Performance of Containerized and Bare-root Transplants with Soil Fumigants for Florida Strawberry Production

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Summary. Field studies were conducted in three Florida locations (Bradenton, Gainesville, and Quincy) during 1998–99 and 1999–2000 to: 1) compare the performance of two transplant systems under diverse MBr alternative programs in 'Chandler' strawberry (*Fragaria ×ananassa*), and 2) determine the efficacy of these treatments on soilborne pest control in strawberry. Fumigant treatments were: 1) nonfumigated control, 2) methyl bromide plus chloropicrin (MBr + Pic) at a rate of 350 lb/acre, 3) Pic at 300 lb/acre and napropamide at 4 lb/acre, 4) 1,3-dichloropropene (1,3-D) plus Pic at 35 gal/acre and napropamide at 4 lb/acre, 5) metam sodium (MNa) at 60 gal/acre and napropamide at 4 lb/acre, and 6) MNa followed by 1,3-D at 60 and 12 gal/acre and napropamide at 4 lb/acre, respectively. Strawberry transplants were either bare-root or containerized plugs. There were no significant fumigant by transplant type interactions for strawberry plant vigor and root weight per plant, whereas ring nematode (*Criconema* spp.) and nutsedge (*Cyperus rotundus* and *C. esculentus*) populations, and total marketable fruit weight were only influenced by fumigant application. The nonfumigated plots had the lowest strawberry plant vigor and root weight per plant in all three locations. In most cases, plant vigor and root biomass per plant increased as a response to any fumigant application. With regard to the transplant type, bare-root transplants had similar plant vigor as plugs in two of the three locations. Fumigation improved nutsedge and ring nematode control. All fumigants had higher early and total marketable yield than the nonfumigated control, whereas transplant type had no effect on total fruit weight.

During 2004, U.S. strawberry production represented more than $1.47 billion in gross value [U.S. Department of Agriculture (USDA), 2005]. Florida is the second leading state in the U.S. in planted area and value with 7100 acres and $178 million, respectively (USDA, 2005). Strawberry harvest in Florida occurs between December and March, when other growing states are not planting the crop, allowing local growers to take advantage of high market prices during winter and early spring.

Traditionally, strawberry is transplanted in polyethylene-mulched beds with drip irrigation and the soil is treated with MBr + Pic to control soilborne diseases, nematodes, and weeds (Simonne et al., 2003). However, MBr is being phased out according to the Montreal Protocol, because it is an ozone-depleting molecule (Watson et al., 1992). During the last decade, various molecules have been proposed as MBr replacements to control soilborne diseases, nematodes, and weeds in polyethylene-mulched crops. Among those alternatives, the application of 1,3-D + Pic has been demonstrated to be an effective means to reduce the incidence of soilborne diseases in tomato (*Lycopersicon esculentum*) (Jones et al., 1995). De Cal et al. (2004), testing various alternatives to MBr in Spanish strawberry nurseries, found that Pic and 1,3-D were comparable to MBr for soilborne disease control. However, 1,3-D + Pic has weak activity against troublesome weeds, such as nutsedge (Noling and Gilreath, 2002).

Another molecule that has been indicated as a MBr alternative is MNa, which is a broad-spectrum fumigant that upon soil application generates methyl isothiocyanate (Ajwa et al., 2003a). This fumigant has been tested in a variety of conditions with mixed results. Locascio et al. (1997) and Fennimore et al. (2003) suggested that MNa failed to reach the soilborne pest control levels of MBr + Pic, whereas other research has found that it can be a viable MBr alternative (Ajwa et al., 2003b). Despite these discrepancies, MNa is a relatively low-cost and versatile product that could be soil-sprayed or drip-applied, and further research is necessary to determine its efficacy in combination with other materials. The use of herbicides to complement the activity of MBr alternatives against weeds has been proposed for mulched-vegetable crops (Noling and Gilreath, 2002). The herbicide napropamide applied in preemergence is currently labeled for use in strawberry and pro-

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
29.5735	fl oz	mL	0.0338
0.3048	ft	m	3.2808
0.0929	ft^2	m^2	10.7639
3.7854	gal	L	0.2642
9.3540	gal/acre	$L\cdot ha^{-1}$	0.1069
2.54	inch(es)	cm	0.3937
16.3871	$inch^3$	cm^3	0.0610
1.1209	lb/acre	$kg\cdot ha^{-1}$	0.8922
0.0254	mil	mm	39.3701
28.3495	oz	g	0.0353
6.8948	psi	kPa	0.1450
2.2417	ton/acre	$t\cdot ha^{-1}$	0.4461

vides acceptable to excellent control of most grasses and several broadleaf weeds (Stall, 2004; United Phosphorus, 2004). In strawberry, studies are needed to examine the effect of the previously mentioned MBr alternatives in combination with napropamide on soilborne pest control.

It is widely known that plants with vigorous roots can resist more readily soilborne disease and nematode infections, as well as weed competition for space, nutrients, and water. Strawberries are usually established from either bare-root or containerized (plug) transplants (Simonne et al., 2003). Bare-root plants are obtained from open-field nurseries, where stolons from mature plants are allowed to produce roots and establish in the soil. These new plants are then removed and shipped to planting fields. In contrast, plug nurseries utilize rooted stolons, which are transplanted in multicell trays and grown in greenhouses. This system for producing transplants results in plants with different root biomass and architecture, which have an influence on early plant establishment (Poling, 2003).

It has been hypothesized that because of their highly developed rooting system, containerized strawberry transplants could be less susceptible to soilborne pest damage (Burelle, 2003). Durner et al. (2002) and Poling (2003) outlined some of the advantages of plug transplants over bare-root plants, such as greater grower control of transplanting dates, improved plant survival and water management, and earlier flowering and fruit setting. Other studies have indicated that plug transplants resulted in faster root growth and establishment, earlier yields, and higher total yields than bare-root transplants (Burelle, 2003; Sances, 2000). Diverse reports have shown that although containerized transplants may have higher early marketable yield than bare-root plants, there is no difference in total marketable yield between both transplant types (Duval et al., 2004; Hochmuth et al., 2001; Poling, 2003). The combined effect of MBr alternatives and transplant type on soilborne pest control and strawberry fruit production has not been studied. This type of research could help researchers to devise new soilborne pest management strategies. Therefore, the objectives of this study were to: 1) compare the performance of two transplant systems under diverse MBr alternative programs in strawberry, and 2) determine the efficacy of these treatments on soilborne pest control in strawberry.

Materials and methods

Two field trials were conducted in three locations of west-central, north-central, and northern Florida during the 1998–99 and 1999–2000 winter strawberry seasons. In west-central Florida, the experimental plots were established at the Gulf Coast Research and Education Center of the University of Florida in Bradenton, where soils are classified as EauGallie fine sand (Alfic Haplaquod). In north-central Florida, the study was conducted at the Horticultural Research Unit of the University of Florida in Gainesville, where soils are classified as Arredondo fine sand (Grossarenic Paleudult), whereas the soil at the North Florida Research and Education Center of the University of Florida in Quincy is Dothan sandy loam (Plinthic Kandiudult).

The experimental sites have a history of moderate to heavy nutsedge and nematode infestations, which can severely limit crop yield when they are not controlled. In all three locations, 12 treatments were distributed in a split-plot design with five replications in Gainesville and Quincy, and six replications in Bradenton. Fumigant treatments were: 1) nonfumigated control, 2) MBr + Pic (67:33, by weight) at 350 lb/acre and napropamide at 4 lb/acre, 3) Pic at 300 lb/acre and napropamide at 4 lb/acre, 4) 1,3-D + Pic (65:35, by volume) at 35 gal/acre and napropamide at 4 lb/acre, 5) MNa at 60 gal/acre and napropamide at 4 lb/acre, and 6) MNa followed by 1,3-D at 60 and 12 gal/acre and napropamide at 4 lb/acre, respectively. 'Chandler' strawberry transplants were either bare-root or plug plants, which were approximately 10 inches tall and were purchased from a commercial strawberry nursery in North Carolina. Fumigants were injected in the main plots to facilitate uniformity of application on each experimental unit, whereas transplant types were distributed in the subplots.

One day prior to fumigation, all treatment beds, except the nontreated control and MBr + Pic, were applied with the herbicide napropamide in preemergence at a labeled rate of 4 lb/acre to reduce weedy grass populations (United Phosphorus, 2004). In Bradenton, napropamide was sprayed on bed tops with a tractor-mounted three-nozzle boom equipped with 11004 flat-fan nozzles (Spraying Systems Co., Wheaton, Ill.), calibrated to deliver 55 gal/acre, and the application lines were pressurized with carbon dioxide at 30 psi. In Gainesville and Quincy, the herbicide application was accomplished with a backpack sprayer equipped with an 8004 flat-fan nozzle (Spraying Systems Co.) and calibrated to deliver 30 gal/acre at 32 psi. The fumigant MNa was tractor-applied with similar equipment as for napropamide application, with application lines calibrated to deliver 150 gal/acre at 30 psi. Immediately after application, MNa was incorporated between 4 and 6 inches deep with a rototiller. The fumigants MBr + Pic, Pic, 1,3-D + Pic, and 1,3-D were injected between 6 to 8 inches deep into the finished bed using a N-propelled fumigation rig with two (Gainesville and Quincy) and three (Bradenton) chisels per bed. This application occurred between 3 and 4 weeks before transplanting. Each chisel was spaced 6 inches (Bradenton) and 8 inches (Gainesville and Quincy) apart. Fumigant delivery was controlled by a flow meter that was calibrated to deliver the specified quantity of fumigant.

In Gainesville and Quincy, 500 lb/acre of 10N–4.4P–8.3K were applied as starter fertilizer, whereas 200 lb/acre of 15N–0P–24.9K were used in Bradenton. The fertilizer was applied on the same day as fumigation and was incorporated within the top 6 inches of the soil using a rototiller. Immediately after fertilizer incorporation, beds were pressed and a single drip irrigation line (0.45 gal/min per 100-ft row) and black low-density polyethylene film (1.25 mil thick) were placed on bed tops. Approximately 3 weeks after treatment (WAT), double rows of strawberry plants were transplanted on 28-inch-wide beds, and between- and in-row spacing was 12 inches. Within 1 h after transplanting, the experimental sites were sprinkler-irrigated between 6 and 8 h per day for approximately 2 weeks. This procedure helps to provide enough moisture to the soil through the planting holes and row middles to ensure proper transplant establishment. In Gainesville and Quincy, experimental units were 18 ft long (42 ft^2), whereas plots in Bradenton were 20 ft long (47 ft^2). Irrigation, drip fertilization, frost protection, and insecticide and fungicide applications followed recommended commercial practices for Florida strawberry production (Simonne et al., 2003).

Nutsedge populations were assessed by counting the number of plants emerged through the polyethylene mulch. In Gainesville, this variable was determined at 3 and 10 WAT during the 1998–99 and 1999–2000 seasons. In Bradenton, nutsedge counts were obtained at 10 and 22 WAT in 1998–99 and at 8 and 22 WAT in 1999–2000. Nematode populations were determined between 20 and 22 WAT by extracting soil samples with a soil probe (1 inch wide × 8 inches deep) from the rhizosphere of 20 strawberry plants per plot, and the nematodes were separated and counted from 100 cm^3 soil using a standard sieving and centrifugation procedure (Jenkins, 1964). Although weed and nematode populations appeared to be present, only strawberry plant vigor, root weight, and marketable yield were collected in Quincy.

During both planting seasons, strawberry plant vigor was estimated at 20, 22, and 14 WAT in Bradenton, Gainesville, and Quincy, respectively. Plant vigor was determined using a scale from 0% to 100%, where 0% equals plant death and 100% indicates optimum growth. The latter was defined as strawberry plants with fully developed foliage, flowers, and fruits according to their vegetative stage, and free of leaf deformations, chlorosis, or damage. To assess plant vigor, treatments were compared within each replication. At the end of each season, the 10 central plants within each plot were excavated and their roots were shaken to remove soil from their surface. Within 10 min, roots were weighted and averaged to obtain root weight per plant. Marketable fruit weight was collected twice per week, resulting in between 18 and 26 harvests in each location per planting season. Fruit harvests began approximately 7 weeks after transplanting. Early fruit yield was determined by adding the marketable fruit weights from all the December and January harvests.

Plant vigor values were expressed as percentages and transformed with arc sine square root prior to analysis of variance to normalize the treatment means, whereas the ranked means of the nutsedge and nematode populations were examined with Friedman's nonparametric test (Berenson and Levine, 1992; Howell, 1992). The significance of the main effects and the interaction between both factors on root weight per plant and marketable fruit weight were examined with analysis of variance. When significant differences were obtained, treatment means were separated with the Waller–Duncan multiple comparison procedure (SAS version 8; SAS Institute Inc., Cary, N.C.).

Results and discussion

There was significant treatment by location interaction for strawberry plant vigor, root weight, and early and total marketable fruit weight. Therefore, data from each location will be discussed separately. On the other hand, the planting season by treatment interaction was nonsignificant; thus data from both seasons within each location were combined for analysis and discussion. For strawberry plant vigor and root weight per plant, there were no significant fumigant by transplant type interactions. The lowest strawberry plant vigor was observed in the nonfumigated plots in all three locations, with 74%, 79%, and 73% in Bradenton, Gainesville, and Quincy, respectively, whereas most treatments responded to fumigation by increasing vigor (Table 1). Particularly in Bradenton and Gainesville, plant vigor in fumigated plots was ≥86%, respectively, regardless of the fumigant treatment. In Quincy, Pic and napropamide, and 1,3-D + Pic and napropamide had similar plant vigor as MBr + Pic, ranging between 76% and 80%, while other treatments had the same plant vigor as the nontreated control. With regard to the transplant type, bare-root transplants had similar plant vigor as containerized-plug plants in two of the three locations (Table 1).

At all three locations, soil fumigation influenced strawberry root

Table 1. Influence of soil fumigants and type of transplant on strawberry plant vigor and root weight per plant at Bradenton, Gainesville, and Quincy, Fla., in 1998–99 and 1999–2000.

Fumigants[z]	Rate[y] (unit/acre)	Plant vigor[x] Bradenton	Plant vigor Gainesville	Plant vigor Quincy	Root wt[w] Bradenton	Root wt Gainesville	Root wt Quincy
		(%)			(g/plant)		
Nonfumigated	---	74 b	79 b	73 bc	143 c	273 b	180 b
MBr + Pic	350 lb	92 a	100 a	87 a	335 a	489 a	229 a
Pic + napropamide	300 lb + 4 lb	86 a	98 a	76 abc	250 ab	394 a	219 a
1,3-D + Pic + napropamide	35 gal + 4 lb	89 a	91 a	80 ab	335 a	378 ab	229 a
MNa + napropamide	60 gal + 4 lb	88 a	93 a	71 bc	262 ab	376 ab	213 a
MNa + 1,3-D + napropamide	60 gal + 12 gal + 4 lb	90 a	98 a	67 c	255 ab	454 a	222 a
Significance		*	*	*	*	*	*
Transplant type							
Bare root	---	88	94	86 a	293 a	377	210
Plugs	---	84	93	66 b	244 b	415	221
Significance		NS	NS	*	*	NS	NS

[z]MBr = methyl bromide; Pic = chloropicrin; 1,3-D = 1,3-dichloropropene; MNa = metam sodium.
[y]1 lb/acre = 1.1209 $kg\cdot ha^{-1}$; 1 gal/acre = 9.3540 $L\cdot ha^{-1}$; 1 g = 0.0353 oz.
[x]Plant vigor obtained at 20, 22, and 14 weeks after treatment in Bradenton, Gainesville, and Quincy, respectively. Data from two seasons were combined. Plant vigor values expressed as a percentage scale where 100% = optimum plant vigor and 0% = plant death. Data transformed with arc sine square root prior to analysis of variance (ANOVA) and treatment means were separated with Waller–Duncan multiple comparison procedure ($P \leq 0.05$).
[w]Root weight per plant collected at the end of the strawberry season in each location. Data analyzed with ANOVA and treatment means were separated with Waller–Duncan multiple comparison procedure ($P \leq 0.05$).
[NS],*Nonsignificant or significant at $P = 0.05$, respectively.

weight per plant, whereas in only one site (Bradenton) did the type of transplant have a significant effect on this variable (Table 1). In Bradenton, the average root mass per plant of the fumigated plots was 287 g/plant, which was more than twice that of the nontreated control (143 g/plant). A similar situation was observed in Quincy, where the fumigated plots had an average root weight of 222 g/plant, in contrast with only 180 g/plant in the nonfumigated control, which represented an approximately 20% increase. In Gainesville, only the plots treated with either MBr + Pic, Pic and napropamide, or MNa, 1,3-D and napropamide were different from the control, having about 1.6 times more average root weight (446 g/plant) than the nonfumigated control (273 g/plant). In Bradenton, a 17% root weight reduction was measured as transplant types changed from bare-root to containerized plugs.

Fumigant application influenced nutsedge densities in Bradenton and Gainesville, whereas no transplant type effect and transplant type by fumigant interaction were observed. Although the nutsedge pressure in these studies is considered low (<13 plants/10 ft^2 row) based on grower standards, the application of Pic and napropamide, 1,3-D + Pic and napropamide, MNa and napropamide, and MNa, 1,3-D and napropamide provided similar nutsedge control as MBr + Pic. Ring nematode populations were affected only by fumigant application. In Bradenton, the nontreated control had the highest population (7.2 juveniles/100 mL), while all the fumigants reduced the nematode counts to <1 juvenile/100 mL soil (Table 2). The nematode pressure was more intense in Gainesville, where the nontreated control had a root population of 24.5 juveniles/100 mL soil. There was no significant difference among all fumigants.

In Gainesville and Quincy, early strawberry yield was individually influenced by both factors, whereas in Bradenton only the fumigants had an effect on this variable. There was no significant fumigant by transplant type interaction at all three locations. In Gainesville, plug transplants had higher early yield than bare-root transplants, whereas the opposite occurred in Quincy (Table 3). At all experimental sites, the nonfumigated control had

Table 2. Influence of soil fumigants on ring nematode (*Criconema* spp.) and nutsedge (*Cyperus* spp.) populations in strawberry fields at Bradenton and Gainesville, Fla., in 1998–99 and 1999–2000.

Fumigants[w]	Rate[z] (unit/acre)	Ring nematode population[y] Bradenton	Ring nematode population[y] Gainesville	Nutsedge density[x] Bradenton	Nutsedge density[x] Gainesville
		(juveniles/100 mL)		(plants/10 ft^2)	
Nonfumigated	---	7.2 a	24.5 a	1.61 a	12.61 a
MBr + Pic	350 lb	0.8 b	0 b	0.44 b	0.20 b
Pic + napropamide	300 lb + 4 lb	0 b	0 b	0.70 ab	0.60 b
1,3-D + Pic + napropamide	35 gal + 4 lb	0.8 b	0 b	0.19 b	3.74 b
MNa + napropamide	60 gal + 4 lb	0 b	13.2 ab	0.19 b	5.49 b
MNa + 1,3-D + napropamide	60 gal + 12 gal + 4 lb	0 b	4.0 b	0.81 ab	0.83 b
Significance		*	*	*	*

[z]1 lb/acre = 1.1209 $kg \cdot ha^{-1}$; 1 gal/acre = 9.3540 $L \cdot ha^{-1}$; 1 juvenile/100 mL = 37.8541 juveniles/gal; 1 plant/10 ft^2 = 1.0764 plant/m^2.
[y]Nematode populations obtained between 20 and 22 weeks after treatment. Data from two seasons were combined. Data analyzed with Friedman's nonparametric test and treatment means were separated with Waller–Duncan multiple comparison procedure ($P \leq 0.05$).
[x]Nutsedge densities collected at 22 and 10 weeks after treatment in Bradenton and Gainesville, respectively. Data from two seasons were combined. Data analyzed with Friedman's nonparametric test and treatment means were separated with Waller–Duncan multiple comparison procedure ($P \leq 0.05$).
[w]MBr = methyl bromide; Pic = chloropicrin; 1,3-D = 1,3-dichloropropene; MNa = metam sodium.
*Significant at $P = 0.05$.

Table 3. Influence of soil fumigants and type of transplant on early and total marketable strawberry yield at Bradenton, Gainesville, and Quincy, Fla., in 1998–99 and 1999–2000.

Fumigants[z]	Rate[y] (unit/acre)	Marketable fruit wt: Total yield Bradenton	Total yield Gainesville	Total yield Quincy	Early yield Bradenton	Early yield Gainesville	Early yield Quincy
		ton/acre					
Nonfumigated	---	3.0 b	1.9 b	3.0 b	14.5 b	12.1 b	12.7 b
MBr + Pic	350 lb	3.5 a	4.0 a	4.0 a	18.7 a	21.7 a	15.0 a
Pic + napropamide	300 lb + 4 lb	3.5 a	3.5 a	3.6 a	18.1 a	19.1 a	14.7 a
1,3-D + Pic + napropamide	35 gal + 4 lb	3.4 a	3.2 a	3.7 a	18.1 a	19.5 a	15.1 a
MNa + napropamide	60 gal + 4 lb	3.4 a	3.1 a	3.7 a	16.9 a	20.3 a	14.2 a
MNa + 1,3-D + napropamide	60 gal + 12 gal + 4 lb	3.6 a	3.3 a	3.5 a	18.1 a	21.4 a	14.6 a
Significance		*	*	*	*	*	*
Transplant type							
Bare root	---	3.3	2.8 b	3.8 a	17.6	19.2	14.2
Plugs	---	3.5	3.6 a	3.4 b	17.1	18.9	14.5
Significance		NS	*	*	NS	NS	NS

[z]MBr = methyl bromide; Pic = chloropicrin; 1,3-D = 1,3-dichloropropene; MNa = metam sodium.
[y]1 lb/acre = 1.1209 $kg \cdot ha^{-1}$; 1 gal/acre = 9.3540 $L \cdot ha^{-1}$; 1 ton/acre = 2.2417 $t \cdot ha^{-1}$.
[NS], *Nonsignificant of significant at $P = 0.05$, respectively.

lower early strawberry yield than any of the fumigant treatments. For total marketable yield, fumigation increased marketable strawberry yield in all three locations, but neither transplant type nor the interaction between both factors had any effect on total fruit weight (Table 3). Total marketable yield improved by 24%, 69%, and 16% with fumigation in Bradenton, Gainesville, and Quincy, respectively.

In summary, nutsedge and ring nematode infestations appeared to be major factors reducing strawberry yield, and they were effectively controlled by all the fumigants tested in this study. These results showed that under the conditions of these studies, bare-root transplants produce strawberry plants with equal or higher vigor and root biomass than containerized plugs, which could be due to the different root architectures of the types of transplants. Although transplant type had an effect on early strawberry yield, the results were inconsistent across locations. At the same time, the increase in root biomass and vigor did not translate into higher total marketable yield or improved fumigant performance against ring nematode and nutsedge. This finding does not agree with previous reports, which established that containerized transplants might improve soilborne pest control with MBr alternatives (Burelle, 2003). Nonetheless, these results consistently confirm other studies, which indicated that there was no total marketable yield difference between the two strawberry transplant types (Duval, 2004; Hochmuth et al., 2001; Poling, 2003).

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