Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Fakulteten för landskapsplanering, trädgårds- och jordbruksvetenskap

Effect of Vortex-processed Water on Tomato (*Solanum lycopersicum*) Plants

Effekt av vortex-behandlat vatten på tomat (*Solanum lycopersicum*) småplantor

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Abstract

This pilot study examined whether treatment with Vortex Process Technology (VPT) of the irrigation water used on tomato (*Solanum lycopersicum*) plants had any effect on plant growth. In a block experiment, with two blocks comprising 12 vases containing 1 L water and two tomato plantlets, treatment in which, nutrient solution was based on Vortex-treated water was compared with an control using untreated water. All vases were kept in a static aerated culture system in a daylight chamber for four weeks. The results showed that the effect of the two blocks exceeded the effect of vortex treatment in terms of leaf area and weight of fresh and dry matter. Plant height, stem width and internodal length were significantly different in tomato plants grown in Vortex-processed water compared with the untreated control. Number of leaves did not vary between the treatments. The study focused only on the early plant growth phase and no other influencing factors were studied.

Sammanfattning

I föreliggande pilotstudie undersöktes inverkan av näringslösning som bereddes på vatten behandlad med Vortex Process Technology, VPT, på tomat (*Solanum lycopersicum*) småplantor. Studien genomfördes som ett blockförsök, med två block och tolv enlitersvaser per block. I varje vas fanns två plantor. Plantor i kontrolledet odlades i näringslösning beredd på obehandlat vatten. Försöken genomfördes I en dagsljuskammare under fyra veckor i ett hydroponiskt system. Resultaten visade att effekten av blocken var större än effekten av behandlingen med hänsyn till bladstorleken samt färsk- och torrvikt. Planthöjden, stamdiametern samt internodländgen påverkades signifikant. Antal blad varierade inte mellan behandlingarna. Föreliggande studie fokuserade enbart på småplantstadium. Inga andra påverkande faktorer undersöktes.

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1 Introduction

1.1 Background

Water is a liquid that is able to dissolve many substances, in fact it is more capable than most other liquids and have because of this specific trait been called the universal solvent. Water dissolves and carries carries along with it valuable chemicals, minerals and nutrients, thus making it essential for life (http://ga.water.usgs.gov/edu/solvent.html, 2012).
The water molecule is an ampholyte, meaning that it can react as both an acid and a base, creating equal numbers of hydroxide (OH^-) and hydronium (H_3O^+) ions. The concentration of H_3O^+ and OH^- is 10^{-7} mol dm^3 and the pH of pure water is consequently 7 (Nationalencyklopedin, 2012).

The concentration of ions is low in clean water, which results in low electric conductivity. Under normal pressure, water has a boiling point of 100°C and a freezing point of 0°C. These abilities are the result of hydrogen bonding between the molecules (Toole & Toole, 1987). Without this, the boiling point of water would be -80°C.
The hydrogen bonds create a fluctuating network in the liquid. When freezing the water forms a more strict structure. The H_20 molecule, which is build up of two hydrogen atoms and one oxygen atom in a nonlinear arrangement, is ideally suited to be involved in hydrogen bonding. The water molecule can act both as a donor and as an acceptor of hydrogen atoms (Stillinger, 1980).

To melt 1 kg of ice at 0°C, 334 kJ of energy are needed and when the ice is melting some of the hydrogen bonds are broken. This leads to a more compact structure and a higher density. With rising temperature, the hydrogen bonds break and the density increases. The water molecules start to move as the temperature rises and need more space (Nationalencyklopedin, 2012).

Water reaches its highest density at +4°C. The amount of energy needed to heat 1 kg of water to a temperature of 25°C is 4.179 kJ, which is a very high amount of energy compared with that needed to heat other similar substances. This also applies to the high surface tension ($7.196x\ 10^{-2}$ N m^{-1} at 25°C) and viscosity ($8.904x\ 10^{-4}$ Pa s at 25°C) (Ayrapetyan et al., 2006;

Nationalencyklopedin, 2012).
The polar abilities and hydrogen bonds of water imbue it with superb solvent properties for salts and molecules with polar groups. The substances that solve in water are called hydrophilic and those which do not are called hydrophobic. These abilities are of great importance in nature (Nationalencyklopedin, 2012).

Water is important to many functions in plants. It is a photosynthetic substrate, supports the plant (turgor pressure) and is used to hydrolyse proteins, amino acids, fats and glycerol. Due to its solvent properties plants are dependent on the function of water in dissolution, uptake and transport of nutrients inside the plant (Toole & Toole, 1987).

Water also plays many other roles in complex biological interactions, filling gaps and cavities and fulfilling unsatisfied hydrogen bonds (Raschke, 2006).

All water movement in plants is passive, with no claim of active transportation having ever been proven, which means that other relationships decide plant uptake of water (Baird & Wilby, 1999). Passive movements are defined as spontaneous movements. Such movements in a system already out of equilibrium means that it always strives towards equilibrium, through an active movement in the opposite direction. However, an active movement needs biological energy and sets the system further away from equilibrium, while the passive movement can be viewed as a counter-direction. Passive movement of water or a substance occurs when it moves from a location where it has higher energy to one where it has lower energy. This can be compared with going downhill on a bicycle, where it is easier to go from a high point to a low. Water will flow into a cell whenever the water potential outside the cell is greater than that inside the cell (Baird & Wilby, 1999). Water uptake and loss are strongly related to plant leaf surface area and roughly 90% of water loss is due to transpiration. Higher transpiration means more uptake of water. Plant transpiration is dependent on external (environmental) and internal factors. External factors include humidity (or vapour pressure), temperature, wind speed, light (intensity and length of day) and, of course, water availability (Baird & Wilby, 1999).

Water tends to form clusters and these clusters constitute the basic structure of water. The long hydrogen bonds in water have an electrostatic nature and are weak in energy. As the water structure is sensitive to environmental factors, the structure continuously changes (Ayrapetyan et al., 2006).

Since water molecules move rapidly in a liquid state (as fast as one pico second, 10^{-12} s) it is almost impossible to give water a determined structure. However in the solid phase (ice), the molecules form a tetrahedral network, a structure that has been used as a model for the structure of liquid water (Stillinger, 1980; Nationalencyklopedin, 2012).

1.2 Vortex Process Technology (VPT)

The company Watreco has developed a patented treatment for water called Vortex Process Technology (VPT).

The process is based on different types of natural movements in water bodies. The technique imposes a strong centrifugal movement of the water at a at a low flow rate and pressure (Watreco, 2012). The Vortex generator consists of three units that are supposed to alter the fluid flow: a preformer, channels and a Vortex chamber. These three units work together to form a stable vortex flow and this flow should then cause reduced pressure and a subpressure along the vortex axis. The result is said to be a shift in chemical balance and under some circumstances cause formation, aggregation and fragmentation of solid matter (Watreco, 2012).

According to the company's information, water treated with the Vortex process has reduced viscosity. Bubbles of undissolved gases are said to be eliminated in the VPT process, which leads to a decline in viscosity of between 3% and 17% depending on the water quality and temperature. The oxygen level is reported to be higher and the lime content reduced (Watreco, 2012).

A change in heat capacity has also been observed, with 5% higher heat capacity for ice and 3% for liquid water. A higher level of electric conductivity has also been observed, 3% higher than in untreated water. Whether this is the result of the lower viscosity or a change in charged particles or ions in the water remained to be determined. The studies in this these results were found were conducted by PTG, Eindhoven, the Netherlands (website: http://www.ptgeindhoven.nl/) (Watreco, 2012).

1.3 Aim of the study

The aim of this pilot study was to examine whether treatment of the water used in nutrient solution with the VPT process has any effect on the early growth of tomato plants compared with nutrient solution based on non-treated water.

1.4 Hypothesis

The starting hypothesis was that: Tomato plants grown in nutrient solution based on VPT-processed water do not differ from tomato plantlets grown in nutrient solution based on non-treated water with respect to vegetative parameters.

2 Materials and methods

The impact of vortex-processed water on tomato plants was studied in a block experiment with two blocks and two treatments. In treatment 1, the water used for preparation of the nutrient solution was vortexed using the Vortex generator (Watreco, Malmö, Sweden), while in treatment 2 (control treatment), the water used for nutrient solution preparation was not vortex-processed.

Tomato seedlings (*Solanum lycopersicum* cv "Tiësto") were germinated for five days at 25°C under dark conditions for each block separately. Block 2 was germinated one week after block 1. After five days, seedlings were transferred at a density of two seedlings per unit to plastic 1-L vases in a static aerated culture system as described earlier by Benton Jones (1982). Oxygen was supplied by pumps and the nutrient solution was exchanged every second day. The plants were held in place in the vases by plastic holders and trolleys were used to hold three vases, which were distributed randomly in a daylight growing chamber at the Alnarp phytotron (Figure 1). The plants were grown for four weeks with relative humidity 80%, day length 16 hours (04:00-20:00) and extra light provided by four high-pressure sodium lamps (400 W) all day. The temperature set point was 20°C day and 20°C night.

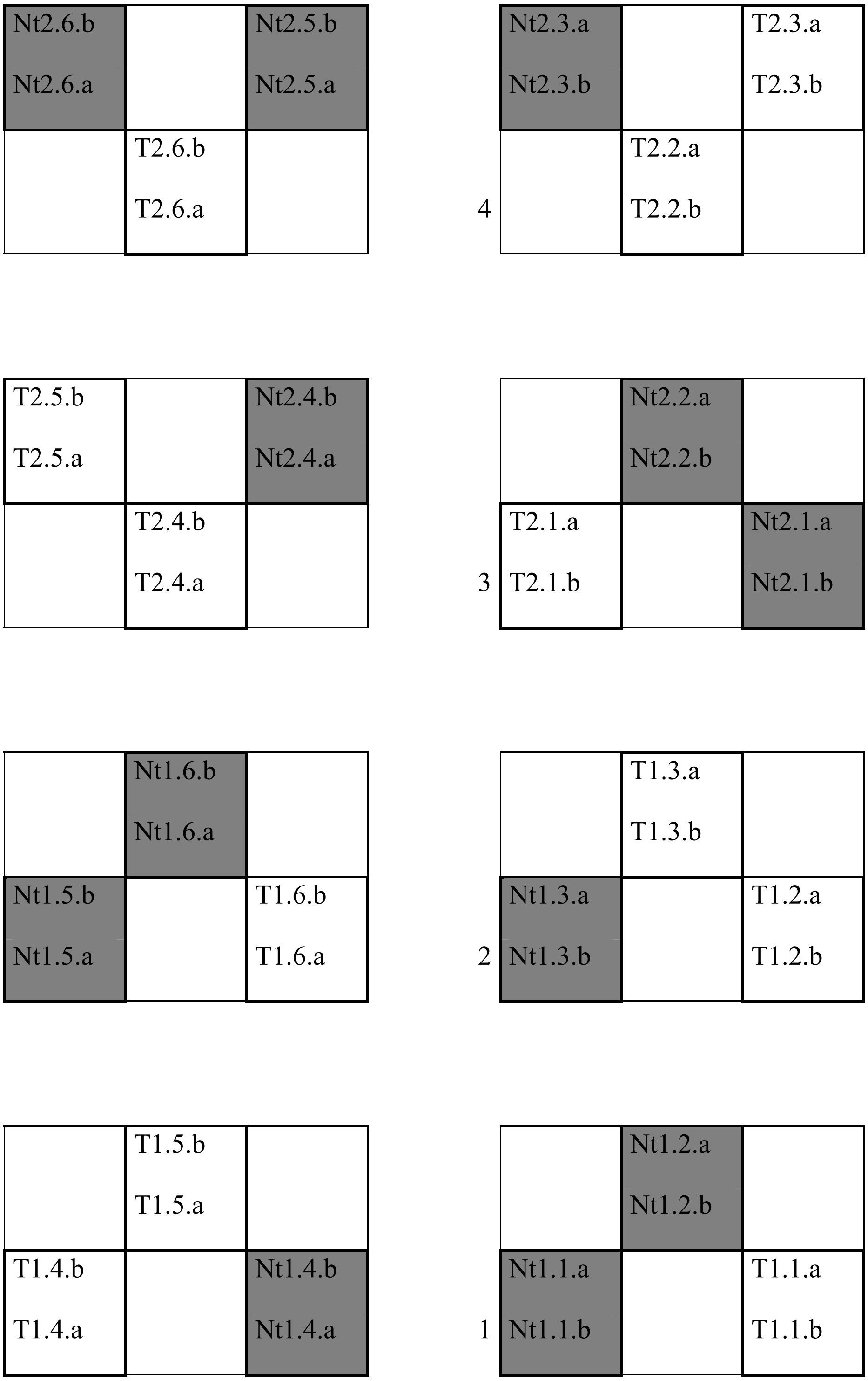

Figure 1. Distribution of treatment in the daylight chamber. Tomato plantlets were grown in two blocks (1,2) with six individual replicates (1-6) in static aerated culture for 4 weeks with or without exposure to vortex-processed water at a density of two seedlings per vase (a,b). Each grey square symbolises a vase with nutrient solution based on treated water (T), and each white square (Nt) a vase with nutrient solution based on non-treated water.

Nutrient solution was freshly prepared before the nutrient solution was exchanged. Water was treated with the VPT process before the nutrients were added. In both the treated and control solutions, tap water was used and not de-ionised water. The nutrient solution was customised for tomato plants from week 1 to week 4, see Table 1.

Table 1. *Nutrient solution used for tomato plants in the hydroponic system from week 1 to week 4 (Jung et al., 2004)*

Macronutrient	**Amount (moles)**			
	week 1	**week 2**	**week 3**	**week 4**
KNO_3	0.09 M	0.104 M	0.11 M	0.114 M
$Ca(NO_3)_2*4H_2O$	0.1 M	0.11 M	0.116 M	0.120 M
$MgSO_4$	0.03 M	0.03 M	0.03 M	0.03 M
KH_2PO_4	0.036 M	0.04 M	0.04 M	0.044 M
K_2SO_4	-	-	-	-
$Mg(NO_3)_2$	0.01 M	0.01 M	0.01 M	0.01 M
NH_4NO_3	-	-	4 mM	0.01 M
FeEDTA	0.37 mM	0.365 mM	0.4 mM	0.7 mM
Micronutrient				
$MnSO_4*2H_2O$	0.15 µM	0.25 µM	0.25 µM	0.25 µM
$ZnSO_4*7H_2O$	0.08 µM	0.13 µM	0.13 µM	0.13 µM
H_3BO_3	0.38 µM	0.63 µM	0.63 µM	0.63 µM
$CuCl_2*2H_2O$	0.01 µM	0.02 µM	0.02 µM	0.02 µM
$Na_2MoO_4*2H_2O$	0.0075 µM	0.0125 µM	0.0125 µM	0.0125 µM

Six independent replicates [vases] were used per treatment and block.

On harvest of the tomato plants, a number of growth parameters were measured. These included the height of the tomato plants from the top of the plastic holder to the last visible node. Plant stem width was measured 0.5 cm under the cotyledons with a pair of callipers (only one measurement per plant). Number of leaves >1.5 cm was counted. Leaf area was measured with a LI-3100 area meter (LI-COR inc., Lincoln Nebraska, USA).

Fresh and dry weight were measured, with roots and green parts weighed together and separately. Roots and green parts were then placed in separate metal foil pouches re-weighed and marked and placed in a heating cabinet for 1 week at 70°C. The pouches were weighed immediately after being removed from the heating cabinet.

When calculating and analysing the results, one vase was counted as one tomato plant.
Each block was counted separately. When calculating significant differences, the Tukey t-test was used, with $p < 0.05$ taken to indicate statistical significance.

3 Results

With regard to leaf area, the block effect was stronger than the effect of the vortex treatment (Figure 2). In blocks 1 and 2, leaf area showed no significant difference in plants that were grown in nutrient solution based on vortex-processed water compared with the control water. However, there was a significant difference in leaf area between block 1 and 2.

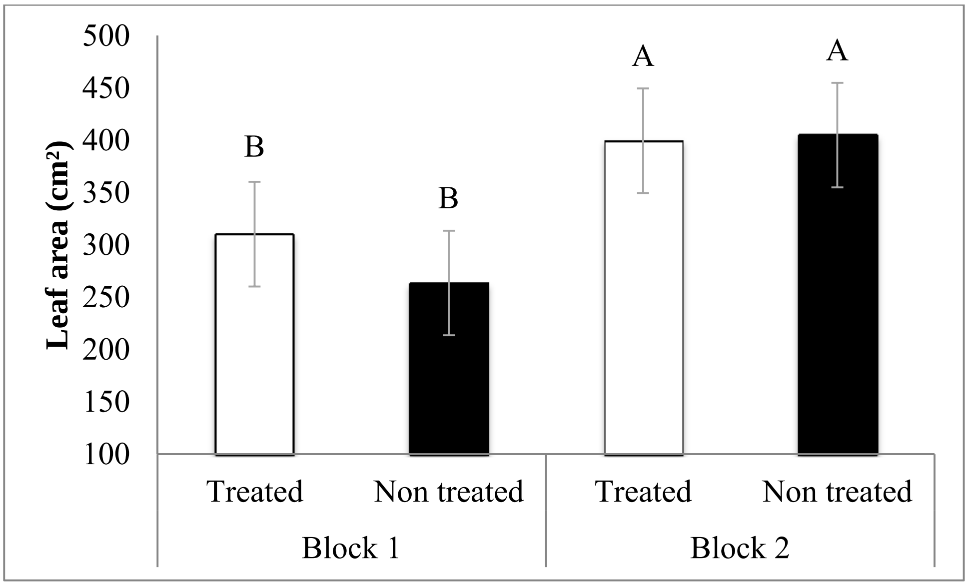

Figure 2. Leaf area (cm^2) of tomato plants grown in nutrient solution based on treated and non-treated water. In the treated blocks, the water used for nutrient solution preparation was vortexed using the VPT generator (Watreco, Malmö, Sweden). The tomato plants were grown in 1-L containers (two plants per container) in static aerated culture for four weeks in a daylight chamber before harvest (n=6). Bars labelled with different letters are significantly different ($p<0.05$; Tukey's t-test).

In both blocks, the standard deviation was considerably higher in plants exposed to nutrient solution based on treated water than in control plants.

The height of the tomato plants was affected by the type of water from which the nutrient solution was prepared. At the end of the experiment, the 4-week-old plants grown in nutrient solution based on vortexed water were longer than those grown with non-treated water (Figure 3). This difference was apparent in both blocks.

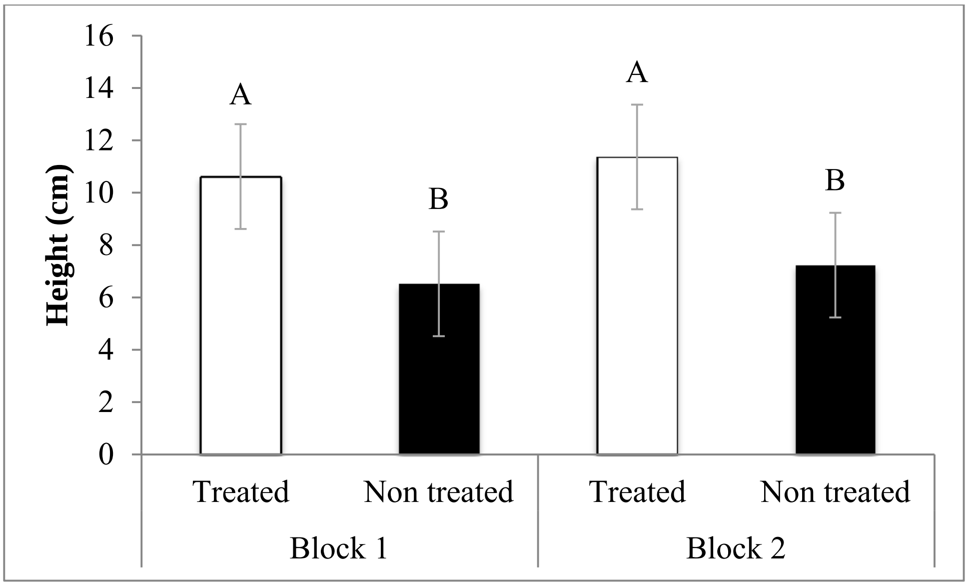

Figure 3. Plant height (cm) of tomato plants grown in nutrient solution based on treated and non-treated water. In the treated blocks, the water used for nutrient solution preparation was vortexed using the VPT generator (Watreco, Malmö, Sweden). The tomato plants were grown in 1-L containers (two plants per container) in static aerated culture for 4 weeks in a daylight chamber before harvest (n=6). Bars labelled with different letters are significantly different ($p<0.05$; Tukey's t-test).

There was no significant difference in average number of leaves in between block 1 and 2 or between plants that received vortex-processed water and control plants (Figure 4). However, there was a tendency for the plants in block 2 to have more leaves than those in block 1. The plants exposed to nutrient solution based on vortex-processed water had significantly longer internodes than control plants exposed to nutrient solution based on non-treated water (Figure 5). This trend of tomato plants being more elongated in the vortex-treated water than in the control was evident in both blocks.

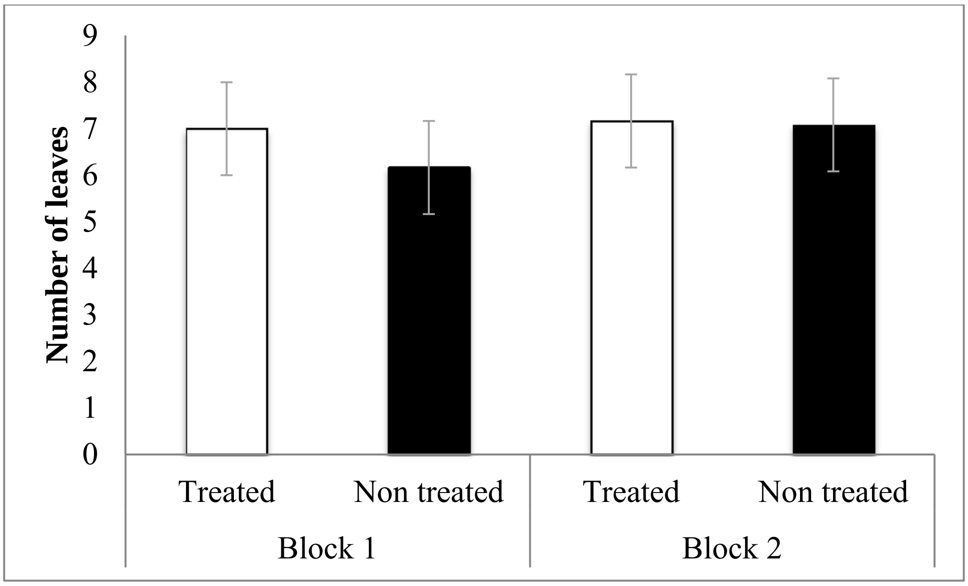

Figure 4. Average number of leaves per tomato plants grown in nutrient solution based on treated and non-treated water. In the treated blocks, the water used for nutrient solution preparation was vortexed using the VPT generator (Watreco, Malmö, Sweden). The tomato plants were grown in 1-L containers (two plants per container) in static aerated culture for four weeks in a daylight chamber before harvest (n=6).

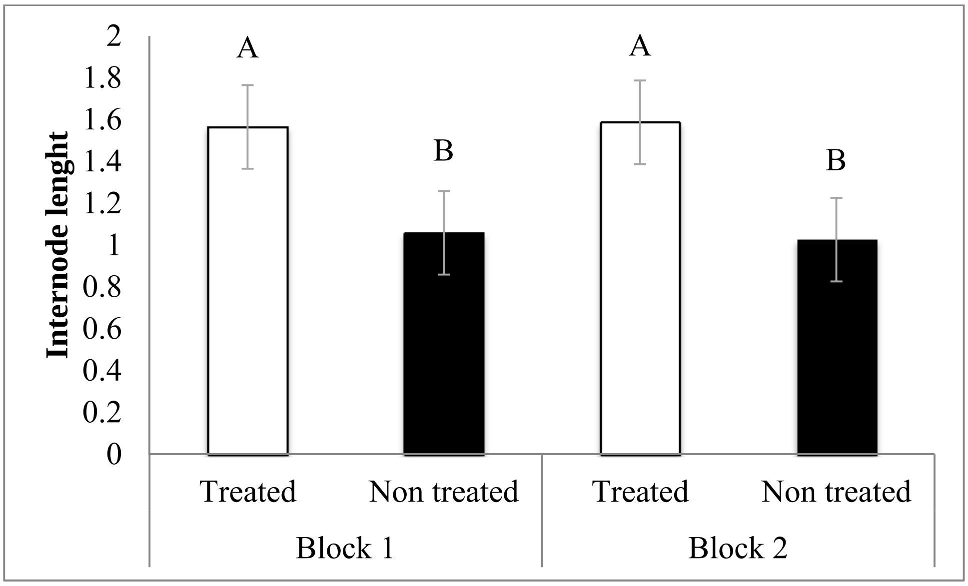

Figure 5. Internode length (cm) of tomato plants grown in nutrient solution based on treated and non-treated water. In the treated blocks, the water used for nutrient solution preparation was vortexed using the VPT generator (Watreco, Malmö, Sweden). The tomato plants were grown in 1-L containers (two plants per container) in static aerated culture for four weeks in a daylight chamber before harvest (n=6). Bars labelled with different letters are significantly different ($p<0.05$; Tukey's t-test).

The stem width of tomato small plants exposed to nutrient solution based on treated water and of control plants was very similar in blocks 1 and 2 with the exception of block 2 control plants, which had a significantly narrower stem than plants in all other treatments (Figure 6).

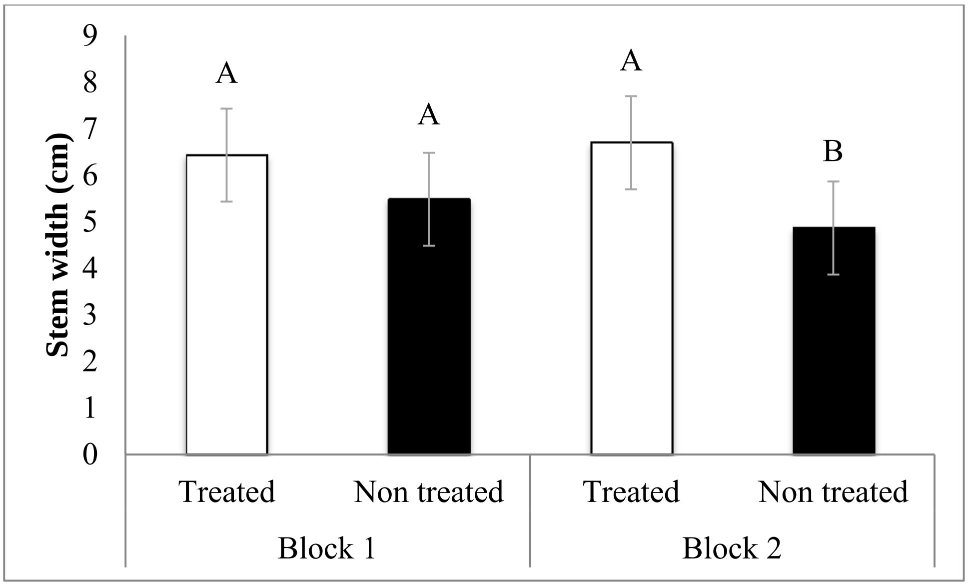

Figure 6. Stem width (cm) of tomato plants grown in nutrient solution based on treated and non-treated water. In the treated blocks, the water used for nutrient solution preparation was vortexed using the VPT generator (Watreco, Malmö, Sweden). The tomato plants were grown in 1-L containers (two plants per container) in static aerated culture for four weeks in daylight chamber before harvest (n=6). Bars labelled with different letters are significantly different ($p<0.05$; Tukey's t-test).

Average weight of fresh and dry matter showed no significant difference between the treatments in either block (Table 2). However, as before, the difference between block 1 and block 2 was significant. The standard deviation was higher amongst tomato plants exposed to the nutrient solution based on vortex-processed water than among control plants.

Table 2. *Average weight of fresh and dry matter and water content of tomato plants grown in nutrient solution based on treated and non-treated water. In the treated blocks, the water used for nutrient solution preparation was vortexed using the VPT generator (Watreco, Malmö, Sweden). The tomato plants were grown in 1-L containers (two plants per container) in static aerated culture for four weeks in a day light chambers before harvest (n=6)*

		Average fresh weight (g)	Standard deviation	Average dry weight (g)	Standard deviation	Water content (%)
Block 1	**Treated**	12.93	4.99	3.35	0.41	93.3
Block 1	**Non-treated**	10.97	4.82	3.6	0.49	92.6
Block 2	**Treated**	21.27	3.4	4.9	0.33	91.6
Block 2	**Non-treated**	20.81	3.14	4.78	0.3	92

4 Discussion

The results obtained in this experiment partly contradict the starting hypothesis of no significant difference between treatments. Number of leaves, weight of fresh and dry matter and leaf area were not affected by the treatment. However, plant length and internode length were significantly greater in tomato plants grown in nutrient solution prepared with vortex-processed water. Stem width was significantly lower in block 2, where control plants were smaller, but not in block 1. The standard deviation was higher in tomato plants exposed to vortex-processed water in both blocks, meaning that these plants were much more variable than those grown using non-treated water. As a consequence, the adult plants might also give varied yield.

The vortexed water, when prepared, always had a higher electrical conductivity (EC) than the non-treated water (2.5dS m^{-1} in non-treated compared with 2.8-2.9 dS m^{-1} in treated). This is also one of the previously reported effects of the VPT treatment on water (Watreco, 2012). The difference in plant height and internode length between the two treatments can be because of the higher EC in the nutrient solution based on vortex-processed water. However, in previous studies EC only had an effect on plant elongation at much higher EC values (> 6 dS m^{-1}) than that of the vortex-processed water, in which cases it reduced internode length (Li and Stanghellini, 2001). Higher availability of nutrients in the water at this stage might also have given the tomato plants in vortex-processed water a slight advantage. Carbon dioxide (CO_2) enrichment has been shown to produce taller plants (Heuvelink, 2005), but in the present study no CO_2 was injected into the daylight chamber and the ambient level was not measured.

High internode length increases plant length, which could result in difficulties with crop management. However, shorter internode length may inhibit net assimilation rate (Wahundeniya et al., 2006).
The obvious difference between block 1 and 2 in leaf area (see Figure 2) might have been because block 2 was placed out in the phytotron one week later than block 1, resulting in better daylight conditions (Heuvelink, 2005). There may also have been differences in the germination process, e.g. block 1 might have had a slower start due to some form of light stress. The leaves of block 1 plants when put out in the phytotron were pale and the root was elongated, but there was no sign of a stem. Block 2 plants had better coloration on both stem and leaf. The results might also have been affected by a nutrient deficiency that was discovered in week 3, which was thought to be manganese deficiency due to the pale, thin leaves. The reasons for this deficiency are unknown, but it may have been due to pH or water quality (Jung et al., 2004).

In conclusion, use of vortex processing in the present study to treat the nutrient solution used for tomato plants gave mixed results. The present results need to be verified in further studies. They also need to be assessed from an agronomic point of view.

5 Conclusions

Based on the results of the present study, it can be concluded that use of VPT for preparation of nutrient solution can affect tomato plant height and internode length.

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