Report to the Pennsylvania Vegetable Research and Marketing Board
Cover Crops as a Solution to High Soluble Salt Levels in High Tunnels

Elsa Sánchez, Professor of Horticultural Systems Management
Tom Ford, Senior Extension Educator, Horticulture
Pennsylvania State University Department of Plant Science and Extension

Farmers across Pennsylvania need solutions for high soluble salts levels in their high tunnel soils. In 2017, with funding from the PVRMB, we worked with 27 farmers across Pennsylvania. We found soluble salts levels averaged 1.48 mmhos/cm, which is well above levels where yields of salt-sensitive vegetables are reduced. Salts accumulate from the use of fertilizers and organic nutrient sources. Interpretation of soluble salt levels is dependent on which testing method is used. Penn State University's Agricultural Analytical Services Laboratory uses the 1:2 (soil:water) method (Gartley, 2011). Soils with soluble salts levels of 1.48 are considered strongly saline, and only salt-tolerant crops, like beets, will grow well (AASL.psu.edu). Most of the 27 farmers told us they were unsatisfied with yields, mostly of tomatoes, from their tunnels, and in some cases, tunnels were taken out of production. While some of them knew about this issue, most did not.

Cover crops with tolerance to high soluble salts levels and that have large above-ground canopies, extensive root systems, and high transpiration rates have the potential to be used to extract salts from the soil. We have suggested this general option to farmers with high soluble salts levels but do not know which specific cover crop types are best for drawing down salt levels.

First Experiment

Study objective: We evaluated cover crops, cut flowers, and tomato cultivars for their ability to extract soluble salts as a solution for high tunnel soils.

How the study was conducted: The experiment was set up in a greenhouse at the Russel E. Larson Agricultural Research Center. Cover crops, cut flowers, and tomato cultivars (Tables 1 and 2) seeds were planted on May 26, 2021, and April 23, 2022, into 3-gallon grow bags filled with soilless potting medium. Seeds were watered with normal strength Hoagland's solution for one week. Plants were watered every other day with 250 mL of 1) normal-strength Hoagland's solution (normal-strength salt solution) or 2) Hoagland's solution + 150 mM NaCl (high-salt solution) beginning on week two. Treatments were arranged in a completely randomized design with three replications. Plant height was recorded weekly for 4 weeks once seedlings had germinated. Height data were converted to percent change in growth between each salt solution treatment in each block and analyzed using the mixed procedure in SAS. Means were separated using pdiff.

Results:

2021

On June 15, all plants receiving the normal-strength salt solution were taller than those receiving the high-salt solution. Winter rye and 'Red Russian' kale were significantly taller with high salt solution treatment than 'Oregon Spring' tomato, birdsfoot trefoil, 'New Girl' tomato, 'Wisconsin' tomato, and sugar beets (Table 1). Winter rye was significantly taller when watered with the high salt solution compared to 'Cauralina' tomato. Sorghum, 'Bolder' beet, and 'Royal' sunflower grew taller with the high salt solution compared to 'Oregon Spring' tomato and birdsfoot trefoil. All other plants were not different from each other.

By June 22, most crops did not significantly differ from each other in the percent change in height. However, birdsfoot trefoil, sorghum, buckwheat, and winter rye grew taller with the high salt solution than the normal-strength salt solution. Winter rye grew taller than all other crops receiving the high-salt solution, and sorghum and buckwheat grew taller than most other crops.

On the last date height was recorded, June 29, most crops receiving the normal-strength salt solution were taller than those receiving the high-salt solution. Rye remained the top performer compared to all other crops except sorghum. Sorghum outperformed most other crops.

2022

On May 14, sunflowers growing with the high salt nutrient solution were taller than those receiving the normal-strength nutrient solution and 'Roadster' tomatoes and malibar spinach were taller when receiving the normal-strength nutrient solution. The percent change in high between these crops was significant. All other crops were not significantly different from each other, or the sunflowers, 'Roadster' tomatoes, or malibar spinach for the percent change in height.

On May 22, sorghum, 'Red' beets, sunflowers, and winter rye growing with the high-salt nutrient solution were taller than those receiving the normal-strength nutrient solution, while 'Roadster' tomatoes and malibar spinach were taller when receiving the normal-strength nutrient solution. The percent change between these crops was also significant.

By May 29th, winter rye and sugar beets growing with the high-salt nutrient solution were taller than those receiving the normal-strength solution, while 'Roadster' tomatoes, malibar spinaches, 'Red Snapper' tomatoes, 'Thunderbird' tomatoes, 'Red Duce' tomatoes, and ornamental kale were taller when receiving the normal-strength solution. Additionally, the percent change in height between these crops was significant.

What the results mean: Some crops grew taller than others with the high-salt nutrient solution compared to the normal-strength salt solution and have the potential to be used to accumulate excess soluble salts in high tunnel soils. Winter rye, sugar beets, berseem clover, and sorghum may be options for cover crops when high soluble salts levels are observed in high tunnels. The key to using cover crops to remove excess soluble salts is to remove them from the high tunnel when they are terminated. Incorporating them back into the soil will add the excess salts back into the soil. Tomatoes did not respond well to the high-salt nutrient solution (Photo 1). By the first or second date height was recorded, plants were stunted compared to plants receiving a normal-strength nutrient solution. At the last date data were recorded, tomatoes receiving the high-salt solution were about 30 to 70% shorter than plants receiving normal-strength nutrient solution. The difficulty in visually identifying the issue with high soluble salts levels in high tunnel soils is that the salts are uniformly found throughout tunnels. This means that all the plants in the tunnel will be stunted because of high soluble salts levels, which masks the problem. If even one plant were not affected, it would be taller, and the stunting of plants throughout the tunnel would be evident. The solution to this issue is to determine the soluble salts levels in high tunnel soil with regular testing. This study provides evidence that certain cover crops can be used to remove excess soluble salts in soils from high tunnels.

Table 1. Percent change in high between plants receiving a normal-strength salt solution and plants receiving a high-salt solution at three dates in 2021. Crops in the purple text were used in the **second experiment** described below.

Crop	**Mean change in plant height (%)**		
	June 15, 2021	**June 22, 2021**	**June 29, 2021**
'Oregon Spring' tomato	0.63 a	0.62 a	0.59 a
Birdsfoot trefoil	0.60 a	-111E-18 a-b	0 ab
'New Girl' tomato	0.51 ab	0.51 a	0.32 a
'Cauralina' tomato	0.50 abc	0.53 ab	0.60 a
'Wisconsin' tomato	0.47 ab	0.50 a	0.68 a
Sugar beets	0.46 ab	<1 a-b	-222E-18 ab
Ornamental kale	0.40 a-d	0.58 a	0.55 a
'Balady 1' Berseem clover	0.26 a-d	0.36 a-c	0.08 ab
'CDC Copeland' barley	0.26 a-d	0.10 a-b	.28 a
'Boro' beet	0.25 a-d	0.38 a	.46 a
Buckwheat	0.22 a-d	-2.02 c	-
'Purple Majesty' millet	0.22 a-d	0.35 a	.22 a
WGF sorghum	0.19 b-d	-1.67 bc	-2.3 bc
'Bolder' beet	0.17 b-d	0.25 ab	.43 a
'Royal' sunflower	0.12 b-d	0.73 a	.78 a
'Red Russian' kale	0.04 cd	0.48 a	.54 a
Winter rye	0.03 d	-4.83 d	-4.7 c

Table 2. Percent change in high between plants receiving a normal-strength salt solution and plants receiving a high-salt solution at three dates in 2022.

Crop	**Mean change in plant height (%)**		
	May 14, 2022	**May 22, 2022**	**May 29, 20200**
'Roadster' tomato	0.42 a	0.56 a	0.61 a
Malibar spinach	0.35 a	0.51 ab	0.52 ab

'Red Snapper' tomato	0.29 ab	0.41 abc	0.45 abc
Birdsfoot trefoil	0.26 ab	0.14 abc	0.29 abcde
'Thunderbird' tomato	0.25 ab	0.38 abc	0.38 abcd
'Red Duce' tomato	0.25 ab	0.36 abc	0.37 abcd
'Purple Majesty' millet	0.23 ab	0.08 abc	0.04 abcdef
'Patsy' tomato	0.16 ab	0.31 abc	0.33 abcde
'CDC Copeland' barley	0.11 ab	0.27 abc	-0.03 cdef
'Bolder' beet	0.07 ab	0.22 abc	-0.01 bcdef
WGF sorghum	0.05 ab	-0.01 c	-0.09 def
'Balady 1' berseem clover	0.04 ab	0.03 bc	-0.14 def
'Red Russian' kale	0.02 ab	0.14 abc	-0.01 bcdef
Sugar beets	0.02 ab	0.09 abc	-0.19 ef
Buckwheat	-0.01 ab	0.12 abc	0.27 abcde
Ornamental kale	-0.03 ab	0.34 abc	0.34 abcd
Winter rye	-0.09 ab	-0.54 d	-0.37 f
'Red' beet	-0.09 ab	-0.10 cd	-0.05 cdef
'Royal' sunflower	-0.26 b	-0.13 cd	0.26 abcde

How to read Tables 1 and 2: Each value is the mean of how each crop grew with the high-salt solution compared to the normal-strength salt solution. Values near zero indicate that plants grown with the normal-strength and high-salt solution were close in height. Positive values mean the plants grew taller with the normal-strength salt solution compared to the high-salt solution. Negative values mean the plants growing with the high-salt solution grew taller than those watered with the normal-strength salt solution. For example, using Table 1, on June 15, 'Oregon Spring' tomatoes growing with the high-salt solution were 63% shorter than plants growing with the normal-strength salt solution.

Photo 1. The tomato plant on the left received the normal-strength salt solution. The one on the right received the high salt solution.

Second Experiment

Study objective: We further evaluated a subset of crops from the first experiment for their ability to extract soluble salts from soils.

How the study was conducted: The first run of this experiment was set up in a greenhouse at the Russel E. Larson Agricultural Research Center in Rock Springs, PA, and the second in a greenhouse at Pennsylvania State University in University Park, PA. Crops (Tables 1 above) were seeded on August 2, 2022, and October 16, 2022, into 3-gallon grow bags filled with soilless potting medium. Seeds were watered with tap water for one week. Beginning on week two, they were watered every other day with 250 mL of 1) normal-strength Hoagland's solution (normal-strength salt solution), 2) Hoagland's solution + 75 mM NaCl (medium-salt solution), or 3) Hoadland's solution + 150 mM NaCl (high-salt solution). Treatments were arranged in a completely randomized design with three replications. On September 11, 2022, and November 28, 2022, above-ground tissues were sent to Pennsylvania State University's Agricultural Analytical Services Laboratory for analysis. A statistics graduate student analyzed data for an M.S. project.

Results and Discussion:

Two-way ANOVA with replications revealed no interaction between the crops and nutrient treatments (Table 3 below).

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
crop	5	585851871.1	117170374.2	2.51	0.0291 *
soln	2	359882265.1	179941132.6	3.85	0.0217 *
crop*soln	10	194774238.9	19477423.9	0.42	0.9388

Table 3: Analysis of variance of the full model

The normality assumption was violated even after data were log-transformed; therefore, non-parametric analysis with the Kruskal-Wallis Test was used (Tables 4 and 5 below). No significant differences between crops or nutrients were observed.

Kruskal-Wallis Test		
Chi-Square	DF	Pr > ChiSq
7.2740	5	0.2011

Table 4: The Kruskal-Wallis Test for types of cover crop

Kruskal-Wallis Test		
Chi-Square	DF	Pr > ChiSq
0.1083	2	0.9473

Table 5: The Kruskal-Wallis Test for types of solution

Figure 1 (below) shows box plots of the concentration of nutrients in each crop evaluated. Notice the nutrient concentrations of berseem clover, winter rye, and sorghum are slightly higher for plants receiving the medium- and high-salt treatments compared to the normal-strength nutrient treatment. These crops have the potential to bioaccumulate excess nutrients and will be further evaluated in 2023 with funding from the USDA.

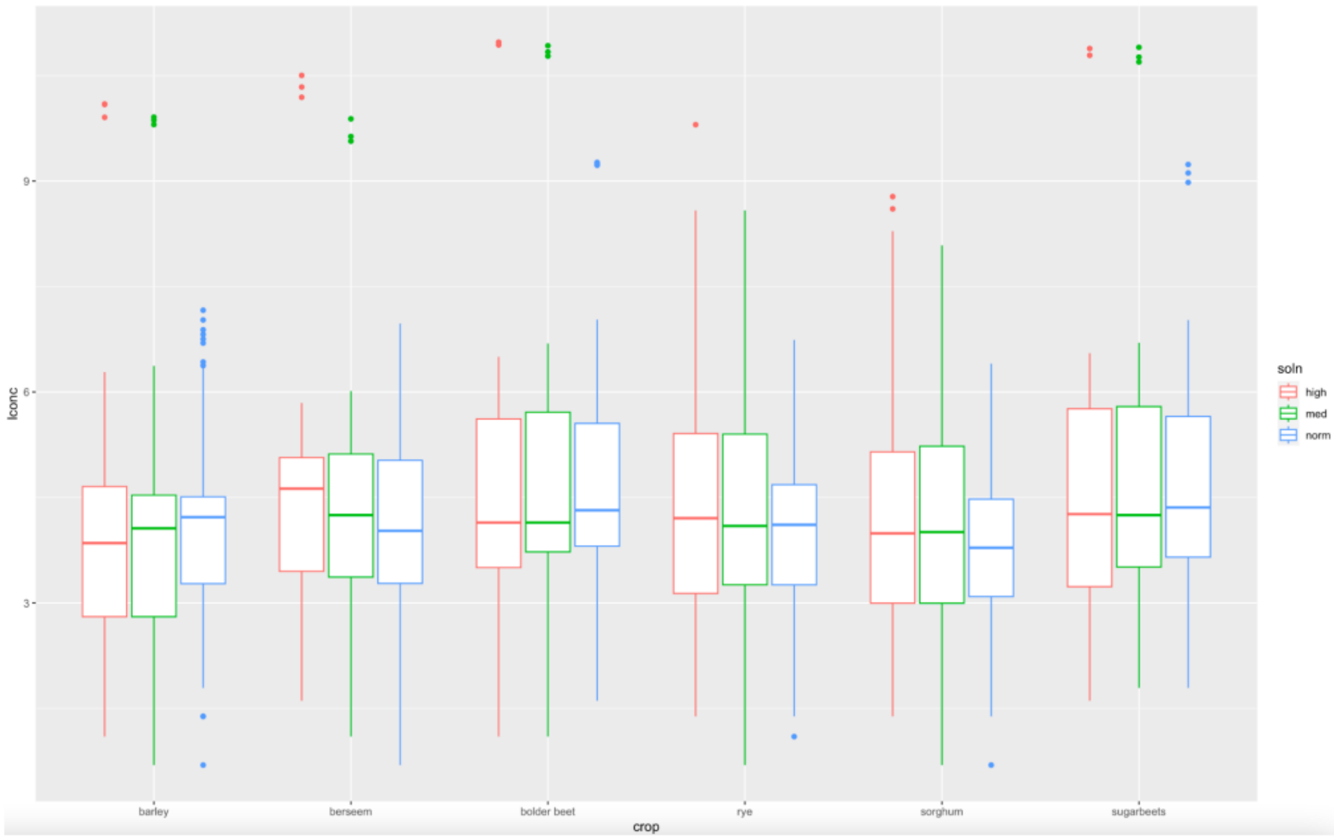

Figure1: Box plot of concentration by cover crops and solutions after transformation

Acknowledgments: Chris Sánchez and Austin Kirt of the PSU Hort Farm Crew and Alan Bauman and Emily Betler, undergraduate, helped make this project successful.