) as reported by the grower when applications rates of methyl bromide were reduced as much as 25 to 50% **when** reduced rates were accompanied by the use of the VIF mulch. At some demonstration sites, improvements were observed in plant growth and vigor and of weed control efficacy with the VIF reduced methyl bromide rate treatment compared to the standard mulch and methyl bromide application rate. At some of the demonstrations sites, problems were incurred during the plastic laying operation, in that tractor speeds needed to be reduced as low as 2 to 3 mph, rather than 4 to 5 mph, to properly install the plastic. Since the VIF plastics are not embossed, they have a tendency to slip from under the rear press wheels during installation causing stoppages in the plastic laying operation.

There is no question that these new VIF mulches will be more expensive (2x) in terms of material and labor costs to install, but use of VIF plastic mulches may become more cost effective as methyl bromide availability decreases and pricing increases in future years, and as growers acquire neccessary skills in which to lay them. In some cases, it may also be possible to mitigate current regulatory restrictions of fumigant use in some crops, such as strawberry, with use of a high barrier VIF plastic mulch.

Post Harvest Crop Destruction

One of the foundation principals of an integrated nematode management strategy is to ensure early destruction of the crop immediately after final harvest. The major objective is to remove the plant food source which maintains nematode reproduction and soil population growth. Any delay in crop termination can increase soil populations of nematodes, particularly in the span of a few weeks after final harvest if the plant and its roots are not killed immediately. In general, the more nematodes left in the soil after a crop, the more which will survive to infect roots of the following crop, and the more difficult it will be to achieve satisfactory nematode control with any preplant fumigant. Clearly, the opportunity to enhance nematode control with soil fumigation and minimize losses in crop yield due to nematodes is dependent upon the adoption of early crop destruction after final harvest.

Currently, tomato and other crop fields are sprayed with paraquat in a 'top-down' approach to kill the foliage after harvesting is completed in the spring or fall. While foliage is killed, roots are initially unaffected by the paraquat treatment, and nematode reproduction continues until nutrient reserves within roots are exhausted and roots die. New field research efforts are evaluating a 'bottom-up' approach in which water soluble fumigants are chemigationally applied via drip irrigation to simultaneously and immediately: 1) kill the roots; 2) stop nematode reproduction; 3) reduce soil population levels of nematodes; and 4) kill the foliage, as in the paraquat treatment. Previous research has demonstrated the feasibility of the approach with drip applied metham sodium (Vapam), and more recently with metham sodium or Telone EC. For example, Telone EC (10 gal/treated acre) was evaluated at four locations for sting nematode control and for post harvest strawberry crop destruction purposes. In these trials, Telone EC significantly reduced sting nematode populations and provided near complete kill of strawberry plants within treated rows. Results of field trials performed during Spring 2001 clearly demonstrated the ability to kill tomato foliage via destruction of roots. Soil populations of nematodes also were substantially reduced in the 'bottom-up' approach. However, the efficiency in reducing nematode populations in soil was directly related to the volume of water supplied and the resultant distribution of the fumigant within the bed. To maximize the efficiency of the 'bottom-up' approach will require additional on-farm chemigation research to determine the most appropriate drip emitter spacing and injection period to maximize uniformity of bed coverage within the plant row.

Crop Rescue

During the past year, numerous tomato fields were identified in which root-knot nematode became a serious problem within the established crop. Infested fields displayed classic symptoms of stunted plant growth and chlorotic foliage. In most cases, the problem appeared to be related to droughty conditions at the time of soil fumigation. Other factors such as reduced methyl bromide application rate and possible formulation effects (ie., 67/33) cannot be excluded as possible contributing causes for the nematode problematic fields.

Once the discovery is made that nematodes have colonized tomato roots and stunted plant growth, the question is whether it is possible to effectively reduce nematode population levels and restore tomato yield potential. At present the only post plant nematicide which can be used to help resolve an established nematode problem is Vydate (Oxamyl). Vydate is not considered a true nematicide, but rather a nematostat. Nematostats, rather than kill nematodes, induce a narcotic effect which paralyzes the nematode and prevents it from feeding, movement, mating, and other normal activities. The narcotic effect is only as persistent as adequate Vydate concentrations are maintained within soil and roots. Following nematode application, irrigation and rainfall can dilute and leach toxic concentration from the nematode environment, thereby restoring its ability to conduct normal bodily functions. As a result, repeated Vydate applications to soil are required to maintain toxic (narcotic) concentrations. Field observations of crop rescue attempts with Vydate injections via the irrigation system have usually demonstrated some improvement to plant growth and vigor, but not necessarily yield. Many factors simultaneously interact to influence the extent to which plants respond to Vydate treatment. Not all factors are well understood at this time.

In general, use of Vydate as a postplant, crop rescue treatment for nematodes should considering the following:

- Foliar applications of an upwardly mobile systemic, such as Vydate, have not proven to be effective for nematode control or for improved plant growth response. Vydate treatment should not be considered unless made via the drip irrigation system.
- Fields with previous history of nematode problems should be closely monitored after transplanting. The sooner a nematode problem is identified in the field and the sooner Vydate treatments are initiated, the greater the response in plant growth and yield will be. Clearly the nematode problem and impact to crop yield will intensify over time if nothing is done, particularly if the plant undergoes periods of moisture stress.
- Regardless of the time of discovery in the field, roots which are heavily galled are not likely to respond satisfactorily (stage a dramatic comeback) to Vydate treatment.
- The inability to uniformly distribute Vydate along the entire plant row via the irrigation system in itself sets a limit to the degree of possible plant improvement.
- After Vydate application, the effect of daily irrigation (ie., two or more times per day) on Vydate soil and root concentrations and crop yield response is not known. However, given the possible dilution and leaching effect of daily irrigation cycles, repeated weekly applications throughout the remainder of the growing season are likely to be superior to 1 or 2 early season applications made immediately after discovery of the nematode problem in the field.

Overview and Future Considerations

The University of Florida, IFAS and USDA ARS in Ft. Pierce continue to conduct collaborative field research programs to evaluate chemical and nonchemical pest management tactics to replace methyl bromide. During recent years we have made significant advances in the integration of some of these tactics, and have devised a pest management system which should be an economically viable replacement for methyl bromide. The cooperation of many growers and agrochemical representatives must also be credited for this achievement. The interactive demonstration trial format we have adopted has worked extremely well for identifying problems, and for expediting the development of a methyl bromide alternative strategy.

All of the research that we have conducted, some of which is documented here, appears to support the general conclusion that consistently effective nematode control can be obtained with broadcast or in-row applications of Telone II, Telone C17, or Telone C35 utilizing the Yetter Coulter soil injection system developed by Mirusso Fumigation & Equipment, Delray Beach, FL. The superiority of the Yetter system is due to deeper soil placement, improved closure and seal of chisel traces, and improved fumigant containment when applications can be made to undisturbed, compact soil. This collaborative work has shown that use of Telone products formulated with chloropicrin can significantly reduced the incidence and severity of soil diseases; however, to obtain consistent soilborne disease control, equivalent or nearly so to that of methyl bromide, may require an additional application of chloropicrin at the time beds are formed and covered with plastic. This work has also shown that tank mix applications of various preemergent herbicides such as Tillam, Devrinol, and Treflan can effectively broaden the spectrum of weed control to the near equivalence of methyl bromide. Unfortunately, we have also seen how applications of these herbicides can introduce opportunity for significant crop injury.

Significant advancements have also been made in our basic understanding of the dynamics of drip irrigation water movement and use of the irrigation system for agrochemical delivery. We have discovered how flaws in irrigation system design and operating pressure can prevent uniform delivery of any chemigated compound. Regardless of method, this work shows that pest control efficacy for all of the fumigant alternatives is generally a little less than that of methyl bromide; and and more highly dependent upon uniform delivery and distribution. Unlike methyl bromide, prevailing soil and climatic conditions pre and post fumigant application are much more important determinants of efficacy and crop response with the alternative chemicals. Growers can also cause significant response variability due to inappropriate land preparation or substandard application procedures. Although our research continues to define optimum conditions and procedures required to maximize performance of Telone, chloropicrin, and other fumigant and herbicide products, it probably cannot be consistently achieved in every field as equivalent to methyl bromide. As a result, growers must learn to expect some disease, some loss, and recognize that some inconsistency is unavoidable.

As the methyl bromide phaseout proceeds, Florida fruit and vegetable growers will have to increasingly rely on these and possible other chemical and nonchemical pest and crop management strategies. During the phaseout period, growers will have to make significant commitment to learn how to effectively use these alternative systems. The change from methyl bromide to a system which relies upon Telone, chloropicrin, and various herbicides will not in all likelihood proceed uneventfully, and the sooner comprehensive testing of alternatives is initiated the better off growers will be.

Many of the new farming considerations will be necessary in the future that were not required for use of a material that was as unforgiving as methyl bromide. For example, in every grower field which has been surveyed, a compacted zone (traffic layer) occurs at a soil depth of 6-8 inches. In some fields the presence of the zone has significantly influenced the overall success of an alternative fumigant treatment. We have observed how failure to adequately manage weeds within the field can not only affect crop yield, but serve as alternative hosts to nematodes, causing potential for additional crop production problems. With methyl bromide, Florida growers have not had to consider before the use of a preplant incorporated herbicide for weed control. They are now only becoming aware of the stunting and crop injury problems which can occur when herbicides like Tillam and Devrinol are not applied or incorporated properly. Uniform management of the soil water table will also be more critical in the post methyl bromide era, since deep injection of some fumigants into saturated soil horizons has been observed to remain undegraded in soil, causing planting delays, crop injury, and potentially other problems. Because additional problems will eventually be uncovered, the sooner on- farm alternatives research is initiated, the better off growers will be in the post methyl bromide era of Florida crop production.

It also is reasonably clear that even with the new formulations of methyl bromide (67/33), weed and nematode problems can develop in an established crop after its use. So even methyl bromide is longer as perfect as it use to be, and problems with nematodes and weeds are expected to increase as a result of any attempt to increased the chloropicrin content of the formulation in the future. In fields with a history of recurring nematode and disease problems, and or of difficult to control weeds, it seems that what we know now is that it is unreasonable to expect that any of the chemical alternatives, alone or in combination, will always achieve the same level of pest control and crop yield as that of methyl bromide. The problem in achieving equivalency with methyl bromide is not simply alchemy, tank mixing of the right products so to speak. Success involves the appropriate application rate, applying not to much or too little. It is equipment calibration and application, achieving product uniformity without spray overlap, streaking, or producing hot spots of phytotoxic concentration. It is incorporation methodology, selection of the proper tillage implement, tractor speed, depth, and machine setting. It is timing these operations within a changing environment, to occur under the right conditions of moisture and temperature. It is differences in soil type, depth to soil layers restrictive to water movement, bed dimensions, tillage operations, will can negatively impact drip water distribution and use of the drip system for delivery of agrochemicals. As we have shown, all of the above factors can have a dramatic impact on pest control efficacy and crop growth response.

No one would probably disagree that methyl bromide has been a silver bullet type compound. In the field it has required no pest problem diagnosis, no rigid set of soil or environmental condition to apply and perform consistently. It is becoming increasingly clear that the new strategies under development, those that include Telone, Chloropicrin, and different herbicides are not perfect but we believe they are acceptible. Growers will have to assume much more care, knowledge, and understanding of the individual products to use them. Finally, we believe that Florida growers are up to these new challenges, and although we won't have the one size fits all pest control strategy anymore, we believe that farming in Florida will survive and prosper after methyl bromide.