Accelerated Plant Growth Results
From an Intensive Shallow Bottom Heat System
Using Waste Geothermal Hot Water and Steam Condensate in Iceland

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\textbf{ABSTRACT}

The authors have developed an enhanced intensive shallow bottom heat agricultural system using waste geothermal hot water and steam condensate that is analogous to a heated sidewalk at the Agricultural University of Iceland, the Keilir Institute of technology and HNLFI clinic in Iceland. The gardens are heated throughout the year. The results confirm the survival of out of zone plants, including tomatoes and zucchinis that produced a harvestable crop. Plant growth was often increased by 20% or more while the growing season was extended by about 4 to 6 weeks that may increase the value of the crop. Green grass has been documented during the winter. The authors have developed an analogous system in New York City using waste CHP heat in a similar cascade utilization that has demonstrated comparable results.

\textbf{Introduction}

The authors have developed and are testing an intensive shallow bottom heat agricultural system year round in Iceland since 2007 that is analogous to heated sidewalks [1, 2, 3, 4, 5, 6, 7]. A temperature of 25º-30º C is maintained year round at a depth of 8 cm. The overall effect on plants is similar to what would be expected in an unheated greenhouse [2, 3]. The potential benefits of heated ground agriculture (bottom heat) on plant growth were also confirmed by Harvard Forest research [4, 5, 7]. Their research attempted to investigate the possible effects global warming would have on plant growth.

There is some history of outdoor heating of soil (bottom heat) for agricultural purposes using geothermal hot water outdoors in Iceland. A few existing outdoor heated ground agricultural systems have pipes that are about 40 to 80 centimeters below the surface and up to a meter apart. This approach usually creates minimal soil heating in range of 6-12 ºC at depths of 10-15 centimeters. The heating often occurs only during a few months in the spring whereas the author’s system provides a substantially greater temperature increase of often more than 20ºC at the same depth while often providing bottom heat year round [3, 4, 5].

The first heated garden test bed was installed in 2007 at Agricultural University of Iceland in Hveragerdi. The second test bed was installed in 2010 at the Keilir Institute of Technology (KIT) at Asbru in Reykjanesbaer. A third test bed at the HNLFI clinic was in operation between 2011 and 2013. A full growing season was never achieved at this site.

Polypropylene plastic pipes with 2.5-cm diameter were used in all of the heated gardens. The pipes were placed 25cm apart, using polypropylene spacer clips, resulting in a temperature profile shown in Figure 1. As the profile indicates, there are temperature spikes every 25 cm. This enables the plant roots to have a range of temperatures [3, 4, 5, 7]. Note the constant 10 ºC temperature of the unheated control soils.
The plastic pipes were manufactured by Set ehf in Selfoss, Iceland and the spacer clips were manufactured in Hafnarfjörður, Iceland by Bergplast ehf.

The Keilir heated garden is 75 square meters. It cost 90 Euros per square meter, counting all labor, piping, the control system and the soil. The EsBro proposed 150,000 square meter greenhouse for Grindavík, Iceland was projected to cost 270 Euros per square meter [8]. From 2009-2015 there has been very little snow cover on the Agricultural University of Iceland heated garden. The winter energy consumption of the heated garden averages approximately 0.17 kWh per square meter [3]. The control gardens were identical to the heated gardens, but had no circulating fluid. An image of the heated garden in the winter and a corresponding thermal image are shown in Figure 2.

The authors are using waste CHP hot water in New York City working fluid to create heated green roofs at the Cooper Union’s 51 Astor Place building. There are 4 heated 2.5 square meters green roof beds with a total area of 10 square meters. A green roof system is an extension of the existing roof which involves a high quality water proofing and root repellent system, a drainage system, filter cloth, a lightweight growing medium and plants. The green roofs’ benefits of carbon sequestration, the reduction of the urban heat island effect, and storm water retention benefits are also well known.

The heated green roof transfers 0.33 kWh of heat per square meter. This heat is approximately double the 0.17 kWh of heat per square meter transferred to the Iceland gardens. The system has enabled a small harvest of cotton in New York City.

![Figure 2](image1.png)  
**Figure 2.** Winter snow cover melted on garden area (left), infrared image (right).

### Materials and Methods

A number of different plant types were tested in the heated gardens. The choices included indigenous plants and cultivars that normally thrive in a climate that is at least one United States Department of Agriculture (USDA) hardiness zones warmer.
At the Agricultural University of Iceland the seeds for each type of plant were first germinated in a greenhouse for a few weeks, until each plant was about 15 cm tall. In the greenhouse, there were 50 specimens of each tomato plant and 20 specimens of the cucumber. These were numbered according to rows.

All plant selections and plant locations in the heated and control gardens were determined by using assigned numbers drawn from a hat in a double blind process. All beds were treated the same, no special watering frequencies or amounts were instituted for the heated or the unheated test beds. No fertilizers or artificial lighting were used.

Plant growth was measured by recording the height, stem spread and stem diameters. A 4 by 4 cm plastic 3 mm thick plastic square was placed on the soil near the plant stem as a measurement base. The plant height was measured from the plastic square to the highest point of the plant using a standard folding meter stick. The plastic square also served as a level surface for plant stem diameters at 2 cm height using a Mitutoyo digital caliper. The spread was measured in two directions using the folding meter stick. The maximum spread was the measure of the longest distance across the plant, measured from the tips of the leaves. The minimum spread was the distance perpendicular to the maximum spread.

At the Agricultural University of Iceland in 2009 three different soil types were used at depths of 10cm and 20cm in both the control and heated gardens. Local peat soil, peat soil and sand, and a locally developed garden soil were selected. This resulted in 6 test beds and 6 control beds.

Tomatoes (*Lycopersicon esculentum* Mill. cv. Butcher Boy) and zucchini (*Cucumbita pepo* L. cv. Sure Thing) were sown in early June and the seedlings were typically transplanted in 10 cm plastic pots in a heated greenhouse. Tomatoes and cucumbers were then transplanted in the garden in mid-June. The varieties planted included: cucumbers, 4th of July tomato, Best Boy tomato, Steak Sandwich tomato, and strawberries. Figure 3 shows a diagram of the garden in 2009 with plant locations. Beds 1-12 had three of each tomato, two of each cucumber, and one strawberry, planted 50 cm apart from each other in randomized locations. Bed 1 is used as fallow and bed 2 is used as a staging area. Beds 13 and 14 were smaller and only had six plants each. Tomatoes were the main plants chosen for the garden because they are easy to grow and maintain.

The 2012 plant varieties included: 28 cucumber plants, 25 squash plants, 18 Better Day tomatoes, 22 Fourth of July tomatoes, 11 Bloody Butch Tomatoes, two oak trees, and two sunflowers. These plants were pre-grown in pots at the Agricultural University’s greenhouses several weeks before transplant to the outdoor garden. The plants were transferred from the greenhouse to the garden on June 11th, 2012.

The planting procedure for the Agricultural University in 2013 and 2014 were identical to the procedure practiced in previous years. Long term rainfall during the summer of 2013 caused many of the plants to die. Celery was one of the few varieties that survived through September. In 2014 several plant varieties including kale, turnip, and sugar beet were planted and data was recorded on their growth from June through July.

**Results**

Tomato height, spread, and stem diameter data was collected at the Agricultural University of Iceland in 2009. The data was recorded each week for seven weeks starting at the end of July through September. Figure 4 shows the average tomato height for garden soil at 10cm depth. Figure 5 shows the average tomato height for 20 cm garden soil. The height of all tomato plants in the heated and control beds were averaged each week.

The average height of both heated and control tomatoes in 10 cm and 20 cm soil was approximately 26cm at week 1. By week 7 the height of the heated tomatoes in both 10 and 20 cm garden soil were approximately 50 cm. The height of the control tomato in 10 cm soil was 36 cm and the height was 31 cm in the 20 cm soil. The average heated tomato height, spread, and stem diameter data was collected at the Agricultural University of Iceland in 2009. The data was recorded each week for seven weeks starting at the end of July through September. Figure 4 shows the average tomato height for garden soil at 10cm depth. Figure 5 shows the average tomato height for 20 cm garden soil. The height of all tomato plants in the heated and control beds were averaged each week.

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height in the 10 cm soil was 1.4 times greater than in the control. The average height of the heated tomato plants in the 20 cm soil was 1.6 times greater than the control.

The average stem diameter for the tomatoes in 10cm garden soil is shown in Figure 6. The average tomato stem diameter in 20cm garden soil is shown in Figure 7. The average stem diameter for the heated tomatoes was greater than the control tomatoes over the seven weeks for both 10 and 20cm soil beds. By week seven the average stem diameter for the heated tomatoes in the 10cm bed was 1.5 times greater than the control diameter. In the 20cm soil the average heated tomato diameter was 1.9 times greater than the control.

At the Agricultural University of Iceland in 2009 four varieties of grass were grown: *Agrostis stolonifera Nordlys*, *Poa pratensis Bartender*, *Festuca rubra Bargreen*, and *Lolium perenne Corvus*. The height of the grass was monitored for seven weeks from July through to September. Figure 8 shows the height of each variety of grass differentiated by the soil type, soil depth, and whether the grass was grown in a heated or control bed.

Photographs of the tomato plants in the heated and unheated beds are shown in Figure 9. The heated bed on the left has living tomato plants while all the tomato plants in the unheated bed had died. Figure 10 shows a photograph of unripe tomatoes growing on a heated tomato plant. The tomato plants were unable to develop fully ripe tomatoes before the first frost due to late planting and a temporary malfunction and shutdown of the hot water circulation system.
In 2012 tomato and zucchini squash plants were grown in the Agricultural University of Iceland experimental heated garden. Growth data on these plants were collected between June and September 2012. Figure 11 shows the difference in growth between the average spread of tomato plants between June and September. The heated tomato plants grew by 87% while the unheated plants grew by 17%.

Figure 12 shows the average stem diameter of the tomatoes in June and September 2012. The diameter of the tomato plants in the heated beds increased by 103%. The stem diameter increased by 43% for tomatoes in the unheated beds.

Figure 13 shows the change in stem diameter of the zucchini plants. The stem diameters in the heated beds increased by over 83% while the stem diameter in the unheated beds increased by less than 2%.

The change in the average zucchini plant stem spread is shown in Figure 14. The

Figure 9. 10cm heated peat soil tomato and grass (left) 10cm control peat soil heated tomato and grass (right) September 20th, 2009. After heavy frost.

Figure 10. Iceland tomatoes in 20 cm heated garden soil on September 14, 2009, after 6 weeks in garden, seedling initial height.

Figure 11. Average stem spread of tomato plants, June and September 2012.

Figure 12. Average stem diameter of tomato plants, June and September 2012.

Figure 13. Average stem diameter of zucchini plants, June and September 2012.

Figure 14. Average stem spread of Zucchini plants, June and September 2012.
spread of the zucchini plants in the heated beds increased by 4% in 3 months. The zucchini plants in the unheated beds decreased by 227% and were all nearly dead by September.

Figure 15 show the unheated and heated test beds, respectively. The tomatoes, planted in the unheated test bed, that were still alive in September – 3 month after being transplanted – shrunk by 13.2% and all the unheated zucchiniis died. Figure 16 shows a ripe tomato and zucchini fruit produced by the plants in the heated test bed. A close-up photo of ripe tomatoes in the heated garden is shown in Figure 16. This seems to be unprecedented, according to the Head of the Faculty of Vocational and Continuing Education at the Agricultural University of Iceland [5].

Figure 17 shows the average growth in height of celery from July 1st to September 20th, 2013. The average height of the heated celery plant grew by 0.1cm during the month of July. The height of the unheated celery grew by 0.5cm over the same period. Between July 30th and September 20th, the average height of the heated celery increased by 2.6cm while the unheated celery decreased by 1cm.

When the celery plants were first measured on July 1st, the average heated and unheated spread was approximately the same. From July 1st to July 30th, the spread of the unheated celery plant stayed the same while the heated celery spread increased by 3.9cm. Between July 30th and September 20th the unheated spread increased by 3 cm to 9.7cm while the heated celery spread increased by 9.4 cm to 17cm. Figure 18 shows the growth in celery spread from July 1st to September 20th.

Between July 1st and September 20th the average height of the celery plants in the heated gardens increased by 37.5%. Over the same time period, the average height of the unheated celery plants decreased by 0.08%. The average spread of the heated celery increased by 165% while the average spread of the unheated celery increased by 44%.

Figure 19 compares kale in the heated bed 3 and the unheated bed 13. The heated kale’s growth rate is greater than the unheated during June and July. The fertilizer did not have an observable effect on the growth of the unheated plant. The heated and unheated kale plants both started at a height of 5cm. The final height of the heated kale was 42.4cm while the unheated kale height was 2.8cm. The heated kale height increased by 748% while the unheated kale height decreased by 44%.

At the Keilir Institute of Technology, the initial growth studies of strawberry plants. Strawberries were grown in control beds that received no soil heat, beds that received waste water at 40°C, and beds that received waste water at...
60°C. The difference in the growth of strawberry plants in the control bed, 40°C bed, and 60°C bed between June 28 and September 6, 2011 is shown in Figure 20.

There were a total of 36 strawberry plants, one placed in each bed. The number of stems in the 60°C bed increased by 118%, by 80.6% in the 40°C bed, and 28% in the 20°C control bed. There was a 29% increase in spread in the 60°C bed, a 9% increase in the 40°C bed, and a 17% decrease in spread of the strawberry plants in the 20°C control beds.

**Conclusions**

Tomatoes are only grown in greenhouses in Iceland. The results demonstrate the survival and ripening of out of region cultivars, such as tomatoes zucchinis and other cultivars during the growing season in Iceland (May 15 through September 15). These plants are normally grown outdoors only in warmer climates until the heavy frosts. As in their normal USDA hardiness zones these plants do not grow in the heated gardens during the Icelandic winter, Strawberry plants experienced accelerated growth at the Keilir Institute of Technology [8]. Banana plants in the heated garden survived outdoors from June through September, while the unheated control banana plant died. Average plant growth increases greater than 20% more than the control gardens have been noted. The results in Iceland mirror possible the Harvard study’s positive effects global warming would have on plant growth [2]. The heated gardens use waste heat in cascade utilization so there are no real heating expenses Traditional heated green houses in Iceland produce waste hot water at a temperature of 60-90°C which the authors have already used to heat gardens [7]. The cost of 90 Euros per square meter for a 75 square meter greenhouse can be compared to the EsBro proposed 150,000 square meter greenhouse for Grindavik, Iceland was projected to cost 270 Euros per square meter [8]. Like all outdoor agricultural endeavors, climatic uncertainties are an economic
risk. As stated by Guðríður Helgadóttir, Head of the Faculty of Vocational and Continuing Education at the Agricultural University of Iceland [5], “To have a banana plant alive outdoors in September, after being outdoors from early summer is spectacular. Some growers have tried to grow tomatoes outdoors without shelter from polytunnels or sun frames but the plants have not survived for long, let alone produced fruit. The same can be said about zucchinis. The conclusion we come to here is that the heated garden gives the plants approximately the same advantage as if the plants had been grown in polytunnels or sun frames in Iceland.” Additional testing of the current test subjects and other cultivars will increase the validity of the research which should further increase commercial and philanthropic interest in this unique technology.

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