A New Hydroponic Substrate
GREENHOUSE TOMATO CULTIVATION ON GROWSTONES GROW BAGS

A comparison between cultivation on Growstones and Rockwool
Written by Paula Costa, Ph.D
Director of Research & Development and Technical Support, Growstone, LLC

SUMMARY
Tomato fruit production and fruit quality were compared for the tomato variety *Mecano* (Rijkzwaan), which was hydroponically grown in both Growstones and stonewool (also known as Rockwool) substrates at the Wageningen University and Research Center (WUR)[1], The Netherlands, in 2007. The trial clearly confirmed previous results in which the cultivation of cucumbers in Growstones offered several advantages over stonewool. The most important advantage in the tomato trial was the high steer-ability of Growstones, a rigid porous recycled glass substrate, over Rockwool. Growstones was confirmed not only to be a highly steer-able substrate, it was also proven to be a naturally more reproductive substrate. As a result, it was easier to steer the tomato crop towards a balance from an initially overly vegetative crop growth pattern. This resulted in a fruit production that at times was significantly higher than plants grown in Rockwool. In the tomato crop grown in Rockwool, BER occurrence associated with a longer response time to reproductive environmental measures arose, delaying fruit development and decreasing Rockwool final yields.

Another important finding was the significantly high and natural release of silicon from the Growstones over time, which accumulated in the leaves of plants in Growstones. The beneficial effect of silicon accumulation in the leaves of several vegetable and flower crops against fungal diseases and perforating insects has been well documented in literature. This benefit was also demonstrated in the 2006 Growstones cucumber trial at the same Research Center (WUR), where the incidence of Phythium was significantly lower in Growstones compared to Rockwool.

INTRODUCTION
Awareness of the environmental impacts of the hydroponic industry have already affected government policies and changed growers' practices in The Netherlands. Looking to increase control over the water content in the root zone environment at any time of day, large-scale growers all over the world are testing drier aggregate based substrates. Simultaneously, there is increasing interest in finding more environmentally sustainable alternatives to strip-mined substrates such as Rockwool and perlite. These actions are in line with mandatory government policies to promote growers' adoption of practices that increase production efficiency of energy and fertilizer inputs, while minimizing the environmental impact of the hydroponic industry.

Growstones, made from recycled glass bottles, are 35% drier than Rockwool and serve the drier root zone requirements of crops such as tomatoes and cucumbers, while also fulfilling the required move to environmentally sustainable practices.

EXPERIMENT
The tomato trial was conducted in a Venlo-type glass greenhouse at the Wageningen University and Research Center (WUR)[1], in The Netherlands. The crop season was March 20 to October 17, 2007. Rockwool cubes and blocks were used for germination in both treatments. Plant density was initially 2.14 plants per m^2 single head; and 3.2 plants per m^2 after week 21. Day/night temperature regime was 22/20 ºC (71.6/68^o F). Photoperiod was extended to 16 hours per day with assimilation lights from 4:00 pm to 8:00 pm (160 µmoles PAR). The irrigation volume per day was 110 ml per cycle in Rockwool and 55 ml in

Growstones. Maximum irrigation interval was 2 hours. Drainage percentage was kept at 30% in Rockwool and 50% for Growstones. Drainage water from lysimeter units for each substrate was kept separate for evaluation of transparency and pH stability. In both cases, drainage water from all the treatments in this greenhouse compartment, as well as from the entire WUR Research Center complex, was collected in one central storage tank. As a result there was no accumulation or depletion typically associated with recirculation systems, and the drainage system was defined as an apparent free drainage system. A standard tomato nutrient solution was delivered to both substrates and corrected on central tank sampling.

Figure 1. Tomato seedlings right after transplant; not yet in the planting hole but connected to the drippers.

RESULTS

Yields

Fruits were harvested twice a week from May 25 until October 17, 2007. Initially yields from Growstones and Rockwool were similar. After a while Growstone yields were significantly higher than Rockwool. This difference was due to the intense incidence of BER in Rockwool plants, which naturally reduced marketable yields in Rockwool (Figure 2).

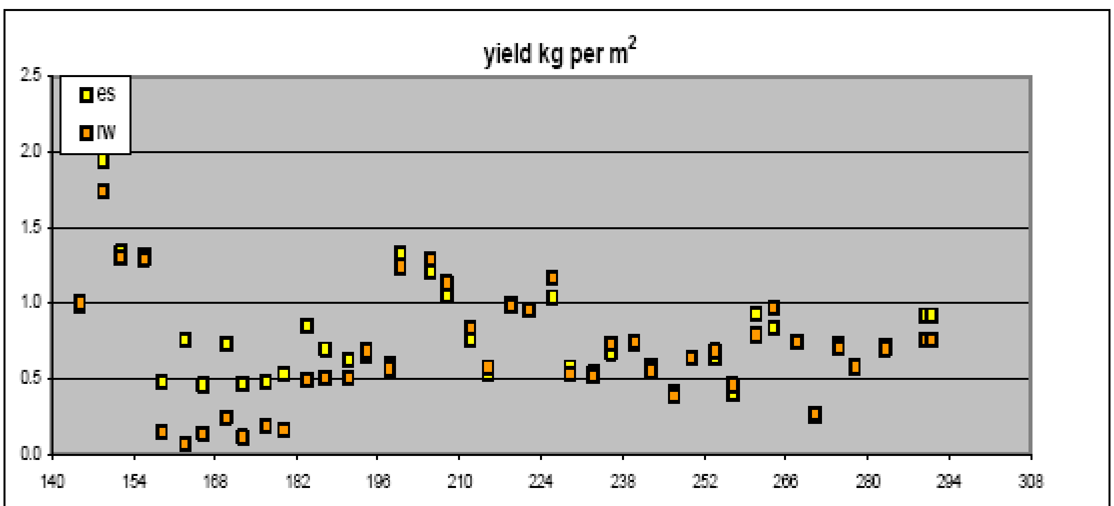

Figure 2. Tomato yields (kg/m^2) in each harvest in Growstones (es) and Rockwool (rw) during the crop season.

Yields per harvest date were higher in Growstones than Rockwool between day 159 and 191 (Figure 2). The lower yields were due to higher incidence of BER in Rockwool plants during that period. Under these specific growing conditions, BER incidence in Growstones was two times lower than Rockwool.

For statistical analysis, yields were divided into 3 distinct periods (Table 1). Period 1 ran from the onset of harvest on May 25 to June 5. Period 2 began when BER first appeared on June 6 and lasted until July 13, when BER was no longer present. Period 3 started on July 19 and lasted until the end of the crop on October 17.

Table 1. Daily tomato marketable yield in Growstones and Rockwool (kg per m^2) with the probability estimate.

Date	Earthstone $Kg.m^{-2}$	Rockwool $Kg.m^{-2}$	F.probability
May 25	0.98	1.00	0.937
June 1	1.33	1.29	0.742
June 5	1.32	1.29	0.862
June 8	0.47	0.15	<0.001
June 19	0.73	0.24	<0.001
July 10	0.62	0.50	0.002
July 19	1.32	1.24	0.186
August 14	1.04	1.17	0.122
September 11	0.63	0.68	0.365
October 2	0.72	0.70	-0.688

During periods 1 and 3, there were no statistical differences in yield between the two substrates. However, in period 2 yields were significantly higher in Growstones for all harvest dates (Table 1). This was the result from heavy BER incidence in fruits on highly vegetative plants in Rockwool. Yields in Rockwool were aggravated by the longer time these plants took to respond to environmental and crop management strategies to steer the plants out of an overly vegetative growth pattern and into a balance.

On the contrary, plants grown in Growstones, which initially showed the same overly vegetative tendencies, responded quickly to the same strategies. The higher steer-ability observed in Growstones substrates is thought to be directly related to its drier nature and subsequent greater ease in controlling the moisture content of the root zone at all times compared to Rockwool.

As a result, cumulative yields were higher in Growstones (Figure 3).

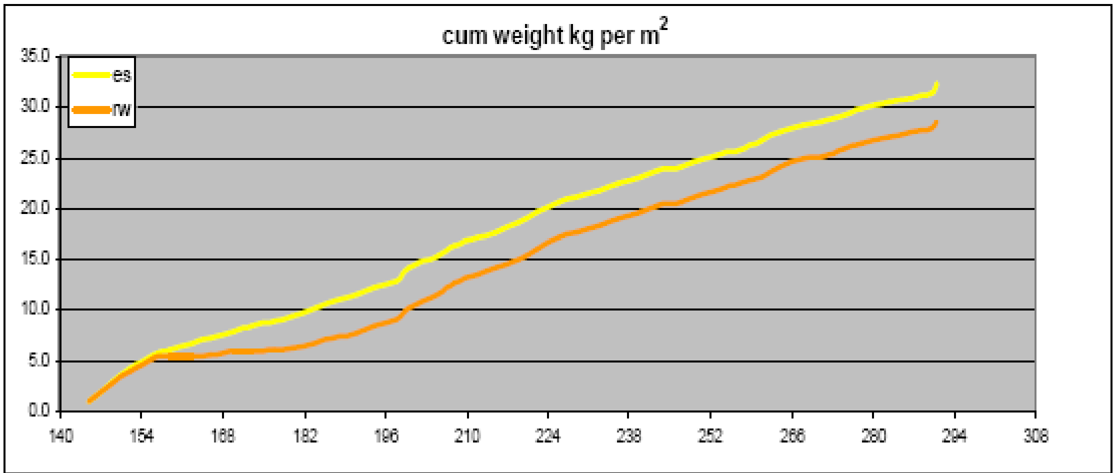

Figure 3. Cumulative yields of tomatoes (kg/m^2) growing in Growstones (es) and Rockwool (rw) between first harvest on May 25, and the end of trial on October 17, 2007.

Steer-ability

Higher steer-ability of Growstones compared to Rockwool is depicted by the lower proportion of vegetative biomass (leaves and stems combined) compared to reproductive biomass (fruits). This is reflected in the vegetative/reproductive ratio (dw) (Figure 4).

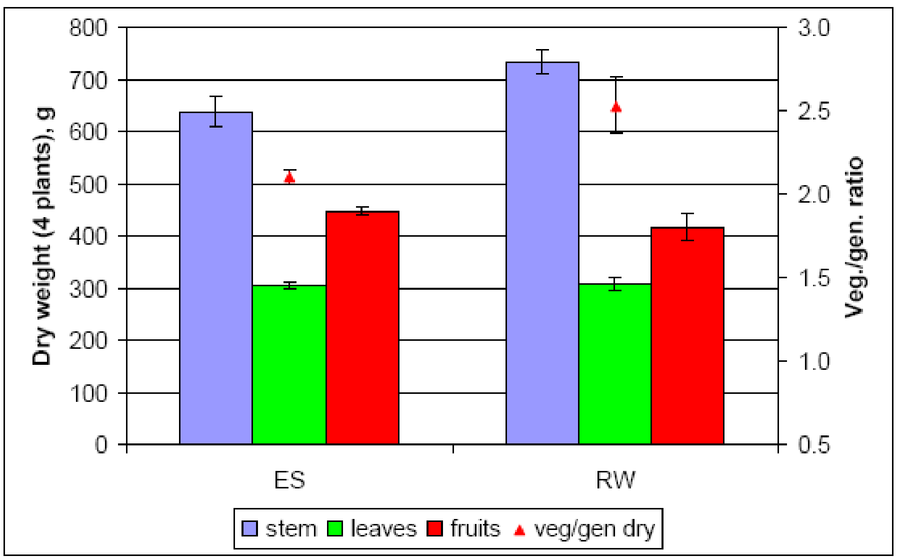

Figure 4. Vegetative/reproductive ratio measured at the end of the experiment.

Stems were the plant part that varied the most between the two treatments throughout the experiment. Dry weight of stems was significantly lower in plants grown in Growstones. This is consistent with the smaller stem diameter observed in this treatment as well as the fast response to environmental measures to steer the plants towards a balanced growth. Dry weight of leaves and fruits were very similar between the two treatments (Figure 4). As a result, the vegetative/reproductive ratio was significantly lower for Growstones. This result confirms the practical significance of using the stem diameter as an indicator of plant balance or lack thereof.

Stem diameter at 15 cm from the growing tip (apical meristem) was monitored weekly during the entire experimental period. A balanced tomato plant is indicated by a stem diameter (measured at 15 cm from the tip) of approximately 10 mm, with little margin for deviation from this value. A larger stem diameter indicates an overly vegetative plant, which invests a large portion of its photoassimilates in developing more vegetative plant parts and not fruits. A smaller stem diameter indicates an overly reproductive plant. In both cases the result is an unbalanced plant that leads to reduced yields in the long run. The weekly mean stem diameter of plants for both substrates is presented in Figure 5.

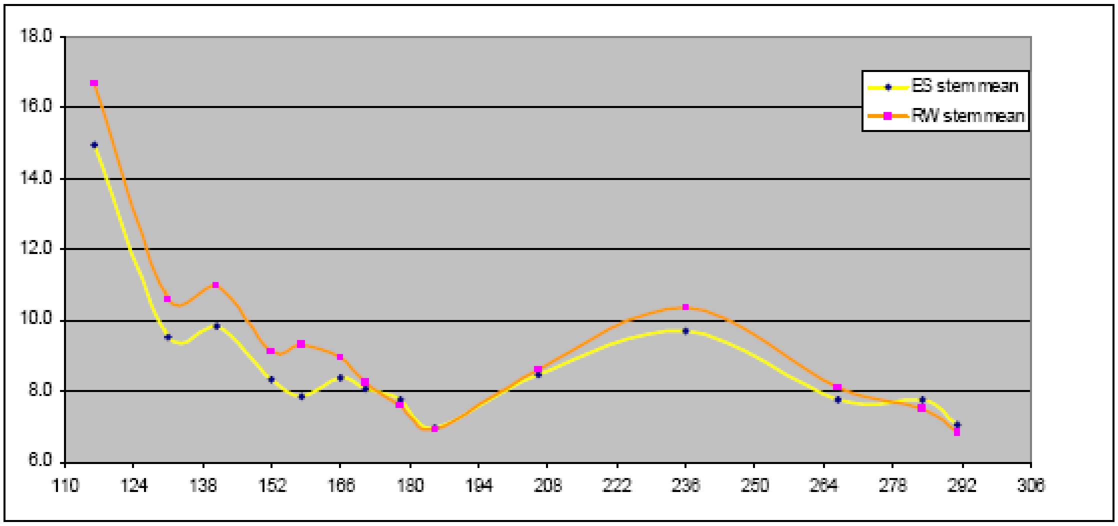

Figure 5. Mean stem diameter (mm) measured at 15 cm from the tip vs. day number in Growstones (ES) and Rockwool (RW) during the entire crop season.

In Growstones, overall growth was clearly more reproductive. This is indicated by the smaller stem diameter throughout the entire experiment, compared to Rockwool. Note that the initially excessive vegetative growth pattern was observed in both substrates (stem diameter larger than 14 mm). Also note the longer time it took for Rockwool plants to reach the desired 10 mm stem diameter, compared to those in Growstones, as a response to environmental and crop management strategies to steer the plant towards a balance. The very low stem diameter reached for all substrates after day 166 (Figure 4) was associated with the period in which a second head was allowed to grow in order to increase plant density to 3.2 heads per m^2 and take advantage of the effect of higher leaf area under increasing radiation levels.

Leaf area

Leaf area index (LAI, m^2 m^{-2}) is an important indicator of the amount of light a crop can intercept and thus use for plant growth and biomass production. With an LAI between 3 and 4 m^2 m^{-2}, indetermined tomato crops theoretically intercept approximately 90% of the total incident light (Heuvelink and Dorais, 2005). Further increases in LAI have only a marginal effect on photosynthetic rate, and thus on yield.

At the end of the experiment, LAI was quantified by destructive measurements with a LI-COR© area meter, on 16 plants per treatment Average LAI was 3.6 m^2 m^{-2} for Growstones and 3.8 m^2 m^{-2} for Rockwool, a non-significant 7% difference between the two treatments. At this time plant density was 3.2 heads per m^2.

Fruit quality

Fruit quality was assessed through total soluble solutes (Brix, %). For both treatments, average Brix was 4.0.

Silicon content
Leaf silicon content was quantified by ICP at the end of the crop season (7 months after transplant). Leaf silicon content was 30% higher in the leaves of plants grown in Growstones, compared to those grown in Rockwool (Table 2).

Table 2. Leaf silicon content in 7 month old tomato plants.

Substrate	silicon (mmol per kg, dry weight)
Growstones	7.0
Rockwool	5.1

Analytical method: ICP

The leaf silicon content observed in plants grown under both substrates show that tomato plants are not silicon accumulators, as the highest levels of silicon accumulated are two orders of magnitude lower than those found in ornamentals grown with Growstones based mixes. Nevertheless, the higher leaf silicon concentration in Growstones seem to be directly related to an increased level of soluble silicon in the root zone of Growstones grow bags.

A high silicon content in Growstones that slowly gets "solubilized" into the root zone in a form easily taken up by roots (mono silicic acid), is a highly positive characteristic for crops such as tomatoes and cut flowers. Multiple studies have shown beneficial effects from adding potassium silicate to the fertilization regime. It has been proven that increased soluble silicon increases plant growth, resistance to Mg toxicity, and most importantly, plants' resistance to fungal diseases such as *Pythium* and perforating insects such as leaf miners.

Transplant and pH issues
Prior to transplant, Growstones were rinsed with standard pH-adjusted nutrient solution while inside the slabs in order to reduce substrate pH. This practice fits well into the existing practice of soaking Rockwool slabs before transplant. After the initial rinse, no extra acid was required to control pH. Drainage holes cut about 5 mm from the bottom of the bags allowed for complete drainage.

Irrigation frequency and drainage
Irrigation frequency was adjusted according to integrated solar radiation in order to allow for 30% drainage. Both substrates were irrigated with the same total volume per day. This was accomplished by adjusting the radiation threshold for irrigation to 70 J per cm^2 and 110 ml for Rockwool, and to 35 J per cm^2 and 55 ml for Growstones. Therefore, Growstones plants were irrigated at double the frequency, but half the duration, of Rockwool plants.

Furthermore, the irrigation of Growstones was extended into the night. This adjustment was initially thought important given the lower water retention capacity of Growstones compared to Rockwool, but resulted in 55% drainage. The higher percent drainage compared to Rockwool suggests that night irrigation could have been reduced and even eliminated in order to keep drainage at 30%, which was thought to be adequate for both substrates.

Other observations
Sterilization of recirculating water. The transparency of the drainage water from both substrates was excellent. This is of practical significance because it means the solution can be easily sterilized with commonly used UV-light systems.

Leaning and lowering. Propagation blocks tend to tilt if stems are leaned sideways to the vine twine too early. It is recommended to wait 1-2 weeks before leading the stems sideways to allow sufficient root growth through the Growstones bag. No negative effects of tilting were observed.

Irrigation. Night time irrigation should be minimized as it is thought to be unnecessary.

DISCUSSION

This trial clearly proves that Growstones is an effective sustainable alternative to Rockwool regarding yields.

Results also confirmed Growstones' advantage relative to comparatively higher steer-ability and soluble silicon available to roots. Furthermore, due to its drier nature, results show that Growstones tend to enhance reproductive plant growth compared to Rockwool substrates. These two characteristics are of great practical value, particularly in climates that naturally tend to promote vegetative growth as well as fungal or insect infestations, such as regions with low light levels and high humidity.

CONCLUSIONS

- It is possible to safely grow tomatoes at the same cumulative yield levels in Growstones and Rockwool, with minor adaptations regarding irrigation schedule.
- Plants in Growstones respond faster to environmental and EC changes compared with plants in Rockwool. This suggests Growstones are more easily steerable than the type of Rockwool used in the experiment.
- Growstones are 30% drier than the type of Rockwool slab used, promoting more reproductive growth.
- Susceptibility to BER is two times lower in Growstones, under the specific growing condotions of the test.
- Growstones slowly releases silicon into the root zone in a form plants can uptake.

FINAL THOUGHTS

The fact that Growstones are composed of 98% recycled glass bottles that would otherwise be accumulating in landfills is another reason to prefer Growstones. Also, by recycling the glass, the need for strip mining is reduced. Therefore, the use of Growstones substrates reduces waste and strip mining, a two-fold positive impact in our environment, while maintaining vegetable fruit production and quality for the fresh market.

Acknowledgements:
[1] The study was conducted at the Wageningen University and Research Center (WUR) in The Netherlands under the guidance of Chris Blok, MSc. Project Manager Rooting Media and Plant Nutrition.