Reducing Time and Expense to Recycle Perlite for Repeat Use in Greenhouse Tomato Operations

Hanna Y. Hanna[1]

ADDITIONAL INDEX WORDS. ***Solanum lycopersicum*, reconditioning action, hot water treatment, leaching excess salt, fruit pruning**

SUMMARY. **Planting greenhouse tomatoes (*Solanum lycopersicum*) in the same perlite more than once without reconditioning to restore medium loose structure, desalination to remove excess salt, and disinfection to guard against pest contamination is risky, and replacing the perlite to produce every new crop is costly. Reconditioning and treating perlite with hot water at a minimum cost provides a favorable solution for both problems and saves natural resources. A study was conducted in a 30 × 96-ft greenhouse in Spring 2007, 2008, and 2009 (January–July) to evaluate three methods for perlite recycling cost, desalination efficiency, and effects on tomato yield at three or four fruit per cluster. Each recycling method consisted of two components: the reconditioning action and the hot water treatment. The three recycling methods included no stir/sift then disinfect, stir then disinfect, and sift then disinfect. Perlite recycled with the no stir/sift then disinfect method was not reconditioned before the hot water treatment. Instead, it was agitated with a nozzle mounted on a pressure washer wand during the hot water treatment. Perlite recycled with the stir then disinfect method was reconditioned first with an auger mounted on an electric drill and then treated with hot water. Perlite recycled with the sift then disinfect method was reconditioned first by sifting the perlite with a homemade apparatus and was then treated with hot water. Recycling perlite with the no stir/sift then disinfect method reduced labor input by 49% and 81% compared with the stir then disinfect and the sift then disinfect methods, respectively. The no stir/sift then disinfect method reduced recycling cost by 22% and 50% compared with the other two methods, respectively. Perlite that was not reconditioned (no stir/sift) had higher nitrate-nitrogen (NO_3-N) before hot water treatment than the stirred perlite and equal NO_3-N to the sifted perlite. Hot water treatment significantly reduced medium electrical conductivity, NO_3-N, potassium, and sodium. Tomatoes grown in perlite recycled with any of the three methods produced similar marketable and cull yields and fruit weight. Pruning fruit to three per cluster increased marketable yield, fruit weight, and reduced cull yield. There was no significant recycling method × cluster pruning interaction for yield components, indicating that all recycling methods had similar effects on tomato yield at three or four fruit per cluster. We conclude that the no stir/sift then disinfect method is less time consuming, more economical, and has no negative impact on yield. Tomatoes grown with three fruit per cluster in perlite recycled with any of the three methods produced greater marketable yield, less cull yield, and heavier fruit than tomatoes grown with four fruit per cluster.**

Perlite is an excellent growing medium for many horticultural crops, including greenhouse tomatoes (Szmidt et al., 1988). The initial rock found in nature is crushed to small pieces and heated to 1000 °C to evaporate the inside moisture and expand the granules like popcorn (Papadopoulos, 1994). This lightweight medium is inert, pathogen-free, and easy to handle. Replacing perlite every growing season to produce a new tomato crop is costly (Hanna, 2009), and recovering the expense by increasing fruit sale price may not work well in a competitive market. Reusing perlite without reconditioning, desalination, and disinfection to grow successive tomato crops is risky because of medium compaction, salt build-up, and pest contamination (Hanna, 2005, 2006; Hanna and Smith, 2002). Previous research has indicated that high salt concentration in the medium can reduce fruit size (Chrétien et al., 2000) and decrease fruit number (Del Amor et al., 2001). According to Schwarz and Kuchenbuch (1997), an electrical conductivity (EC) of 6.0 $mS·cm^{-1}$ can reduce tomato yield by 64% compared with an EC of 1.0 $mS·cm^{-1}$. Schwarz (2003) indicated that salt buildup in the root environment can reach 10 $mS·cm^{-1}$ and can negatively impact root and shoot growth of young and mature tomato plants.

Steam sterilization of used perlite before planting a new crop has been recommended to safeguard against pathogen contamination (Wilson, 1988). This treatment requires steam generators that are expensive for the small growers and may not be adequate to restore perlite loose structure and reduce medium salt.

Previous research has indicated that sifting used perlite with a homemade apparatus to restore medium loose structure followed by hot water treatment to disinfect and leach excess salt significantly reduced replacement cost, salt concentration, and had no negative impact on yield (Hanna, 2005). Subsequent research indicated that stirring used perlite in the grow bag with an auger mounted on an electric drill to restore perlite loose structure, followed by hot water treatment, achieved the same results at less cost (Hanna, 2006). Each method encompassed two separate steps collectively called perlite recycling. The first step was conducted to recondition the perlite with some mechanical means to restore the medium loose structure, and the second was conducted to leach residual salts and disinfect the medium with hot water.

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1	mmho/cm	$mS·cm^{-1}$	1
28.3495	oz	g	0.0353
1	ppm	$mg·L^{-1}$	1
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

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Louisiana State University Agricultural Center, Red River Research Station, 262 Research Station Drive, Bossier City, LA 71112

[1]E-mail: hhanna@agcenter.lsu.edu.

In this investigation, a new method is developed to accelerate recycling perlite before planting a new crop and possibly reduce cost. The developed method does not include perlite stirring or sifting for reconditioning before hot water treatment; however, the medium is agitated during desalination and disinfection with hot water. The operator combines the penetrating power of the released hot water from a nozzle mounted on the wand of a pressure washer with his or her action to break the perlite/root aggregates, leach residual salts, and disinfect the medium all at the same time.

Pruning recommendations for beefsteak cultivars range from three to five fruit per cluster (Hochmuth, 1991; Ontario Ministry of Agriculture and Rural Affairs, 2001; Papadopoulos 1991; Snyder, 2001). Hanna (2005, 2006) indicated that tomatoes grown with three fruit per cluster in recycled perlite produced greater marketable yield than tomatoes grown in new perlite, but yield response to four fruit per cluster in recycled perlite was not investigated.

The objectives of this study were to determine the time and cost to recycle perlite with the new and previously developed methods, to evaluate the efficacy of each method on reducing medium salts, and to assess tomato yield in perlite recycled with each method at three and four fruit per cluster.

Materials and methods

Studies were conducted in Spring 2007, 2008, and 2009 (January–July) in a 30 × 96-ft double-polyethylene greenhouse used to grow 640 tomato plants in 320 polyethylene bags. In every study, tomato plants were grown in 5-gal upright bags filled to 2 inches from the top with perlite. The same perlite in each treatment was recycled and used for the entire duration of the study. To recycle perlite with the new method, all plants with the crown roots of the previous tomato crop were removed from the greenhouse after the last harvest. For the no stir/sift then disinfect method, the medium was not reconditioned before hot water treatment. Instead, the perlite was agitated in the grow bag during the hot water treatment with a heavy-duty water breaker (model 400; Dramm, Manitowoc, WI) mounted on the steel wand of a hot water pressure washer. A hot water pressure washer (Versa 4200 SS; MGM Sales & Service, Siloam Springs, AR) connected to a municipal water source and discharging 4.0 gal/min was used after replacing the pressure tip with the water breaker. The operator moved the water breaker front and back, up and down, and sideways in the grow bag. This action allowed the water power from the breaker's 400 mini-holes to loosen the perlite/root aggregates, leach excess salt, and disinfect the medium at the same time. The wash water continually leached out excess salt during the process through drain holes existing at the bottom and sides of the grow bags until the water color changed from blue (residual fertilizer color) to clear. Each bag was drenched with water exiting the pressure washer at 195 °F for about 1 min to make sure that perlite returned to the original loose structure, residual salt was leached out, and perlite temperature reached 160 °F and stayed above 50 °C for at least 30 min (Pullman et al., 1981; Stapleton and DeVay, 1983).

To recycle perlite with the stir then disinfect method, the medium was reconditioned in the bags after removing all plants with an auger mounted on an electrical drill to restore medium loose structure. To protect the medium from dispersing out of the bag, the auger was operated inside a bottomless 5-gal bucket placed over the grow bag (Hanna, 2006). In the sift then disinfect method, perlite was reconditioned before hot water treatment using a homemade sifter that allowed for the perlite granules to pass through the sifter strainer to a receiving bag for collection (Hanna, 2005). In the stir then disinfect and the sift then disinfect methods, perlite was treated with hot water after reconditioning using the same water breaker as described in the no stir/sift then disinfect method for valid comparison. The time required for recycling the perlite in 320 bags with all three methods was recorded and labor costs were calculated at $7.25/h.

To determine the effectiveness of all recycling methods on reducing medium salt concentrations, a representative sample was collected after crop termination (before media reconditioning) and another sample was collected after hot water treatment. Samples were collected using a soil probe (AMS; Ben Meadows, Janesville, WI) from each treatment/replication combination, mixed thoroughly, and nutrient solution was expelled from each sample with a light pressure using a garlic press that agrees in principle with the drill press technique described by Scoggins et al. (2000). The EC of the pressed solution was determined using a conductivity tester (OakTon; Cole-Parmer, Vernon Hills, IL). Medium nitrate-nitrogen (NO_3-N), potassium (K), and sodium (Na) were determined using Cardy ion meters (Horiba Instruments, Irvine, CA).

Transplants from the cultivar Quest were grown in plastic trays with 38 cells (Growing System, Milwaukee, WI) filled with the soilless mix Pro-Mix BX (Premier Horticulture, Quakertown, PA) for 4 weeks before being planted in the grow bags. Two transplants were planted at a 3-inch depth to cover the root ball and were spaced 7 inches apart in each bag. Using the V-training system, plants were spaced 17 inches apart within the row and rows were spaced 3 ft apart at the overhead supporting wire. The greenhouse had 10 rows of plants with north/south orientation. A single feeding tube was installed for each plant in the bag that provided ≈0.5 gal/d of a nutrient solution having an EC of 2.0 to 2.5 $mS \cdot cm^{-1}$ in a run to waste system that allowed for ≈20% drainage. Other cultural practices consisted of standard recommendations for growing greenhouse tomatoes for fresh market production in Louisiana (Hanna, 2003).

The experiment was a 3 × 2 factorial of recycling method (no stir/sift then disinfect, stir then disinfect, and sift then disinfect) and cluster pruning (three or four fruit) in a randomized complete block design with three replications (plots) of 10 plants. Clusters were pruned to remove excess fruit and flowers as soon as three or four fruit per cluster were visible in each respective treatment.

Tomatoes were harvested from each treatment at the light red color stage two times per week for 19 weeks. Fruit with blossom-end rot and other defects were removed, and the remainder was graded according to U.S. Department of Agriculture standards (USDA, 1997). Early marketable yield was determined by weighing fruit graded medium or larger in the first five harvests. Total marketable yield was determined by weighing fruit graded medium or larger in all harvests. Cull yield was the weight of all fruit with visible defects and small size. Mean fruit weight was determined on all marketable fruit.

Data were analyzed as a randomized complete block design with three replications, using the PROC MIXED procedure of SAS (version 9.1.3; SAS Institute, Cary, NC). Blocks (replications) nested within years were considered random, and recycling and pruning methods were considered fixed. Levels of significance of the main effects and interactions in the analysis of variance table were determined with the F test. Means separation of the main effects was conducted using the DIFF option of the least square means. When significant interactions were found, means separation was performed using the PDIFF SLICE option.

Results and discussion

The no stir/sift then disinfect recycling method required 5.7 person-hours to agitate, disinfect, and leach excess salt with hot water in 320 grow bags. Assuming wages were $7.25/h, it would cost $41.33 for labor expenses. It required 1366 gal of municipal water at a cost of $4.55 per 1000 gal for a total of $6.22. The rent of a diesel hot water pressure washer was $125 per day and fuel cost was $28.16. The heavy duty nozzle cost, prorated over 2 years, was $6 per year. The total expense to recycle perlite using this method was $206.71 (Table 1). The stir then disinfect method required 5.9 h to recondition the perlite before hot water treatment and 5.2 h to agitate, disinfect, and leach excess salt with hot water for a total of 11.1 person-hours and a cost of $265.65 (Table 1). The sift then disinfect method required 24.5 h to recondition the perlite before hot water treatment and 5.0 h to agitate, disinfect, and leach excess salt with hot water for a total of 29.5 person-hours and a cost of $414.97 (Table 1).

Data indicated that the no stir/sift then disinfect recycling method reduced labor input by 49% (5.7 vs. 11.1 person-hours) compared with the stir then disinfect method and by 81% (5.7 vs. 29.5 person-hours) compared with the sift then disinfect method. It reduced recycling cost by 22% ($206.71 vs. $265.65) and 50% ($206.71 vs. $414.97) compared with the other two methods, respectively.

Reconditioning actions applied before hot water treatment significantly affected medium EC, NO_3-N, Na, and had no effect on medium K (Table 2). Perlite reconditioned with the no stir/sift action had higher NO_3-N before hot water treatment than perlite reconditioned with the stir action and had similar NO_3-N to perlite reconditioned with the sift action (Table 2). Stirring perlite is known to change the physical structure of recycled perlite (Hanna, 2006). It is possible that the change in physical structure may have contributed to lower NO_3-N content in the stirred than in the non-stirred/sifted perlite. Hot water treatment reduced medium NO_3-N and K regardless of the reconditioning action (Table 2). Reconditioning actions × hot water treatment interactions were significant for medium EC and Na (Table 2). Regardless of perlite EC and Na differences due to the reconditioned actions, hot water treatment significantly reduced these components to similar values (Table 3).

In general, medium analysis over the 3-year period indicated that hot water treatment significantly reduced medium salts regardless of the reconditioning action. The no stir/sift then disinfect recycling method was as effective as the other two methods in reducing medium residual salts mainly because of the hot water effect. Previous research has indicated that high salt in the media can reduce fruit size (Chrétien et al., 2000) and decrease fruit number (del Amor et al., 2001).

During the hot water treatment, every effort was made to insure that the temperature of the hot water released from the pressure washer reached 195 °F and average perlite temperature measured at 5-inch depth in the center of the grow bags with a long stem Traceable Thermometer (Daigger, Vernon Hills, IL) reached 160 °F and stayed above 50 °C for at least 30 min. This temperature was defined by Pullman et al. (1981) that killed a culture of *Rhizoctonia solani*, and Stapleton and DeVay (1983) that killed nematodes; both are serious tomato pests.

Tomatoes grown in perlite recycled with all three methods produced

Table 1. Time and expense needed to recycle perlite with the no stir/sift then disinfect, stir then disinfect, and sift then disinfect methods in 320 5-gal (18.9-L) polyethylene bags in a 30 × 96-ft (9.1 × 29.3-m) greenhouse at Louisiana State University Agricultural Center, Bossier City.

	No stir/sift then disinfect		Stir then disinfect		Sift then disinfect	
Action	Time (person-hours)	Expense ($)	Time (person-hours)	Expense ($)	Time (person-hours)	Expense ($)
Sifting and filling the bags	NA[z]	NA	NA	NA	24.5	177.63
Stirring perlite in the bags	NA	NA	5.9	42.78	NA	NA
Hot water treatment	5.7	41.33	5.2	37.70	5.0	36.25
Water cost[y]	NA	6.22	NA	5.63	NA	5.44
Pressure washer rental	NA	125.00	NA	125.00	NA	125.00
Fuel cost[x]	NA	28.16	NA	25.54	NA	24.65
Water nozzle[w]	NA	6.00	NA	6.00	NA	6.00
Auger cost	NA	NA	NA	23.00	NA	NA
Building a sifter[v]	NA	NA	NA	NA	NA	40.00
Total	5.7	206.71	11.1	265.65	29.5	414.97

[z]NA = Not applicable.
[y]Treating perlite with hot water required 1366 gal (5170.9 L) for the no stir/sift then disinfect method, 1238 gal (4686.3 L) for the stir then disinfect method, and 1195 gal (4523.6 L) for the sift then disinfect method at $4.55 per 1000 gal (3785.4 L).
[x]Fuel consumption was 2.25 gal/h (8.517 $L \cdot h^{-1}$) at $2.20/gal ($0.581/L).
[w]Nozzle cost was $12.00 prorated over 2 years.
[v]Building a sifter would cost about $200 and can be used for at least 5 years.

statistically similar early and total marketable yields, cull yields, and fruit weight (Table 4). The stir then disinfect and the sift then disinfect recycling methods were evaluated before with no negative impact on yield (Hanna, 2005, 2006), indicating that the new no stir/sift then disinfect method did not have a negative impact on yield either.

Pruning clusters to three fruit significantly increased total marketable yield, fruit weight, and reduced cull yield (Table 4). Hanna (2009) indicated that pruning fruit cluster to three achieved similar results. There was no significant recycling method × cluster pruning interaction, indicating that the three recycling methods had similar effect on tomato yield at three or four fruit per cluster (Table 4).

Conclusion

The no stir/sift then disinfect method was the third in a series of perlite recycling methods developed. This method was less time consuming and more cost effective than the previous two methods because no labor or tools were needed to recondition the medium before hot water treatment. Replacing perlite at the onset of every tomato crop is expensive. Processing perlite for recycling can reduce the replacement cost by 56% if the sift then disinfect method was used (Hanna, 2005) and by 78% if the stir then disinfect method was used (Hanna, 2006). Recycling the medium with the no stir/sift then disinfect method can reduce the replacement cost even further. Most processing expense is labor related, and smaller producers can do the job themselves more efficiently to save money. The rent of a hot water pressure washer and the cost of few miscellaneous items can be the only out-of-pocket expense.

Yield reduction of greenhouse tomatoes planted in the same perlite more than once without reconditioning and desalination is a serious problem. Highly soluble salts can cause root injury and impair the ability of roots to take up water and nutrients. Results of this investigation indicated that medium EC, NO_3-N, K, and Na were higher before processing but dropped significantly after recycling. The no stir/sift then disinfect method was equally effective in reducing medium salts after hot water treatment

Table 2. Analysis of variance and mean separation by least square means for recycled perlite electrical conductivity (EC), nitrate-nitrogen (NO_3-N), potassium (K), and sodium (Na) in 2007, 2008, and 2009 as related to treatment effect in a 30 × 96-ft (9.1 × 29.3-m) greenhouse at Louisiana State University Agricultural Center, Bossier City.

Recycling perlite[z]	EC ($mS \cdot cm^{-1}$)[y]	NO_3-N ($mS \cdot cm^{-1}$)[y]	K ($mS \cdot cm^{-1}$)[y]	Na ($mS \cdot cm^{-1}$)[y]
	$P > F$			
Reconditioning action (R)	0.0007	0.0062	0.2227	0.0245
Hot water treatment (W)	<0.0001	<0.0001	<0.0001	<0.0001
R × W	0.0134	0.6795	0.0666	0.0073
Reconditioning action				
No stir/sift	NA[x]	183.5 a[w]	168.6 a	NA
Stir	NA	161.4 b	157.2 a	NA
Sift	NA	171.4 ab	152.1 a	NA
Hot water treatment				
Before	NA	227.2 a	239.6 a	NA
After	NA	117.1 b	78.9 b	NA

[z]Recycling perlite consisted of two components: a reconditioning action and hot water treatment.
[y]1 $mS \cdot cm^{-1}$ = 1 mmho/cm; 1 $mg \cdot L^{-1}$ = 1 ppm.
[x]Not applicable because of significant interaction effects.
[w]For each reconditioning action and hot water treatment, means within columns followed by the same letter are not significantly different at $P \leq 0.05$ by least square means.

Table 3. Interaction effects of reconditioning action and hot water treatment (collectively called recycling perlite) on medium electrical conductivity (EC) and sodium (Na) in a 30 × 96-ft (9.1 × 29.3-m) greenhouse in 2007, 2008, and 2009 at Louisiana State University Agricultural Center, Bossier City.

	Hot water treatment			
	EC ($mS \cdot cm^{-1}$)[z]		Na ($mg \cdot L^{-1}$)[z]	
Reconditioning action	Before	After	Before	After
No stir/sift	6.37 C a[y]	4.29 A b	473.3 C a	334.4 A b
Stir	7.89 A a	4.56 A b	627.8 A a	327.8 A b
Sift	7.16 B a	3.98 A b	574.4 AB a	298.9 A b

[z]1 $mS \cdot cm^{-1}$ = 1 mmho/cm; 1 $mg \cdot L^{-1}$ = 1 ppm.
[y]For each factor (EC or Na), means within columns followed by the same upper case letter are not significantly different at $P \leq 0.05$ by least square means. For each factor (EC or Na), means within rows followed by the same lower case letter are not significantly different at $P \leq 0.05$ by least square means.

Table 4. Analysis of variance and mean separation by least square means for tomato marketable and cull yields and fruit weight of cultivar Quest grown in 2007, 2008, and 2009 as related to treatment effects in a 30 × 96-ft (9.1 × 29.3-m) greenhouse at Louisiana State University Agricultural Center, Bossier City.

	Tomato yield (lb/plant)[z]			
	Marketable			
Treatment	Early[y]	Total[x]	Cull[w]	Fruit wt (oz)[z]
	$P > F$			
Recycling method (M)	0.2276	0.7406	0.4723	0.8651
Cluster pruning (P)	0.1649	0.0368	<0.0001	<0.0001
M × P	0.5352	0.3595	0.6280	0.3210
Recycling method				
No stir/sift then disinfect	3.9 a[v]	23.3 a	1.5 a	7.5 a
Stir then disinfect	3.6 a	22.9 a	1.4 a	7.4 a
Sift then disinfect	3.8 a	23.6 a	1.3 a	7.5 a
Cluster pruning (fruit/cluster)				
Three	3.6 a	24.0 a	0.72 b	7.9 a
Four	3.8 a	22.5 b	2.10 a	7.0 b

[z]1 lb = 0.4536 kg; 1 oz = 28.3495 g.
[y]Early marketable yield is the marketable fruit graded medium or larger in the first five harvests.
[x]Total marketable yield is the marketable fruit graded medium or larger in all harvests.
[w]Cull yield is the unmarketable fruit.
[v]For each recycling and cluster pruning method, means within columns followed by the same letter are not significantly different at $P \leq 0.05$ by least square means.

and had the same impact on tomato yield as the previously developed methods. Two of the recycling methods were evaluated before and tomatoes grown in perlite recycled with either method was as productive as tomatoes grown in new perlite. In this study, the new and the previously evaluated methods had equal impact on plant yield, indicating that tomatoes grown in perlite recycled with the no stir/sift then disinfect method are expected to produce similar yield to tomatoes grown in new perlite.

Reusing perlite without disinfection to grow successive tomato crops is risky because of pest contamination. Hot water treatment raised perlite temperature higher than the lethal temperature range that killed fungi and nematodes known to cause economic tomato losses.

Recycling perlite with the no stir/sift then disinfect method can save the smaller grower significant amount of money and does not reduce tomato yield. It eliminates labor time and effort to remove old medium from the greenhouse, transport it to a land fill or a vacant field for disposal, and fill other bags with new perlite. This method should offer the smaller grower another tool to recycle perlite for cost-effective tomato production and save valuable natural resources.

The physical structure of recycled perlite may change over time, but field tomatoes are known to grow well in diverse soils ranging from fine sand to heavy clay with fine particles. We have been growing tomatoes in recycled perlite in part of our operations for 14 years with no negative impact on yield. Efficient management of limited-space greenhouse tomato operations by reducing production cost and improving plant yield should help smaller producers do well in a competitive market.

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