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WASTE GEOTHERMAL HOT WATER FOR ENHANCED OUTDOOR AGRICULTURAL PRODUCTION

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ABSTRACT
In Iceland there is a super abundance of waste hot water from geothermal power plants. Some of this is re-purposed (sequentially used) for district heating and heated swimming pools. This vast underused energy source can also enable the growth of out of zone plants, enhance agricultural production by 20% and extend the growing season. The authors have developed and field tested an energy intensive shallow system of bottom heat using the existing heated sidewalk materials. Tomatoes that do not survive outdoors in Iceland have produced ripe fruit. A zucchinis harvest was documented and the test banana plant was still alive in September after the first frost. These plants all died in the control garden which had the same piping system, and identical soil types and depths. Heat transfer data, infrared analysis and plant growth data were gathered to preliminarily document and quantify the system's viability and market potentials.

Keywords: Geothermal waste heat, Heated soil, Heated ground agriculture, Cascade utilization, Enhanced growing season

INTRODUCTION
In high temperature areas in Iceland, geothermal steam is extracted at 160-350°C from boreholes. After electricity production the waste heat can have a temperature of up to 130-160°C. This waste heat is available for cascade utilization in district heating.

Municipal geothermal heated swimming pools and greenhouses are common in Iceland. Due to the now higher costs of energy, materials and labor, many of the older style greenhouse operations are being modernized [1].

Other well known cascade utilizations of geothermal energy in Iceland are aqua culture and heated sidewalks [1, 2]. The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) specifications for heated sidewalks [3] are commonly used as the engineering reference for these heated sidewalks.

There is a history of outdoor heating of soil (bottom heat) for agricultural purposes. 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 the increments of 6-12 °C at a depth of 10-15 centimeters. The heating often occurs only during a few months in the spring [1]. There is some ongoing research into heating golf course greens and athletic fields to extend the playing season [1].

The authors developed and have been testing in Iceland since 2007 a more energy intensive year round shallow system of outdoor heated ground agriculture that is analogous to heated sidewalks. Preliminary results were published in a previous work [4] and in this paper updated results based on last two years' harvesting are presented. Furthermore, this paper also presents the design and buildup of a new test bed installed at Náttúrulækningafélag Íslands (NLFI) in Iceland.

MATERIALS AND METHODS
Three heated experimental test bed geothermal heated gardens have been established by the authors. The first 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. The third test bed was installed in 2011 at Náttúrulækningafélag Íslands (NLFI Spa and Medical Clinic) in Hveragerdi.

Located at the Agricultural University of Iceland at Reykir, Ölfusi near Hveragerdi is a geothermal borehole which supplies steam and steam condensate at temperatures from 100 to 125°C. This fluid is piped to a traditional shell and tube heat exchanger - manufactured in Iceland - that heats up a mixture of water and 20% methanol. The heat exchanger is elevated 1.5 meters above the heated gardens. A semi-sealed expansion chamber is used for surcharging the system. A recirculation pump is used to circulate the heated water/methanol mixture continuously throughout the year. Standard ball valves control the flow rate. A Danfoss AVTB T self-acting temperature controller regulates the flow rate of the steam and steam condensate that reheats the hot water. A dial thermometer and pressure gage manufactured by Flexcon is mounted on the top of the heat exchanger to determine the water-out temperature. A Rexotherm KL 2.0 dial thermometer with a temperature range of 0-120°C, is connected to the retour just above the flow meter. The Brook Crompton Parkinson KP6736 1-HP hot water circulator pump creates a flow rate of 10 liters per minute as measured by a Blue-White F-410N 1-inch NPT vertical float type flow meter.

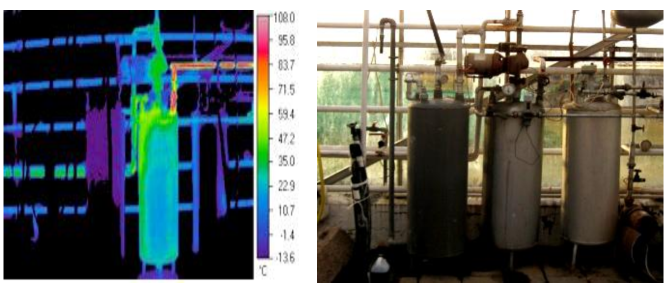

Figure 1: Mikron infrared image of the Hveragerdi heat exchanger (left), standard digital image (right).

A 5 by 10 square meter experimental heated garden and a 5 by 5 square meter control garden were constructed in a workman like manner, using construction methods, tools and materials commonly used in Iceland for heated sidewalks, as shown in Figure 2.

The heated and the unheated control garden were constructed, maintained, and monitored in the same manner and using the same materials, with the exception that no hot water circulates through the pipe of the control garden.

The soil in the heated garden receives the water/methanol mixture at 60-65°C in the colder months and between 40-50°C during the summer months. The energy consumption of the garden can be estimated using a steady flow energy equation

$$q = mC_p(T_h - T_c). \tag{1}$$

Where m is the mass flow of the fluid mixture (kg/s), C_p is the specific heat of the fluid mixture (kJ/kg), T_h is the temperature of the mixture when it enters the pipe and T_c is the temperature of the fluid mixture when it exits the garden pipe. The temperatures can be in either in Kelvins or Celsius.

The energy consumption per square meter of a heated garden has been estimated to be 0.155 kWh per square meter on average. The calculations were based on the following. The flow rate of the fluid mixture was 10 liters per minute. The mass of the 80% water / 20% methanol mixture per cubic meter was estimated to be 957 kg/m^3 (80% 1000 kg/m^3 & 20% 787 kg/m^3) and the mass flow rate 0.1595 kg/s. The temperature of the mixture leaving the garden varied between 45°C and 50°C, hence the temperature drop $T_h - T_c$ was between 10 and 15 degrees. The average of 12.5 degrees was used for the estimation of the gardens energy consumption. By using an average temperature of 55°C the specific heat of the fluid mixture, C_p, was calculated to be 3.895 kJ/kg.K (80% 4.183 kJ/kg.K & 20% 2.745 kJ/kg.K).

Figure 2: Hveragerdi spiral piping layout (left), sand over layer construction detail (right).

A 2.5-cm diameter polypropylene plastic pipe, manufactured by Set ehf in Selfoss, Iceland, was selected because of its workability, resistance to puncture and its ability to withstand several freeze-thaw cycles. Approximately 260 meters of pipe was installed in a spiral pattern to provide a more even heating profile. The plastic pipe was placed with a 25-cm separation distance, maintained by using polypropylene spacer clips manufactured by Bergplast ehf in Hafnarfjörður. As mentioned, both products are manufactured in Iceland and commonly used in heated sidewalks.

The pipes were placed on a 20-30 cm bed of pre existing compacted sand. They were covered by an additional compacted sand over-layer of 4-5 centimeters. Above this, layers of garden soil, peat soil, and peat and sand soil were placed in both the heated and the control gardens at 10 cm and 20 cm depths, to create 6 separate beds in each garden.

At the Keilir Institute of Technology (KIT) at Asbru in Reykjanesbaer a 16 by 6 square meter garden, as shown in Figures 3-6, was constructed to investigate the potential of utilizing the waste geothermal hot water from Icelandic houses to enhance the plant growth of trees, flowers and vegetables. The garden is heated by two hot water circulation systems, at 40°C and 60°C.

Figure 3: The controls for the Keilir garden

Each circulation system has a separate manual temperature controller valve to control the temperature and flow of water. ENFM dial thermometers with a temperature range of 0 -120°C are connected to each system, as the hot water exits to the garden. A second dial thermometer is connected to the return of both circulation systems. The waste water is sent to the sewers in the same manner as the geothermal heated houses in Iceland. The controls piping for the garden are shown in Figure 3. Flow meters will be installed in 2013.

The garden has the identical materials and construction specifications as the Agricultural University of Iceland gardens in Hveragerdi. Figure 4 shows photos taken during the construction of the garden which consists of 36 separate beds divided by preserved wooden panels. This creates 6 beds at each of the three soil depths (10, 20, and 30 cm). These beds are further divided into three temperature zones, 40°C and 60°C as described and control (unheated). Figure 5 shows the layout of the Keilir garden. There are 2 sections for each temperature and depth. Figure 6 shows the finished garden with the first transplanted plants.

Figure 4: The construction of the Keilir garden.

	Rows						
	1	2	3	4	5	6	°C
A	1	2	3	4	5	6	60
B	7	8	9	10	11	12	40
C	13	14	15	16	17	18	Control
D	19	20	21	22	23	24	60
E	25	26	27	28	29	30	40
F	31	32	33	34	35	36	Control
Depth (cm)	20	30	10	20	30	10	

Figure 5: Schematic of the Keilir garden.

Figure 6: The Keilir garden with the first harvest showing.

The NLFI Rehabilitation and Health Clinic, in Hveragerdi, has its own geothermal steam well located on the NLFI grounds. A separate NFLI heated garden is being constructed that uses waste hot water from their geothermal heated swimming pool's heat exchanger. The 55- 80°C fluid's discharge pipe drained into the nearby Varmá River. The hot water for the garden is tapped from the underside of this discharge pipe by a Shanxi Solid Industrial Co., Ltd. stainless steel tee repair clamp.

This creates a gravity feed system for the garden's working fluid.

Figure 7: Overhead view of the NLFI test bed connections detail photo left, infrared image right. Note the plastic air vent pipes on the bottom of the left photo correspond with the light blue pipes in the right photo.

Figure 7 shows the connections of the gravity feed system to the discharge pipe (the right IR image was taken at an offset angle). There are two separate lines to the garden. By adjusting the ball valves, the blue handles shown in the middle of the left figure, two temperature zones can be created by restricting the hot water flow to the two lines separately. The temperature of both pipes can also be lowered simultaneously by flow restriction. There is a control section shown in the right side of Figure 8. Both garden pipes are drained into the Varma river. Both pipes have a flow rate of 4 to 8 liters per minute. The water temperature drops by approximately 10°C to 15°C as it passes through the garden.

Figure 8: The pipe layout for the test bed at Varmá.

Figure 9: Left, before garden construction, right, after garden construction. The rectangular concrete and stone cooling pit for the waste hot water is visible in foreground of the right image.

This garden also has the identical materials and construction specifications as the Agricultural University of Iceland gardens in Hveragerdi. The NLFI garden is still under construction.

RESULTS AND DISCUSSION

In addition to the dial indicators, temperatures were measured using variety of systems including a Linear Labs C-1600 non-contact infrared thermometer, a Fluke 867B graphical multimeter with a temperature probe, and a Mikron 7200 thermal camera. For longer term soil temperature monitoring, an Onset Computer Corporation Hobo Water Temp Pro v2 Data Logger system was used in Hveragerdi. The beds' soil moisture content is being monitored by a Delmhorst KS-D1 Digital Soil Moisture Tester, used with the GB-1 Gypsum Soil Blocks.

At a depth of 8 centimeters, the soil temperature average was between 20-35°C, depending on the weather conditions and the season. Figures 10-13 show the soil temperature from the Hveragerdi experiment.

The Agricultural University of Iceland heated gardens experienced heating system problems and were subject to system interruptions due to steam borehole temperature inconsistencies. This was caused by earthquake activity, and equipment failures. The gardens also suffered from wind damage and vermin. Despite these limitations, and the lack of sophisticated temperature control and irrigation systems, there were dramatic increases in overal plant growth and yields that mirrored the results of the Harvard Forest soil heating studies [5, 6].

A three-year parallel study of heated and soil test beds using the identical materials, construction specifications and hot water settings was conducted at the Cooper Union for the Advancement of Science and Art, in New York City, by the authors. The plant growth statistics mirrored the Iceland experiments. An extensive soil analysis and comparison of the heated and unheated soils revealed no significant soil chemistry differences [7].

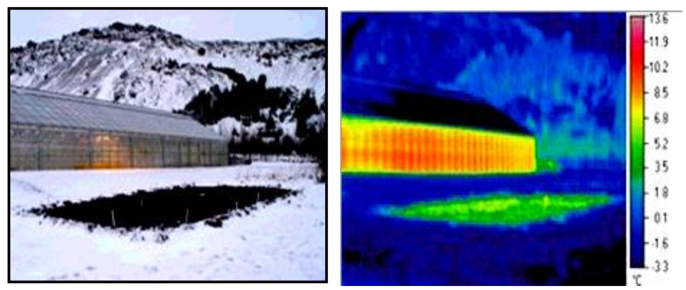

Figure 10: The test bed at the Agricultural University of Iceland heated gardens on 22 February 2008, the winter snow cover has melted on garden area (left), infrared image (right).

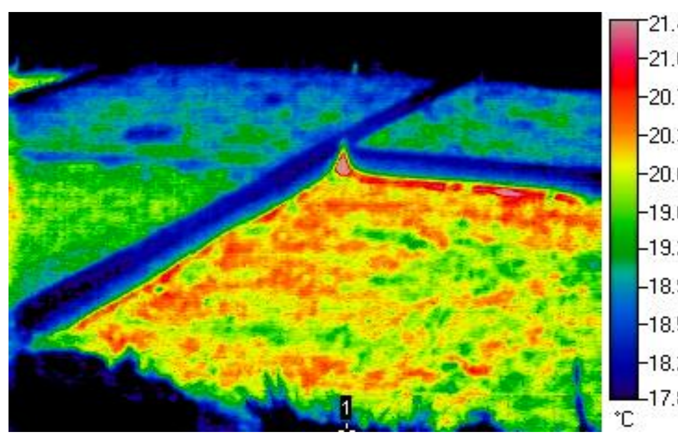

Figure 11: Infrared image of the heated garden at the Agricultural University of Iceland. The soil depth for the area in foreground is 10 cm and 20 cm in the area on the left.

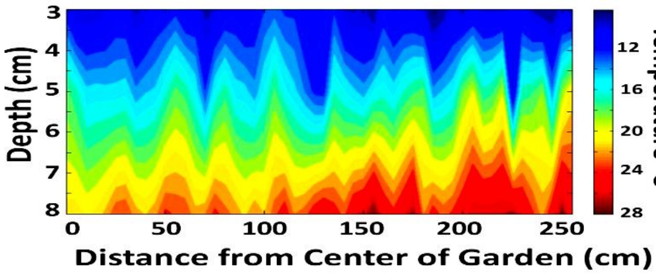

Figure 12: Thermal soil temperature profiles (NTS) at the Agricultural University of Iceland. Note: The temperature peaks are located over the pipes that are 25 cm apart.

The thermal cross section denotes temperature peaks over the pipes. These readings were taken from the center of the garden to the outside edge. The hot water entered the spiral piping system on the outer perimeter and exited 10˚C cooler from the center of the garden. This causes the temperature of the soil to increase as the distance from the center increases.

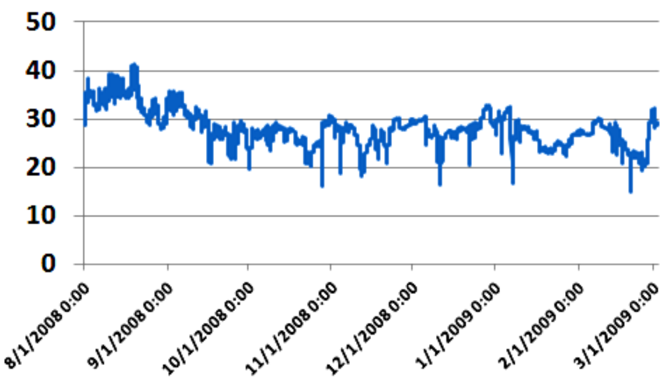

Figure 13: The soil temperature in degrees Celsius at a depth of 8 cm at The Agricultural University of Iceland heated gardens from 1 August 2008 to 1 March 2009 from a Hobo Water Temp Pro v2 Data Logger

In Figure 13, the temperatures were taken at a fixed point. The rectalinear probe was placed in the center of the garden parallel to the burried pipes and equidistant from the contiguous pipes. The temperature decreased as expected as the seasons progressed. However, a uniform temperature of approximately 20 to 30 ºC was maintained.

The Agricultural University of Iceland heated gardens, as shown in Figure 14, the hot water circulated through the heated garden on February 22nd 2008 had a temperature of 68°C as it left the heat exchanger. There was a highly visible strip of green grass directly over the buried hot water pipes that formed the connection between the heat exchanger in the greenhouse and the heated garden. In February 22nd, 2009, exactly one year later, the water temperature was 48°C, due to a reduction in the borehole temperature. As seen in Figure 15, there was no readily noticeable green grass. Both years had similar winter severities.

Figure 14: Measurement taken on 22 February 2008.

Figure 15: Measurement taken in February 2009.

Plant growth, stem spread and stem diameters were recorded. The plant growth at all of the heated gardens was measured by total plant height and width using Mitutoyo digital calipers and meter measuring sticks. A 4 by 4 cm rigid 3 mm plastic square was placed near the plant stems during measurements to serve as a level surface for plant vertical dimensions and stem diameters at 2 cm height.

Tomatoes (*Lycopersicon esculentum Mill. cv. Butcher Boy*) and zucchini (*Cucubuta pepo L. cv. Sure Thing*) were sown on May 17 in a heated greenhouse. They transplanted to the gardens on June 11. 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.

Figures 16 and 17 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 zucchinis died (shown in Figure 16).

Figure 16: The unheated test bed on 17 September 2012.

Figure 17 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 18. This seems to be unprecedented, according to the Head of the Faculty of Vocational and Continuing Education at the Agricultural University of Iceland [9].

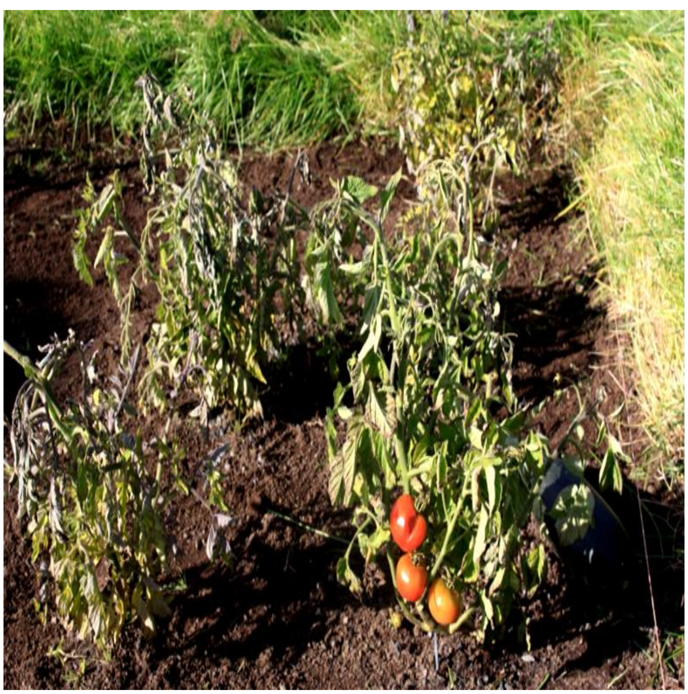

Figure 17: The gardens at the Agricultural University of Iceland on 17 September 2012.

Figure 18: Ripe tomatoes outdoors, 17 September 2012, at the heated garden in Agricultural University of Iceland at Hveragerði.

These results mirror previous results obtained 3 years earlier, or in 2009. Figure 19 shows two photos of the two test beds in 2009.

Figure 19: Unheated control garden, 9 September 2009 (left) and the heated garden on the same date mirror the 2012 results.

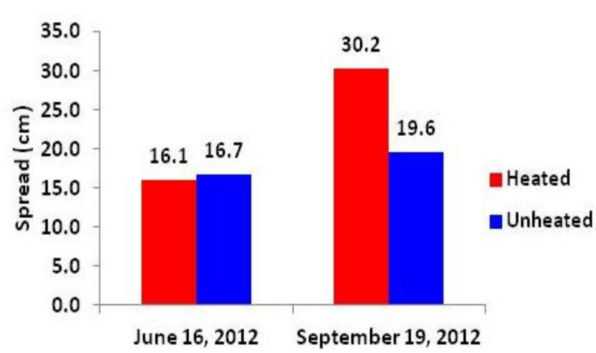

Figure 20: A comparison of the average stem spread of the tomato plants measured in June and September 2012.

The average spread of the tomato plants in the heated and unheated beds are shown in Figure 20 for comparison. The spread of the heated tomato plants increased by over 87% on average while the spread of the tomato plants in the unheated beds increased on average slightly over 17%.

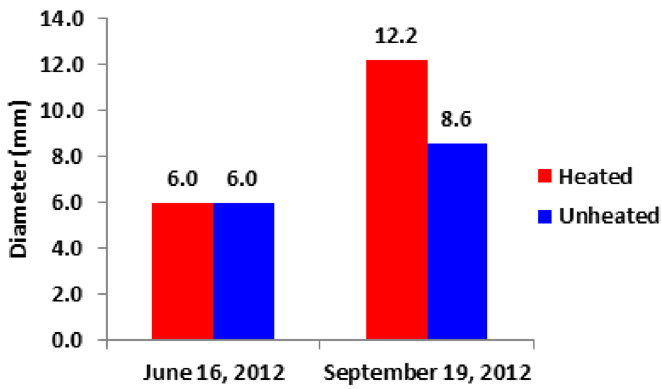

Figure 21: A comparison of the average stem diameter of the tomato plants measured in June and September 2012.

Figure 21 shows the average stem diameter of the tomatoes in June and September 2012. As can be seen from the figure the stem diameter of the tomatoes in the heated bed increased by over 100% on average, during the 3 month interval, whereas the diameter of the unheated tomato plants increased by 43% on average.

Figure 22 shows the average stem diameter of the zucchini plants in June and September 2012. The stem diameter of the zucchini plants in the heated bed increased by over 83% on average, during the 3 month interval, but the stem diameter of the zucchini plants in the unheated beds increased by less than 2%.

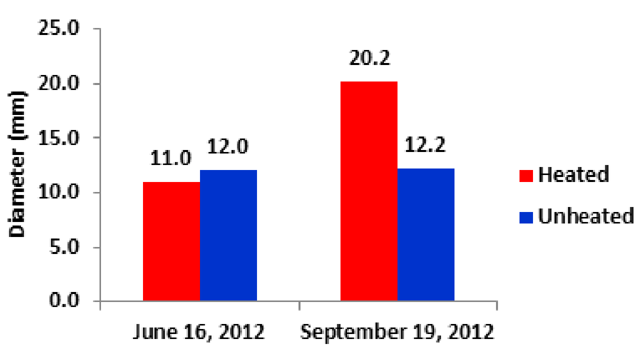

Figure 22: A comparison of the average stem diameter of the zucchini plants measured in June and September 2012.

The change in the average Zucchini plant stem spread is shown in Figure 23. The spread of the zucchini plants in the heated beds increased by 4% but the zucchini plants in the unheated beds died.

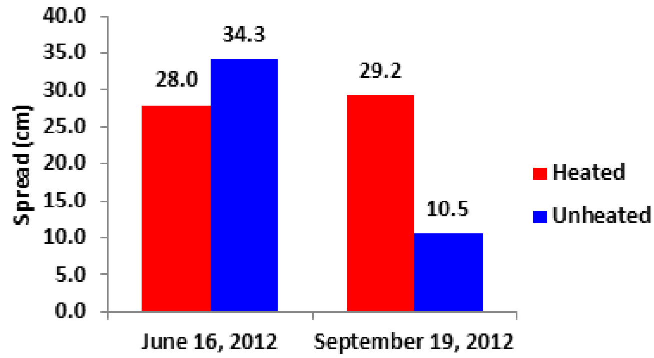

Figure 23: A comparison of the average stem spread of the zucchini plants measured in June and September 2012.

Figure 24 shows a photo of a zucchini fruit from the heated test bed that had ripened by September 2012. The fruit was more than 25 cm in length.

Figure 24: A 25-cm long zucchini fruit from the heated test bed in September 2012.

The weights of all eight of the ripe zucchini fruits were measured and are shown in Figure 25. The fruits were from the heated beds, all zucchini plants in the unheated beds had died.

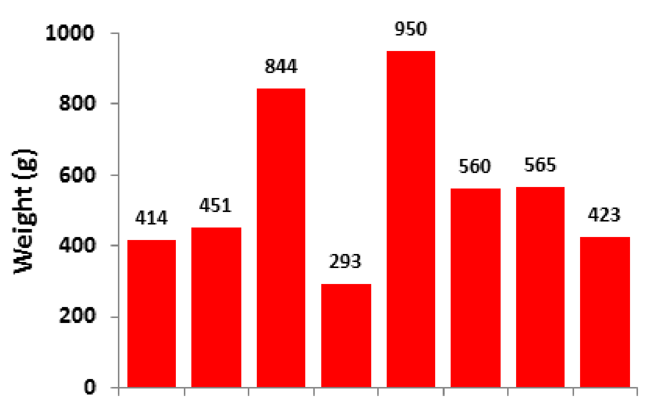

Figure 25: The weight of the zucchini fruits in the heated bed measured on 17 September 2102. The zucchini plants in the unheated test beds all died.

Banana plants seedlings were planted in the heated and unheated gardens on 15 June 2012. In September 2012 the banana plant in the heated bed was still alive while only a 10 cm dead stalk remained in the unheated bed, shown in Figure 26.

Figure 26: Photos taken in September 2012 of banana plants which were planted on 15June 2012. Left photo shows the plant in the heated bed which is still alive and the right photo shows the dead stalk in the control bed.

At the Keilir Institute of Technology (KIT) at Asbru in Reykjanesbaer, initial growth studies of strawberry plants also produced encouraging results[8]. Similar to the Agricultural university of Iceland gardens, all plant selections and plant locations in the heated and control (unheated) test beds 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. Furthermore, no fertilizers or artificial lighting were used.

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 27 for comparison. There were a total of 36 strawberry plants, one placed in each bed. The total number of strawberry stems in each of the corresponding beds were added and displayed below.

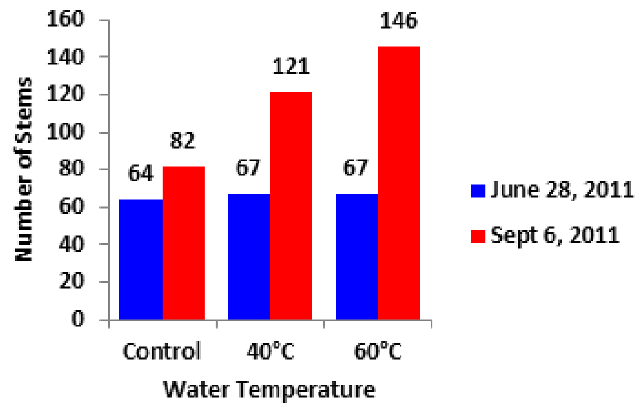

Figure 27: A comparison of the number of stems on the strawberries measured in June and September 2012.

The number of stems in the 60°C bed increased by 118%, by 80.6% in the 40°C bed, and 28% in the control bed.

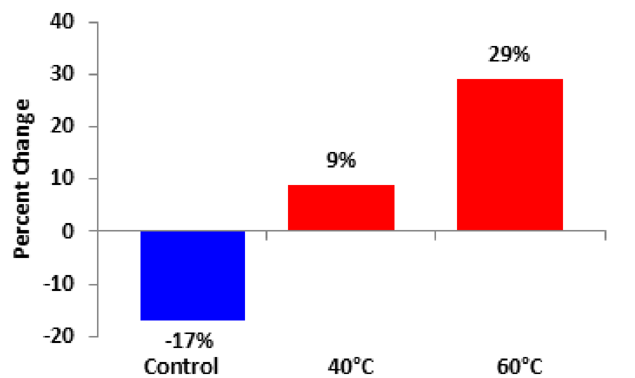

Figure 28: Percent change in strawberry plant spread. Results are based on measurements taken on 28 June and 6 September 2011.

As shown in Figure 28, 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 control beds. A thriving strawberry plant growing outside in the heated garden is shown in Figure 29.

Figure 29: Keilir Institute of Technology strawberry plant.

The NLFI Rehabilitation and Health Clinic heated gardens have thus far only produced anecdotal indications of success due to the ongoing construction process.

CONCLUSIONS

Tomatoes are only grown in greenhouses in Iceland. The results demonstrate and ripening of out of region cultivars, such as tomatoes and zucchinis during the growing season in Iceland (May 15 through September 15). These plants are normally grown outdoors in warmer climates until the heavy frosts. 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 in the heated gardens was 20% more than in the control gardens. According to Guðríður Helgadóttir, Head of the Faculty of Vocational and Continuing Education at the Agricultural University of Iceland [9]: ***"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."***

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