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Effects of water inclusion in microclimate modification systems for warm and cool season vegetable crops on temperature and yield

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Abstract

Four microclimate modification methods including spun-bonded and slitted low tunnels both with and without the addition of water-filled plastic tubes were tested for their effect on early and total yields of warm and cool season vegetable crops in Morgantown, West Virginia, USA. Peppers, tomatoes, radishes, and lettuce were organically grown in 2006 and 2007. Early season pepper yields were higher when water tubes were included with low tunnels while early tomato yields did not differ. Total yields for warm season crops in some microclimate modification treatments were higher than the control, and harvests started up to four weeks earlier in the spring. Cool season crop yields in the four treatments showed no increase over the control despite one to three weeks earlier harvests for radish and lettuce. These results show potential for earlier safe planting dates and increased yield, especially in warm season vegetable crops using low tunnels and water tubes. Additionally, economic analysis demonstrated a potential for increased profits over control plots using these microclimate modification techniques.

Key words: Slitted polyethylene low tunnel, spun-bonded row cover, water tubes, organic vegetable production, tomato (*Solanum lycopersicon*), lettuce (*Lactuca sativa*), radish (*Raphanus sativus*), bell pepper (*Capsicum annuum*)

Introduction

Techniques to modify the microclimate have been used for many years by growers on a variety of scales and climates (Wells and Loy, 1985; Wittwer and Castilla, 1995). Microclimate modification can extend growing seasons by allowing both earlier spring harvests and later fall crops (Lamont, 2005; UK, 2007) while producing several main benefits for growers. An increase in vegetable production is possible because of a lengthened growing season in addition to a concomitant increase in earnings because of extended sales and price premiums for early and late season produce. There is also a potential benefit of an expanded customer base because produce can be made available for a greater portion of the year (Bachmann, 2005; UK, 2007). Advances in crop production techniques and technologies now allow farmers greater levels of control over crop growing conditions. These technologies include structures, such as low and high tunnels, employed to create specific microclimates around developing crops (Lamont, 2005; Wells and Loy, 1985; Wittwer and Castilla, 1995). However, initial costs of these techniques vary and some growers may desire the benefits of microclimate modification while using lower cost techniques, such as spun-bonded, slitted, or perforated row cover materials applied as low tunnels instead of high tunnels or greenhouses.

Row covers and low tunnels, often used with plastic mulches, have been shown useful in many climates for a number of crops. The purpose of such covers is to modify temperatures in a way that has the potential to alter the growth and yield of horticultural crops (Wells and Loy, 1985). Muskmelons (*Cucumis melo*) have been studied often in row cover and low tunnel research with several reports of increased early and total yields (Hemphill Jr. and Mansour, 1986; Ibarra *et al.*, 2001; Jenni *et al.*, 1998; Loy and Wells, 1982; Taber, 1993). In addition, spun-bonded row covers have also been shown to enhance early season tomato yields (*Solanum lycopersicon*) (Reiners and Nitzsche, 1993) and raise watermelon (*Citrullus lanatus)* yields by increasing transplant survival and earlier harvests (Marr *et al.*, 1991). The combination of row covers and mulches has also shown increased growth and yields in watermelon (Soltani *et al.*, 1995) and cucumber (*Cucumis sativus*) (Nair and Ngouajio, 2010).

Row covers and low tunnels can also be beneficial in the production of cool season crops. Floating row covers and/or tunnels have been shown to allow earlier planting and harvest of broccoli (*Brassica oleracea*) (Westcott *et al.*, 1991) and increased maturity and yield of crisphead lettuce (*Lactuca sativa*) (Rekika *et al.*, 2009). Chinese cabbage (*Brassica rapa*) crops grown under row covers and low tunnels also showed higher yields than uncovered plots due to increased air and soil temperatures (Moreno *et al.*, 2002). Other benefits, such as potential for reduced disease pressure and increased marketable yield, have also been observed with row cover use in bell pepper (*Capsicum annuum*) and watermelon production (Alexander and Clough, 1998; Avilla *et al.*, 1997; Walters, 2003).

Additionally, row covers and low tunnels have the potential to be combined with other microclimate modifying techniques. The use of water-filled tubes has been tested in growing systems for its ability to moderate both high and low ambient temperatures and protect temperature sensitive crops (Aziz *et al.*, 2001; Jenni *et al.*, 1998). Jenni *et al.* (1998) reported that certain combinations of tunnels, mulches, and thermal water tubes in the growing environment could lower chilling injury and increase muskmelon early yields. Additional research (Aziz *et al.*, 2001) on the use of water tubes in vented low tunnels showed reduced temperature fluctuations which had the potential to indirectly affect plant growth rates.

These relatively low-cost techniques, such as low tunnels and water tubes, can potentially increase the cropping season by allowing earlier planting and harvesting and protecting warm season crops during low-temperature events early in the season. Such techniques have been used on a variety of crops with research often focusing on tomatoes and melons. The effect of these technologies has not been as extensively investigated on some cool season crops. Additionally, the inclusion of water tubes in microclimate modification systems has been tested on a relatively narrow range of crops and to an even lesser extent to study planting crops earlier despite the real possibility of doing so. In most research, controls are planted at the same time as the microclimate modification techniques are applied, ignoring the practical aspect of being able to plant earlier with the additional protection afforded by microclimate modification.

The purpose of this study was to compare the effects of low tunnels and the inclusion of water tubes on air and soil temperatures and total and early yield of warm season pepper and tomato crops as well as cool season lettuce and radish crops. In addition, an economic analysis was carried out to determine the feasibility and profitability of the microclimate modification methods under investigation. These techniques could be used as a cost-effective way for growers to enhance early yield through modifying growing environments without investment in higher input methods, such as high tunnels or greenhouses.

Materials and methods

Location and plant material: The West Virginia University Plant and Soil Sciences Organic Farm in Morgantown, West Virginia, under certified organic production since 2003, was the location for our experiments. The soil was a moderately well-drained silt loam classified as a fine-silty, mixed, semiactive, mesic Typic Fragiudults.

Organic seed was obtained from Johnny's Selected Seeds (Winslow, ME) and High Mowing Seeds (Wolcott, VT), and all crops were grown under USDA National Organic Program rules. The warm season crops were tomato ('WV '63') and bell pepper ('Orion'). Cool season crops included lettuce ('Parris Island Cos') and radishes (*Raphanus sativus*) ('Easter Egg' and 'Pink Beauty'). The tomato seeds used in this experiment were collected from the previous growing season at the WVU Organic Research Farm. Tomato, pepper, and lettuce plants were sown in the West Virginia University Plant and Soil Sciences greenhouse and later transplanted to the field while radishes were direct seeded. Tomato and pepper plants were sown eight weeks before planting, and were transplanted to cell packs four week after seeding. Lettuce was planted in the field directly from the seeding flats (288-cell) approximately four weeks after seeding. The greenhouse medium consisted of 50% composted dairy manure (WVU Animal Sciences Farm, Morgantown, WV), 25% peat moss (BFG Horticultural Supply, Burton, OH), and 25% perlite (BFG Horticultural Supply, Burton, OH).

Experimental treatments: The experiment was conducted in both the 2006 and 2007 growing seasons. The four low tunnel treatments and the control were arranged in a randomized complete block design with three replications. The dimensions of the fifteen plots were 3.7 x 4.9 m with a total area of 18.1 m^2 per plot. The four crops in each replicate were planted side-by-side in four 4.9 m long rows each planted to one crop with 0.75 m between-row spacing. The in-row spacing for tomatoes (6 plants per replicate) was 0.75 and 0.5 m for peppers (8 plants per replicate). Lettuce (12 plants per replicate) was spaced at 0.3 m in-row while radish seeds were sown at approximately 100 seeds m^{-1}.

The control consisted of the four crops grown without the use of low tunnels or water tubes described below. The first treatment consisted of spun-bonded polypropylene (Agribon 17 g m^{-2}, Hummert International, Earth City, MO) used as a floating cover for cool season crops and supported above the warm season crop by 3.4 mm wire hoops to form low tunnels. All coverings were secured by placing soil on the edges. The second treatment used the same spun-bonded covering but 15 cm-diameter water-filled polyethylene (6 mil) tubes (U-Line Shipping Supply, Chicago, IL) were placed on the soil on either side of the crop rows in 1 m sections heat sealed on each end after filling. In each replicate, approximately 100 L of water was contained in the tubes. The third treatment used slitted polyethylene (0.5 mil) stretched over hoops to form low tunnels (Hummert International, Earth City, MO) as described above. The fourth treatment consisted of the slitted polyethylene low tunnel with the addition of water tubes as described in the second treatment.

The control plots were established according to predicted frost-free dates using long-term temperature data for the area (National Climactic Data Center). Warm season crops were planted when only a 10% chance of frost remained while cool season crops were planted when temperatures were expected to reach levels necessary for germination and/or growth. Planting dates in the experimental treatments were calculated combining predicted low temperatures, as with the control, with the addition of temperature protection provided by the low tunnel methods, as listed by the manufacturer and based on our own experience. The spun-bonded and slitted low tunnel treatments were therefore assumed to provide approximately 1.1 to 2.2 °C and 0.6 to 1.7 °C of frost protection, respectively. This temperature protection resulted in earlier planting for the experimental treatments because an earlier date was associated with a 10% chance of frost. The year-to-year variations in planting dates (Table 1) occurred because of site-specific weather and soil moisture conditions.

The control and all treatment plots were fertilized through the addition of composted dairy manure (WVU Animal Sciences Farm, Morgantown, WV) at a rate of 55 kg plot^{-1} (18.1 m^2) prior to spring planting in both years. Yearly soil testing confirmed adequate soil nutrient status to support vegetable crop growth with these levels of compost addition (data not shown). Tomatoes and bell peppers were mulched at planting with a double layer of newspaper under 5 cm of hay while lettuce and radish were transplanted or seeded directly in the soil without mulching. The low tunnels were installed at planting for all crops in both 2006 and 2007. They were kept in place until harvest for cool season crops and removed around 10 June in both years for the warm season crops. This was done to avoid excessive heat buildup under the covers (Decoteau, 2000).

Table 1. Planting and harvest dates for cool and warm season crops across the two years of the experiment

Date	Season	2006		2007	
		Control	Treatments	Control	Treatments
Plant date	Cool Season	19 Apr.	31 Mar.	30 Apr.	9 Apr.
	Warm Season	24 May	5 May	27 May	9 May
Harvest date	Cool Season	9 June	15 May	8 June	24 May
	Warm Season	Through 25 Aug.	Through 25 Aug.	Through 4 Sept.	Through 4 Sept.

Data collection*:* Both air (2.5 cm above soil line to capture possible water tube effects on air temperature) and soil (10 cm depth) temperature data were collected hourly in one plot of each treatment and the control with data loggers (Spectrum Tech., East-Plainfield, Il) protected from solar radiation by white plastic tubes. Photosynthetically active radiation (PAR) light measurements at plant canopy height were gathered using a quantum light sensor (Spectrum Tech., East-Plainfield, Il) logging hourly in a control plot with comparison light levels in the experimental plots taken in two-week intervals in a rotation through the season. Yield data were gathered on all three replicates. Early yields were not obtained for cool season crops as a single once-over harvest was conducted when the plants reached marketable maturity. Tomato and pepper fruit were harvested weekly on all plots at marketable maturity and all fruit harvested prior to the appearance of ripe fruit in the control was described as early yield.

Labour and input costs were also gathered for each experimental treatment. To estimate input costs, time and materials needed for each experimental treatment (in excess of those needed for the control) were calculated on a plot basis (18.1 m^2). Additional labour needed to initiate the microclimate modification treatments was calculated at \$6.00 hr^{-1}, while the low tunnel and water tube materials were calculated using the purchase price of the spun-bonded and slitted coverings, and water tubes needed for each individual plot. To determine potential returns in each plot, the treatment yield averages for all four crops were multiplied by actual farmer's market sales prices for that crop and combined to estimate the total plot value. In the warm season crops, early season yields (those harvested before the first ripe fruit in the control) were valued higher than later yields due to price premiums in the market where this produce was sold. The additional labor and input costs of the four experimental treatments were then subtracted from the potential returns calculated from both early and later season yields times the sales price to obtain a measure of how potentially profitable each treatment was in each year of the experiment. The formula for these calculations is then: Net returns =((early season average yields x early season price) + (regular season average yields x regular season price)) – (labour + material inputs).

Statistical analysis: Yield data from the 2006 and 2007 seasons were combined into a single statistical analysis because no significant treatment-by-year interactions were present. The General Linear Model procedure was used to analyze yield data with LSDs to show treatment differences at α= 0.05 using SAS version 9.1 (Cary, NC). Contrasts were used to compare control vs. others, spun-bonded vs. slitted low tunnel treatments and treatments with vs. without water-filled tubes.

Results and discussion

Air and soil temperatures: In the spring seasons of 2006 and 2007, observed air temperatures were generally higher by 1 to 3 ºC in slitted low tunnels and 2 to 3 ºC under spun-bonded low tunnels (Fig. 1). Although statistical analysis was not carried out on the collected temperature data in this experiment, trends in air temperature correspond with other published work. Increases in air temperature and heat units in low tunnels and row cover treatments over bare ground or mulch have been often reported in previous research (Motsenbocker and Bonnano, 1989; Ibarra *et al.*, 2001; Rekika *et al.*, 2009; Waterer, 2003; Loy and Wells, 1982). Waterer (1993) showed spun-bonded and perforated polyethylene tunnel increased mean daily air temperature 3 to 6ºC, while Moreno *et al.* (2002) reported 5 to 7ºC increases. Jenni *et al.* (1998) reported spun-bonded and polyethylene tunnel air temperature increases of around 2 to 3ºC and 3 to 5ºC, respectively. Aziz *et al.* (2001) also consistently showed an average air temperature increase in perforated low tunnels with water tubes over uncovered control plots. Additionally, water tubes included in tunnels were shown to increase minimum and decrease maximum air temperatures over treatments with tunnels but no thermal water tubes (Aziz *et al.*, 2001).

Fewer consistent microclimate modification impacts on soil temperature were observed in this study (Fig. 1) than have been reported previously. Soltani *et al.* (1995) reported mean soil temperatures of 1 to 3 ºC higher with spun-bonded row covers and polyethylene low tunnels over mulch, while Hemphill, Jr. and Mansour (1986) and Moreno *et al.* (2002) reported 2 to 4 ºC and 5 ºC increases, respectively. Jenni *et al.* (1998) demonstrated that perforated low tunnel increased soil temperatures by 1 to 3 ºC

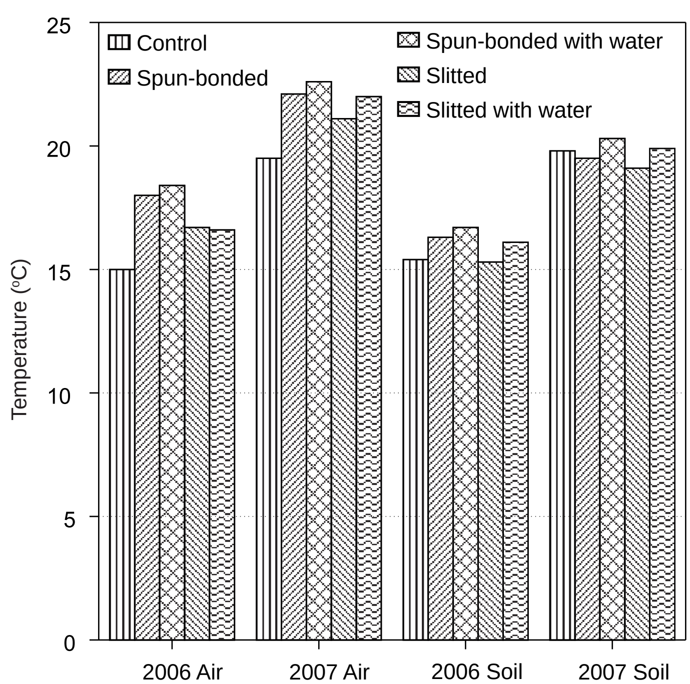

Fig. 1. Mean air and soil temperatures for the spring 2006 (4/4 - 6/13, N=71 days) and 2007 (5/1 –6/11, N=42 days) seasons. Each treatment mean represents the temperatures recorded while microclimate modification techniques were employed.

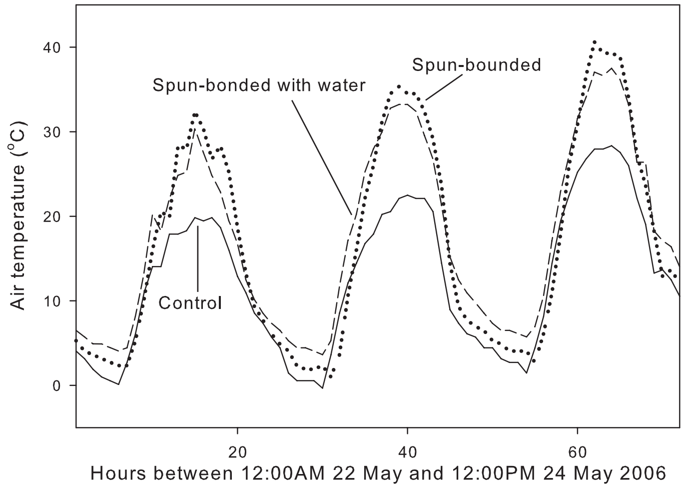

Fig. 2. Hourly air temperatures experienced from 22 May 2006 through 24 May 2006 in the control, spun-bonded and spun-bonded with water treatments. Impacts of the microclimate modification treatments on nighttime low and daytime high temperatures are illustrated.

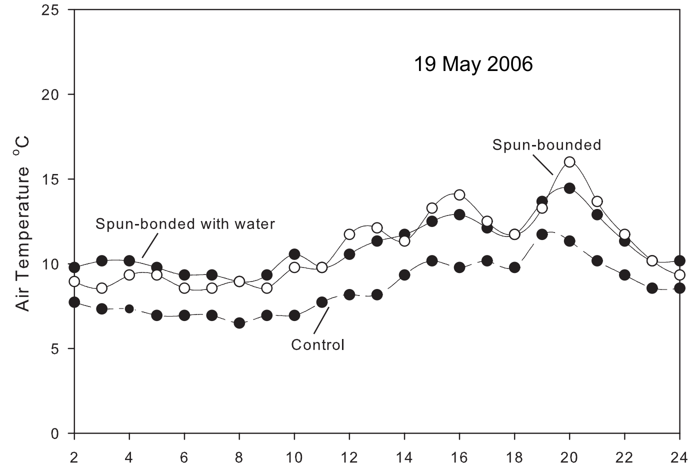

Fig. 3. Hourly air temperatures from 19 May 2006 illustrating the effect of spun-bonded and spun-bonded with water tubes treatments on temperature fluctuations in the plant environment across a spring day.

while water tubes under non-perforated low tunnels increased soil temperatures by 2 to 5 ºC over mulch treatments alone. A possible explanation for our inconsistent trends in soil data as compared to other research is that many other reported soil temperatures differences were measured when low tunnels were used over plastic mulch. Plastic mulches could have produced greater differences than the organic hay mulches used in our work in addition to differences in depths of soil temperature measurement. Differences in material thickness of plastic present further difficulties in accurately comparing air and soil temperatures of spun-bonded and slitted or perforated polyethylene covers with previous research.

While not illustrated by average temperatures over the course of our experiment, experimental microclimate modification treatments demonstrated the potential impact of the low tunnel and low tunnel with water tube microclimate modification methods on temperature. Trends toward increased minimum nighttime air temperature in the spun-bonded tunnels versus the control are depicted. Impacts of water tubes on daytime air temperature were more variable (Figs. 2 and 3). This possible impact on minimum nighttime air temperatures, observed primarily in spun-bonded tunnels, could have contributed to plant survival in low temperature events prior to the planting of the control warm season crops. In 2006, between the experimental treatment planting date of 5 May and the control planting date of 27 May, low temperature events occurred on 22 May through 24 May (Fig. 2), but plant damage due to these low temperatures was not observed.

Photosynthetically active radiation (PAR): Two-week PAR averages for slitted polyethylene and spun-bonded treatments were measured as a percentage of the control for the same two-week intervals of the 2007 growing season. The slitted low tunnel received an average 85% of the PAR of the control, while the spun-bonded tunnels averaged 74% of the control PAR values (data not shown). These values are consistent with published PAR levels in season extension systems. Soltani *et al.* (1995) described 70 to 80% transmittance levels for spun-bonded and polyethylene materials, while Loy and Wells (1982) and Gimenez *et al.* (2002) reported 86% transmittance for slitted low tunnels and 65 to 85% for spun-bonded row covers, respectively.

Total and early yield: Radish and lettuce yields in the spun-bonded row cover and slitted tunnel microclimate treatments were not increased over the control (Table 2). However, the covers did allow earlier planting, which led to harvest occurring twenty-four days earlier than the control in 2006 and fifteen days earlier in 2007. Radish yields in the control plots were higher than the spun-bonded and slitted tunnels without water tubes while the covered treatments with water tubes produced yields similar to the control. The inclusion of water tubes in spun-bonded and slitted covered treatments showed an increase in radish yield in the water tube vs. none contrast (P=0.042). Lettuce biomass was similar in all plots (Table 2). Gimenez, *et al.* (2002) similarly reported spun-bonded floating row covers (17g m^{-2}) not significantly increasing leafy crop yields over those without covers.

In this study, the earlier planting dates of the treatments typically equaled the earlier harvest of cool season crops, meaning that the modified microclimates appeared able to produce crops in a comparable number of days with an earlier spring planting date. In 2006, soil conditions permitted planting eight to ten days earlier than in 2007 and the earliness of yield in the modified microclimate treatments was increased to greater relative degree over the control than in 2007 in these cool season crops. This could illustrate that techniques that modify the microclimates potentially have the greatest relative effect on crop growth when field growing conditions are the most challenging. This topic of when in a season microclimate modification techniques can be used to the greatest advantage likely deserves additional research. In this study, spun-bonded and polyethylene coverings and water tube inclusion techniques were important in controlling the timing of crop harvest in cool season crops by producing comparable yields and allowing similar production schedules in different portions of the spring season.

Pepper total yields were higher in 2007 than in 2006, but treatment effects were similar in the two years and treatment by year interaction was not significant. Pepper total yields (Table 2) were significantly higher than the control for both tunnel treatments that included water tubes, while treatments without the addition of water tubes had yields similar to the control. The spun-bonded and slitted tunnel with water tube treatments produced 138 and 139% of their respective microclimate treatments without water tubes. Tomato yields in the spun-bonded tunnels, spun-bonded tunnels with water tubes and slitted tunnels with water tubes all showed increased total yields over the control. In addition to higher total yields, the harvest period of bell peppers and tomatoes was extended by four weeks and two weeks, respectively, because of earlier planting dates. Since the cessation of harvest occurred at the same time in all plots, earlier yields in the season contributed to an increased total yield in the microclimate modification treatments.

Early yield (before the first harvest in the control) for tomato and pepper were collected in the days or weeks prior to the appearance of ripe fruit in the control plots in each year. The inclusion of water tubes in microclimate modification treatments significantly increased early yields in the pepper crop (P=0.0065). Spun-bonded and slitted tunnel treatments with water tubes produced 179 and 181% of the yield of their respective treatments without water tubes. In contrast to the pepper early yields, the presence of water tubes in the treatments did not increase tomato early yields. There were also no significant difference between the spun-bonded and slitted polyethylene tunnel treatments for early tomato yields (P=0.077). Early pepper and tomato yields were significantly different with 2007 producing more early pepper yield than 2006. In contrast to peppers, early tomato yields, though not significantly different across microclimate treatments, were higher in 2006 than 2007. These data suggest that early yields are temperature sensitive and could be crop specific; therefore, variable seasonal conditions can be critical in early yield determination.

Increased protection in the tunnel treatments facilitated planting warm seasons crops approximately eighteen days before the control in both years. However, harvest of ripe pepper fruit from the spun-bonded and slitted tunnels began occurring about thirty days prior to the control in both years. In the tomato crop, ripe fruit occurred earlier in the tunnel treatments by generally the same numbers of days as early planting occurred. Therefore, the tunnels were able to allow comparable production schedules when begun earlier in the season under colder temperatures as was seen in the cool season crops, but the tunnels and water tubes also increased the development of plants and maturation of pepper fruit.

Many researchers (Hemphill Jr. and Mansour, 1986; Ibarra *et al.*, 2001; Loy and Wells, 1982; Marr *et al.*, 1991; Soltani *et al.*, 1995; Taber, 1993) have reported early and total yield increased by row cover and low tunnels on muskmelon and watermelon crops. Peterson and Taber (1991) showed the potential for increased early tomato yield under low tunnels if excessively high temperatures were avoided. Gerber *et al.* (1988) and Waterer (1992) reported increased early pepper yields when low tunnels were used in addition to plastic mulch while only Gerber *et al.* (1988) showed increased total yields in the covered treatments. Waterer (1992) also found spun-bonded covers to more consistently increase early yields than slitted polyethylene.

The use of tunnels both with and without water tubes for the purpose of moderating microclimate temperatures and therefore potentially increasing growth and yield of warm season crops has been supported by prior experimentation (Aziz *et al.,* 2001; Jenni *et al.*, 1998). Aziz *et al.* (2001) reported that tunnels with water tubes and proper ventilation could impact relative growth rates and plant dry weight in muskmelon early in the growing season. Rangarajan (1998) and Rangarajan and Ingall (1998) also reported an increase of 30% in bell pepper early yields when clear water tubes were used under low tunnels. Similar results were seen in this study with increased early pepper yield in low tunnel treatments with water tubes. However, over the period of harvest in our experiment, total yield was also increased. Bell peppers are warm season crops that can require even higher temperatures than tomatoes for optimum growth and productivity (Decoteau, 2000). Our research suggests that the effects of covers and water tubes were magnified on this cold sensitive crop. Accelerated growth and production by plants in the low tunnel treatments with water tubes were observed in this study because pepper plants seeded and transplanted at the same time produced significantly higher early yields when water tubes were added to the tunnels.

Economic analysis: Economic analysis showed that all microclimate modification treatments tested have the potential to raise returns and profits for growers. When the materials and labour costs in excess of the control for each microclimate modification treatment are subtracted from the potential returns (yield x market price) from each year (data not shown), a comparison of potential profits emerges (Table 3). Control returns were the lowest in both years while the highest potential returns were observed in covered treatments. The potential economic impact of water filled tubes differed slightly by year and type of low tunnel material. Hemphill Jr. and Mansour (1986) and Waterer (1993) showed that net returns in muskmelon production could often be increased by the use of row covers. Rangarajan (1998) also demonstrated an increased earning potential from using water filled tubes under tunnels for pepper production. The ultimate decision of what techniques to implement depends on the level of investment possible and local market conditions. If cold frames or high tunnels prove too great of an initial investment for growers (Waterer, 2003), row covers incorporating a water buffer could be considered a potentially viable microclimate

Table 2. Average total and early yields per plot (grams 18 m^{-2}). Total yields represent all mature biomass removed from the plot over the harvest season. Early yields represent mature fruit harvested from plots prior to the appearance of mature fruit in the control plots. Treatments with the same letter are not significantly different from each other as separated by LSD at P= <0.05. (N= 6)

Treatment	Lettuce total yield	Radish total yield	Pepper total yield	Pepper early yield	Tomato total yield	Tomato early yield
Control	1300	3255 (a)	2980 (b)	0	5700 (c)	0
Spun-bonded	2083	2342 (b)	4735 (ab)	1427 (b)	14840 (ab)	1192
Spun-bonded with water	2205	2788 (ab)	6526 (a)	2549 (a)	21232 (a)	1497
Slitted	1712	2363 (b)	4778 (ab)	1414 (b)	12576 (bc)	444
Slitted with water	2375	2897 (ab)	6668 (a)	2569 (a)	14763 (ab)	1083
	NS	*	*	*	**	NS
LSD		666	2477	1081	7366	
Control vs. others contrast		*	**	NA	**	
Spun-bonded vs. slitted contrast		NS	NS	NS	NS	
Water tubes vs. no water tubes contrast		*	*	**	NS	

NS, *,** Non significant or significant at P= 0.05,0.01, respectively

Table 3. Estimated net returns for each of the experimental treatments

Parameter/ Year	Control	Spun-bonded	Spun-bonded with water	Slitted	Slitted with water
2006					
Income	35.02	73.99	96.22	76.49	91.30
Added costs**	0	12.32	33.32	10.70	31.70
Net returns*	$35.02	$61.67	$62.90	$65.79	$59.60
2007					
Income	54.58	92.57	128.93	70.19	93.46
Added costs**	0	12.32	33.32	10.70	31.70
Net returns*	$54.58	$80.25	$95.61	$59.49	$61.76

Estimated using actual data on labour, material costs and sales prices. The additional labour and input costs of the treatments were subtracted from the potential returns calculated with yields and actual farmers markets sales price to obtain a measure of how potentially profitable each treatment was in each year of the experiment.

* Net returns = ((early season average yields) x (early season price) + (regular season average yields) x (regular season price)) – (added costs)

** Added costs= (additional labour + spun-bonded and slitted cover, water tubes, wire hoops)

modification alternative.

Based on the observations, methods employed in this study could be considered as useful microclimate modification techniques. Warm season tomato and pepper crops showed increases in early and/or total yield as a function of the use of covers and water tubes while cool season radish and lettuce yields were not higher than the control. However, lettuce and radishes were harvested earlier, which could impact early season marketing. Earlier yields were made possible in all crops because of earlier planting or accelerated growth in modified microclimates. Peppers were the most sensitive crop with respect to early and total yield, and higher yields were seen with the inclusion of water tubes when compared to treatments without water tubes. The addition of water as a temperature buffer could potentially be used with any microclimate modification technique to improve overall and early yields in warm season crops.

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