Suppression of Watermelon Mosaic Virus in Summer Squash with Plastic Mulches and Rowcovers

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ADDITIONAL INDEX WORDS. aphids, *Cucurbita pepo*, squash production, virus transmission, watermelon mosaic virus

SUMMARY. Plastic mulches and rowcovers were evaluated in southern Illinois to determine their influence on watermelon mosaic virus (WMV) disease incidence and symptom severity in susceptible and tolerant summer squash (*Cucurbita pepo*). The use of either black or white mulch produced greater early and total marketable yields than no mulch (bare soil) on 'Dividend' and 'Multipik'. More fruit had WMV symptoms with no mulch than with mulch, regardless of cultivar. However, more severe WMV symptoms developed on the fruit of susceptible 'Multipik' compared to tolerant 'Dividend'. The use of plastic mulches provided greater and longer protection to 'Dividend' compared to 'Multipik'. However, 'Dividend' fruit did eventually develop virus symptoms as disease incidence in production fields increased. Rowcovers reduced the number of alate aphids landing on plants which resulted in fewer plants with WMV symptoms and suppression of symptoms on squash plants regardless of mulch type. Rowcovers had a greater influence on reducing the incidence of WMV and the severity of symptoms on 'Dividend' compared to 'Elite'. Rowcovers did not reduce WMV on 'Elite' by the end of the season and were more effective when used with white mulch compared to black mulch. Rowcovers suppressed the incidence and severity of WMV symptoms that developed on a virus tolerant squash cultivar for a greater length of time compared to a susceptible cultivar, which related to increased yields and fewer culls with virus symptoms on the tolerant cultivar.

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Zucchini and yellow summer squash are commonly grown vegetables in the Midwestern U.S. However, summer squash growers in Illinois often suffer significant economic losses due to mosaic virus diseases (Walters et al., 2003). The most problematic virus in southern Illinois is watermelon mosaic virus. However, other viruses including cucumber mosaic virus (CMV), papaya ringspot virus (PRSV), squash mosaic virus (SqMV), and zucchini yellow mosaic virus (ZYMV) can also be problematic (Walters et al., 2003). Viruses are a serious problem in production because chemical control does not provide protection (Zitter et al., 1996).

Aphids are responsible for transmitting most of the important viruses that infect squash (Zitter et al., 1996). Control of aphids with contact insecticides has little influence on the incidence of virus diseases since they do not kill aphids before virus transmission occurs (Broadbent, 1957; Zitter et al., 1996). Foliar or at-planting systemic insecticides have also been ineffective since aphids are able to feed long enough to transmit the viruses before receiving a lethal dose of insecticide. Much research is now directed at locating sources of plant resistance to viruses (Zitter et al., 1996), as this is the easiest and most effective way to suppress virus disease incidence in cucurbit production.

Several cultural practices can be used to control mosaic viruses in summer squash. These practices include oil emulsion sprays, often termed stylet oils (Adams, 1991; Zitter and Ozaki, 1978), reflective mulches (Boyhan et al., 2000; Brown et al., 1993; Chalfant et al., 1977; Lamont et al., 1990; Summers et al., 1995; Toscano et al., 1979), rowcovers (Robinson and Decker-Walters, 1997), plant resistance or tolerance (Rowell et al., 1999; Schultheis and Walters, 1998), and use of precocious yellow gene (Py) cultivars (Snyder et al., 1993). Most research has focused on utilizing only one of these methods for mosaic virus control in summer squash.

Many growers in Illinois use plastic mulches, but will not use reflective mulches due to their higher costs. Many of these growers now use transgenic virus-resistant yellow and zucchini squash cultivars to reduce losses due to cucurbit viruses. However, using cultivars produced via biotechnology is not an option for organic vegetable growers. Several organic vegetable growers in Illinois are currently using reflective plastic mulches (to repel aphids) and/or rowcovers (for aphid exclusion) on several cucurbit vegetables including summer squash. This results in the production of marketable fruit that they would not normally have due to extensive disease incidence in production fields. However, rowcovers must be removed to allow pollination, and after approximately four to five harvests, fruit will become unmarketable due to severe virus symptoms on fruit. Rowcovers can be an expensive input and considerable labor is required for placement and removal. However, growers may receive a financial benefit from their use, since they prevent the development of virus symptoms on fruit for the first four to five harvests, and reduce insecticide use.

The integration of cultural practices with plant tolerance to viruses has not been evaluated nor has the combination of two primary cultural practices such as mulches and rowcovers. The objective of this study was to evaluate the effectiveness of several cultural management strategies along with plant tolerance to suppress WMV in squash. The first test evaluated black and white plastic mulches to reduce virus disease incidence in WMV tolerant 'Dividend' zucchini and susceptible 'Multipik' yellow squash that has the *Py* gene. The second test evaluated the influence of rowcovers and mulch type on WMV suppression in tolerant ('Dividend') and susceptible ('Elite') zucchini squash.

Materials and methods

Two tests were conducted during Fall 1999 and 2000 at the Southern Illinois University Horticulture Research Center in Carbondale. Squash foliage samples (collecting the newest fully expanded leaf) were randomly collected from about fifteen individual plants from within the experimental plot area to determine the specific viruses present at each sampling. In 1999, samples were collected on 22 Aug. and 3 Oct. Samples were collected on 28 Aug. and 2 Oct. in 2000. Samples were evaluated utilizing alkaline phosphatase enzyme-linked immunosorbent assay (ELISA) kits (Agdia Pathoscreen kits; Agdia, Inc., Elkhart, Ind.) for the presence of five viruses: CMV, PRSV, SqMV, WMV, and ZYMV.

MULCH TEST. 'Dividend' zucchini and 'Multipik' yellow squash were evaluated on raised beds [about 8 inches (0.2 m) in height] using three different mulching systems: 1) no mulch (bare soil), 2) white on black plastic mulch [1.25 mil (0.00125 inch, 0.03175 mm)], and 3) black plastic mulch (1.25 mil), with the two mulches obtained from Irrigation-Mart, Ruston, La. The experiment was set up as a 2 x 3 factorial treatment arrangement in a randomized complete block design with four replications. Plots were 20 ft (6.1 m) long with a 5 ft (1.5 m) alley between plots. Center-to-center row spacing was 6 ft (1.8 m) with one row on each raised bed and in-row spacings of 2 ft (0.6 m).

MULCH AND ROWCOVER TEST. This test evaluated the influence of rowcovers to suppress virus symptom development in tolerant and susceptible zucchini squash by preventing aphid movement onto plants early in the growing season. A 2 × 2 × 2 factorial treatment arrangement was used in a randomized complete block design with four replications. Two mulching systems (white on black plastic mulch and black plastic mulch, both 1.25 mil and obtained from Irrigation-Mart, Ruston, La), with or without spunbonded polyester rowcovers [5.6 ft (1.71 m) wide, white, and allows about 75% to 80% transmission of available light (Wells and Loy, 1983); Reemay Inc., Old Hickory, Tenn.] and two zucchini squash cultivars ('Elite' = susceptible to WMV and 'Dividend' = tolerant to WMV) were evaluated. Squash seed were directly sown into the soil. Rowcovers were removed 4 weeks after emergence (WAE) of squash seedlings to allow insect pollination of flowers. Plot size and squash plant spacing were identical to the mulch test.

Standard cultural practices for squash in Illinois were used (Foster et al., 1999 and 2000). Before seeding, 10 lb/acre (11.2 $kg \cdot ha^{-1}$) N, 12 lb/acre (13.4 $kg \cdot ha^{-1}$) P, and 22 lb/acre (24.6 $kg \cdot ha^{-1}$) K were applied to plots. Plots were side-dressed in row middles with 30 lb/acre (33.6 $kg \cdot ha^{-1}$) N 4 weeks after seeding. Overhead sprinkler irrigation was utilized to supplement rainfall, as drip irrigation was not utilized. Disease and insect control was achieved by spraying a tank mixture of esfenvalerate (Asana; E.I. du Pont de Nemours and Co., Wilmington, Del.) or carbaryl (Sevin; Rhone-Poulenc Ag Co., Research Triangle Park, N.C.) and chlorothalonil (Bravo; Zeneca, Inc., Wilmington, Del.) twice a week for the duration of the test. Weeds were controlled by mechanical cultivation between rows. The soil was a Hosmer silt loam, which is a fine-silty, mixed, mesic Typic Fragiudalfs (Herman et al., 1979). Once flowering had started, a honeybee (*Apis mellifera*) hive was placed in close proximity to the test site.

Harvest frequency was every 2 to 4 d with a total of 15 harvests. Fruit harvest began 6 Sept. and ended 7 Oct. in 1999; and for 2000, harvest began 31 Aug. and ended 31 Sept. Fruit at each harvest were graded into marketable [1.5 to 2.5 inches (3.81 to 6.35 cm) diameter], oversize [>2.5 inches (>6.35 cm) diameter], cull (unmarketable, misshapened, off-color, or decaying fruit), and cull with virus symptoms. Yellow sticky cards [3 × 5 inches (7.6 × 12.7 cm); Sensor Monitoring Cards, Whitmire Micro-Gen Research Laboratories Inc., St. Louis, Mo.] were placed in the center of each plot on bamboo stakes about 2 ft from the soil surface. Cards were collected and replaced at weekly intervals for the first 6 WAE. Alate (winged) aphid

Table 1. Total alate aphid number, number of plants exhibiting virus symptoms, and virus severity ratings as influenced by mulching methods in 'Dividend' zucchini and 'Multipik' yellow summer squash at various weeks after emergence (WAE) of squash.[z]

Cultivar/mulch	Aphids (no.)[x]	Rating 1 (4 WAE) No. plants	Rating 1 (4 WAE) Severity	Rating 2 (6 WAE) No. plants	Rating 2 (6 WAE) Severity	Rating 3 (8 WAE) No. plants	Rating 3 (8 WAE) Severity
'Dividend' zucchini							
No mulch	1247	8	3	9	4	10	5
Black mulch	490	2	1	6	2	8	3
White mulch	653	3	1	5	2	7	2
'Multipik' yellow							
No mulch	1207	6	3	9	5	10	7
Black mulch	445	3	1	7	4	10	5
White mulch	632	2	1	7	3	10	5
Contrasts							
'Dividend' vs 'Multipik'	NS	NS	NS	NS	***	***	***
No mulch vs. black mulch	***	***	***	***	***	NS	***
No mulch vs. white mulch	***	***	***	***	***	**	***
Black vs. white mulch	**	NS	NS	NS	NS	NS	NS
No mulch vs. mulch	***	***	***	***	***	**	***

[z]Data are means of eight replications (four replications per year) for tests conducted over the 1999 and 2000 growing seasons.
[x]Aphid numbers are the result of the sum of counts from 3 × 5 inches (or 7.6 × 12.7 cm) yellow sticky cards the first 6 weeks after emergence (WAE) of squash seedlings. Ratings were conducted, 4, 6, and 8 WAE. The number of plants in each plot exhibiting virus symptoms were counted and a rating of the plot was conducted to determine the severity of virus symptoms with 0 = none, 1 to 3 low, 4 to 5 moderate, and 6 to 9 severe. Watermelon mosaic virus was the only virus identified from foliage samples.
NS,**,***Nonsignificant or significant at $P \leq 0.01$ or 0.0001, respectively.

Table 2. 'Dividend' zucchini and 'Multipik' yellow squash yields (lb/acre) as affected by mulch type.[z]

	Early harvest (×1000)				Total harvest (×1000)			
Cultivar/mulch	Mark	Culls	Virus	Total	Mark	Culls	Virus	Total
'Dividend' zucchini								
No mulch	1.4	1.8	1.6	3.2	9.8	16.8	16.2	30.5
Black mulch	4.9	1.0	0.6	6.0	19.7	11.2	10.0	36.3
White mulch	6.4	1.2	1.0	8.1	22.5	13.0	11.3	41.8
'Multipik' yellow								
No mulch	5.5	1.0	0.9	6.6	15.7	7.1	6.2	23.5
Black mulch	8.0	1.0	0.6	9.2	20.8	7.7	6.5	29.1
White mulch	10.6	1.2	0.6	12.1	26.5	9.2	7.5	36.8
Contrasts								
'Dividend' vs 'Multipik'	***	NS	*	***	**	***	***	***
No mulch vs. black mulch	***	NS	**	**	***	NS	NS	**
No mulch vs. white mulch	***	NS	*	***	***	NS	NS	***
Black vs. white mulch	**	NS	NS	**	**	NS	NS	**
No mulch vs. mulch	***	NS	**	***	***	NS	NS	***

[z]Data are means of eight replications (four replications per year) for tests were conducted over the 1999 and 2000 growing seasons. Early harvest is the sum of the first five harvests; and total harvest is the sum of all 15 harvests. Mark = marketable, virus = cull fruit showing virus symptoms, and total = marketable + oversize + cull. Oversize fruit were determined and are contained in the Total. Oversize fruit weights can be calculated by total – (mark + cull); 1.0 lb/acre = 1.12 $kg\cdot ha^{-1}$.

NS,*,**,***Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.0001, respectively.

numbers on the front and back of each card were determined each week and were identified on 10 to 15 random cards taken from throughout the 6 week period for both years by David Voegtlin (aphid specialist) of the Illinois Natural History Survey. At 4, 6, and 8 WAE, the number of plants in each plot exhibiting typical virus symptoms were determined and a rating was conducted to determine the severity of virus symptoms expressed on plants (0 = none, 1 to 3 = low, 4 to 5 = moderate, and 6 to 9 = severe).

Data were subjected to analysis of variance procedures appropriate for a randomized complete block experimental design to determine the effects of cultivars, mulches, and/or rowcovers on aphid numbers, virus incidence/symptom severity and squash yields using SAS (SAS Inst., Cary, N.C.). Linear contrasts were used to make comparisons between cultivars, mulches, and/or rowcovers.

Results

The ELISA tests indicated that WMV was the only virus present in the samples collected during both years. Three species of aphids were identified from yellow cards: cornleaf aphid (*Rhopalosiphum maidis*), melon aphid (*Aphis gossypii*), and spirea aphid (*Aphis spiraecola*).

MULCH TEST. Analysis of alate aphid number, WMV disease incidence and severity, and squash yield data over the Fall 1999 and 2000 growing seasons indicated that the 2 years were different ($P \leq 0.05$) (data not shown). However, years were combined for analysis as the interaction of year with mulching method or cultivar was not significant ($P < 0.05$) (data not shown). The two squash cultivars responded similarly regardless of mulching method as no interaction ($P < 0.05$) was observed between mulch and cultivar for alate aphid number, WMV disease incidence or severity, and squash yields (data not shown).

APHID NUMBER. More alate aphids were found in the no mulch treatments than in the black or white mulch treatments (Table 1). Fewer alate aphids were found on black mulch compared to white mulch, but no differences were observed between the two squash cultivars with respect to alate aphid number. A negative correlation of alate aphid number with early total yield on 'Dividend' ($r = -0.46$, $P = 0.02$) was observed but no correlation existed for 'Multipik'. However, alate aphid numbers on 'Multipik' were correlated with the number of plants exhibiting symptoms of virus infection at 4 WAE ($r = 0.81$, $P < 0.01$), 6 WAE ($r = 0.77$, $P < 0.01$), and 8 WAE ($r = 0.82$, $P < 0.01$), as well as severity of virus symptoms on plants at 4 WAE ($r = 0.52$, $P = 0.01$), 6 WAE ($r = 0.78$, $P < 0.01$), and 8 WAE ($r = 0.89$, $P < 0.01$). No correlations were observed on 'Dividend' between aphid number and the number of plants exhibiting virus symptoms or the severity of symptoms.

DISEASE INCIDENCE AND SEVERITY. More severe WMV symptoms were observed at 6 and 8 WAE on 'Multipik' compared to 'Dividend' (Table 1). Squash grown on no mulch was more severely affected by WMV than that grown on plastic mulch (Table 1), but neither mulch, whether black or white, provided any additional advantage.

EARLY-HARVEST YIELDS. For both 'Dividend' and 'Multipik', the black and white mulches produced greater marketable and total squash yields compared to the no mulch treatments (Table 2). More fruit with WMV symptoms were found on no mulch compared to either the black or white mulch regardless of cultivar. Greater marketable and total squash yields were produced when the white mulch was used compared to black mulch. No differences ($P < 0.05$) were observed between the two mulches for the amount of cull or WMV symptomatic fruit produced (Table 2).

TOTAL-HARVEST YIELDS. For both squash cultivars, greater marketable and total squash yields were produced using either black or white mulch compared to the no mulch treatment (Table 2). For 'Multipik', the no mulch and mulch treatments resulted in similar amounts of WMV symptomatic fruit; but, for 'Dividend', about one-third fewer WMV symptomatic fruit were produced when either black or white mulch was used compared to no mulch.

MULCH AND ROWCOVER TEST. Alate aphid number, WMV disease incidence and symptom severity, and squash yield data were combined and analyzed over the 1999 and 2000 fall growing seasons. The analysis indicated that the two years were different ($P \leq 0.05$, data not presented); however, no interaction of cultivar, rowcover, or mulch with year ($P \leq 0.05$) was observed (data not presented) indicating that treatments responded similarly over the two years. For the 2000 growing season, alate aphid number and WMV disease incidence and symptom severity on squash plants were less than in 1999. The two squash cultivars, 'Elite' and 'Dividend', responded similarly to the mulch and rowcover treatments, as no interactions ($P < 0.05$) were observed between mulch and cultivar or rowcover and cultivar for squash yields (data not presented).

APHID NUMBER. More alate aphids were counted in the white mulch plots compared to black mulch plots (Table 3). Rowcovers reduced the number of alate aphids on zucchini squash plants. However, once rowcovers were removed at 4 WAE (to allow insect pollination of flowers), alate aphid numbers increased to similar levels over the same time period as the treatment without rowcovers (Table 3). Although alate aphids moved onto plants once rowcovers were removed, the total number of alate aphids that landed on zucchini squash plants with rowcovers were less than those without rowcovers (Table 3). Total alate aphid numbers were negatively correlated with early marketable ($r = -0.61$, $P < 0.05$) and early total yield ($r = -0.52$, $P < 0.01$) on 'Dividend'. Early harvested WMV symptomatic fruit were correlated ($r = 0.58$, $P < 0.01$) with total alate aphid numbers for 'Dividend'. Alate aphid numbers obtained between 4 to 6 WAE were negatively correlated with the number of 'Dividend' squash plants exhibiting WMV symptoms and severity of WMV symptoms at 8 WAE ($r = -0.58$, $P < 0.01$ and $r = -0.50$, $P < 0.05$, respectively). No significant correlations were observed for 'Elite'.

DISEASE INCIDENCE AND SEVERITY. Fewer plants having virus symptoms were observed on white mulch over the three rating periods compared to black mulch (Table 3). At the second and third ratings (6 and 8 WAE), 'Dividend' had fewer numbers of plants with virus symptoms and lower severity symptoms compared to 'Elite'. Low amounts of both disease incidence and symptom severity were observed at 4 WAE for both zucchini cultivars. Treatments that included rowcovers had no disease incidence at 4 WAE (Table 3). At 6 WAE, the influence of rowcovers became less pronounced as squash plants showed some virus symptoms on treatments that previously had rowcovers. A squash cultivar by rowcover interaction ($P < 0.05$) was observed at 6 and 8 WAE indicating that rowcovers had suppressed disease incidence and severity symptoms on 'Dividend' to a greater extent compared to 'Elite'. The use of rowcovers on 'Dividend' reduced the number of plants with virus symptoms as well as the severity of symptoms that developed (Table 3).

EARLY-HARVEST YIELDS. No early yield differences were observed between the two zucchini squash cultivars evaluated (Table 4). The use of rowcovers reduced the amount of cull fruit and WMV symptomatic fruit on both 'Dividend' and 'Elite'. The combination of white plastic + rowcovers resulted in greater marketable and total yields compared to black plastic + rowcovers (Table 4).

LATE-HARVEST YIELDS. Marketable and total yields were greater for 'Dividend' than 'Elite' (Table 4), but 'Elite' had more fruit with WMV symptoms than 'Dividend'. Total yields were in-

Table 3. Alate aphid number, number of plants exhibiting virus symptoms, and virus severity ratings as influenced by mulching methods and rowcovers in 'Dividend' and 'Elite' zucchini squash over the 1999 and 2000 growing seasons at various weeks after emergence (WAE) of squash.[z]

	Aphids (no.)[x]								
	WAE			Rating 1 (4 WAE)		Rating 2 (6 WAE)		Rating 3 (8 WAE)	
Cultivar/mulch	1–3	4–6	Total	No. plants	Severity	No. plants	Severity	No. plants	Severity
'Elite'									
Black	170	167	337	2	2	5	5	5	8
Black + rwcvr	4	152	156	0	0	4	2	5	6
White	267	191	458	1	1	4	4	5	6
White +rwcvr	4	139	143	0	0	3	2	5	5
'Dividend'									
Black	162	142	304	2	1	4	2	5	3
Black + rwcvr	5	160	164	0	0	3	1	4	2
White	211	172	383	1	1	3	2	4	3
White + rwcvr	4	144	148	0	0	2	1	3	1
Contrasts									
'Elite' vs. 'Dividend'	NS	NS	NS	NS	NS	***	***	***	***
Black vs. white	***	*	**	**	NS	*	NS	**	NS
Black vs. black + rwcvr	***	NS	***	***	**	**	**	***	*
White vs. white + rwcvr	***	**	***	**	*	**	*	***	*
No rwcvr vs. rwcvr	***	*	***	***	***	***	**	***	**
Black + rwcvr vs. white + rwcvr	NS	NS	NS	NS	NS	*	NS	***	NS

[z]Data are means of eight replications with four replications per year. Rwcvr = spunbonded polyester rowcover (Reemay Inc., Old Hickory, Tenn.).
[x]Alate aphid number is the result of the sum of counts from 3 × 5 inches (or 7.6 × 12.7 cm) yellow sticky cards the first 3 weeks after emergence (WAE), 4–6 WAE, or the sum of the first 6 WAE of squash seedlings. Ratings were conducted, 4, 6, and 8 WAE. Plants with virus symptoms were counted in each plot with a corresponding severity rating at 4, 6, and 8 WAE with 0 = none, 1 to 3 low, 4 to 5 moderate, and 6 to 9 severe. Watermelon mosaic virus was the only virus identified from foliage samples.
[NS,*,**,***]Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.0001, respectively.

Table 4. 'Dividend' and 'Elite' zucchini squash yields (lb/acre) combined over the 1999 and 2000 growing seasons as affected by mulch type and rowcover.[z]

Cultivar/mulch	Early harvest (×1000)				Late harvest (×1000)				Total harvest (×1000)			
	Mrk	Cull	Virus	Total	Mrk	Cull	Virus	Total	Mrk	Cull	Virus	Total
'Elite' zucchini												
Black	7.2	3.5	3.2	12.0	2.2	11.2	10.4	15.8	17.7	21.8	20.2	45.4
Black + rowcover	6.1	0.7	0.0	7.0	3.8	13.4	12.8	18.2	20.5	18.4	16.3	42.2
White	12.2	1.6	0.5	13.8	3.5	10.8	10.6	17.1	27.9	19.2	16.3	52.7
White + rowcover	11.0	0.6	0.0	13.6	3.5	16.8	16.8	23.0	28.9	22.2	20.2	60.3
'Dividend' zucchini												
Black	10.7	1.5	0.9	12.2	5.8	13.9	11.6	25.6	29.5	21.9	18.4	60.1
Black + rowcover	8.8	0.7	0.0	9.5	6.4	9.4	6.9	22.0	27.9	13.3	8.9	52.6
White	8.6	1.7	1.1	11.1	6.5	10.3	8.7	18.8	28.4	17.9	14.7	52.4
White + rowcover	12.3	0.6	0.0	12.9	9.4	11.2	8.5	28.7	37.7	14.7	10.0	64.6
Contrasts												
'Elite' vs. 'Dividend'	NS	NS	NS	NS	***	NS	*	***	**	NS	*	**
Black vs. white ('Elite')	**	**	**	NS	NS	NS	NS	NS	***	*	*	**
Black vs. white ('Dividend')	*	NS	NS	NS	NS	**	**	**	NS	*	*	**
Black vs. black + rowcover	NS	*	**	***	NS	NS	NS	NS	NS	NS	*	NS
White vs. white + rowcover	NS	NS	**	NS	NS	NS	NS	***	*	NS	NS	**
Mulch vs. mulch + rowcover	NS	**	**	**	NS	NS	NS	**	NS	NS	NS	NS
Black + rowcover vs. white + rowcover	***	NS	NS	***	NS	NS	NS	**	**	NS	NS	**

[z]Data are means of eight replications with four replications per year. Early harvest is the sum of the first five harvests; late harvest is the sum of harvests 11 through 15; and total harvest is the sum of all harvests (1 to 15). Mrk = marketable, virus = cull fruit showing virus symptoms, and total = marketable + oversize + cull. Oversize fruit weights can be calculated by total – (mark + cull); 1.0 lb/acre = 1.12 $kg \cdot ha^{-1}$.

[NS,*,**,***]Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.0001, respectively.

creased by rowcover use, but marketable yields were not (Table 4). In addition, white mulch + rowcovers increased total yields for both cultivars compared to black mulch + rowcovers. Black mulch + rowcovers compared to black mulch by itself produced higher total yields for 'Elite' but not for 'Dividend' (Table 4).

TOTAL-HARVEST YIELDS. 'Dividend' produced greater marketable and total yields compared to 'Elite' (Table 4). White mulch + rowcovers increased marketable yields of both cultivars to a greater extent compared to black mulch + rowcovers or either black or white mulch alone.

Rowcovers did not influence the amount of cull fruit that were produced. However, the use of rowcovers reduced the amount of fruit with WMV symptoms on black mulch (Table 4). Rowcovers reduced the amount of cull fruit with WMV symptoms on 'Dividend' to a greater extent than 'Elite' (Table 4). White mulch + rowcovers increased marketable and total yields for both both cultivars compared to white mulch only. Black mulch + rowcovers produced lower marketable and total yields than white mulch + rowcovers (Table 4).

Discussion

MULCH TEST. For early and total yields, the black and white mulches produced greater marketable and total squash yields compared to no mulch (Table 2). When alate aphids were prevented for several weeks from landing and feeding on a cultivar that has tolerance to viruses (e.g., 'Dividend'), we found about one-third fewer fruit with virus symptoms; but this may vary if other viruses are involved or aphid flight time and populations differ. Various types of mulches have been shown to reduce aphid numbers by as much as 96%, which coincided with reductions in virus disease incidence of 85% to 90% (Toscano et al., 1979). However, as disease incidence increases in a field, more fruit having observable virus symptoms will develop, even on virus tolerant cultivars. Over a period of several weeks, increased disease incidence in production fields will cause an increase in observable WMV symptoms on fruit of 'Dividend' even though it is tolerant (not resistant) to WMV. In this study, plastic mulches did not provide as much protection for a cultivar without virus resistance ('Multipik') compared to a virus tolerant cultivar, as WMV symptomatic fruit were similar on mulched and nonmulched treatments for 'Multipik'.

MULCH AND ROWCOVER TEST. Both 'Dividend' and 'Elite' produced the highest total yields on white mulch + rowcovers. Rowcovers reduced the incidence and severity of WMV symptoms. However, rowcovers reduced total early-season yields (Table 4) which may be due to several factors including reduced light transmission (Loy and Wells, 1982), restriction of plant growth, reduced pollination of early flowers (Robinson and Reiners, 1999) and/or adjustment of squash plant growth to rowcover removal. Rowcovers can be utilized to protect plants from insects and thus viruses (Perring et al., 1989; Robinson and Decker-Walters, 1997), but rowcovers must be removed to allow insect pollination of cucurbit flowers; when this is done, aphids will also move onto plants and transmit viruses.

For early yields, rowcovers decreased culls and culls with WMV symptoms on 'Dividend' and 'Elite', regardless of mulch type (Table 4). This effect of rowcovers on early yields was likely due to aphid exclusion. Rowcovers had a greater influence on reducing the number of 'Dividend' plants with WMV symptoms as well as the severity of the symptoms produced compared to 'Elite' (Table 3). By the end of the fall growing season, rowcovers had no influence on reducing WMV symptoms on 'Elite', especially the severity of the symptoms. The use of rowcovers suppressed virus incidence and severity on a virus tolerant squash cultivar for a greater period of time compared to a virus susceptible squash cultivar which was directly related to increased marketable yields. Over all harvests, marketable and total yields were higher when rowcovers were used in combination with white mulch compared to black mulch.

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