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Repurposing Waste Geothermal Hot Water for Outdoor Agricultural Enhancement in Hveragerdi

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ABSTRACT

For the past ten years, the authors have been developing and field testing an intensive soil warming technology using 60-degree C waste geothermal hot water that has enabled outdoor agricultural crops that normally grow in warmer climates. Pipes at a depth of 25 centimeters create a soil temperature greater than 30° degrees C. Recent harvests at the Agricultural University of Iceland in Hveragerdi include oregano, turnips, zucchinis and celery. A small production garden is being developed and commercial viabilities are being investigated. This paper presents the setup and the experimental results.

1. INTRODUCTIONS

Iceland has a substantial history of using geothermal powered, heated greenhouses to extend the growing season, increase crop yields, and to cultivate out of region cultivars (Johannesdottir et al., 1986). Harvard Forest conducted research in Massachusetts using electrical resistance heating elements buried beneath small forest test beds that enabled a 20% increase in plant growth (Yarosh et al., 1972). Outdoor soil heating using hot water encased in plastic pipes as a working fluid for sports fields, and more recently for golf greens, prolongs the playing season (Yarosh et al., 1972; Gunnlaugsson et al., 2003; Ragnarsson, 2003). The heating of soil for agricultural purposes has been referred to as "open field heating", "bottom heat", and "heated ground agriculture" (Yarosh et al., 1972; Ragnarsson, 2003; Dell et al., 2011; Dell et al., 2013a; Dell et al., 2013b; Dell et al., 2014a; Dell et al., 2014b; Dell et al., 2015; Dell et al., 2016).

Previous outdoor heated ground agricultural systems in Iceland use buried pipes spaced up to a meter apart at depths of 40 to 80 cm The resultant soil temperature is typically increased by 6-12 °C at a depth of 10-15 cm (Johannesdottir et al., 1986). This occurs during the spring and produces minimal soil heating to give plants an early start for the growing season (Dell et al., 2011).

The authors have been conducting open field heating research in Iceland and New York City since 2008. Their early soil thermal research resulted in an optimal pipe spacing of 20 - 25cm with a soil depth of 20-30 cm. This pipe spacing was later found to be quite close to the heated sidewalk specifications published by the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE, 2015, Dell et al., 2013a; 2013b; 2014a; 2014b; 2015; 2016). The system can produce temperature increases of 10-30°C at a depth of 10-15 cm throughout the year.

2. MATERIALS AND METHODS

Three test beds were established in Iceland. The first test bed is located at the Agricultural University of Iceland in Olfus, near the City of Hveragerdi (64°00'26.7"N 21°17'74.2"W). It has a 5x10 meter heated plot and a 5x5 unheated control plot. The construction details are identical in both plots, including piping and pipe spacing, gravel substrates, and soil depths and types. The experimental plot has geothermal heated hot water as a working fluid in a closed loop with a circulating pump. A geothermal borehole supplies steam and steam condensate to a traditional shell and tube heat exchanger.

The second is at the NLFI Clinic in Hveragerdi (63°99'67.3"N 21°17'28.2"W). The basic construction details are identical to the Olfus test beds. The heated plot is 5x20 meters and the unheated control plot is 1x29 meters. The working fluid comes from the waste hot water from a geothermal heated swimming pool and a nearby geothermal heated green house. Hot water has a gravity flow. The effluent flows into the Varma River.

The third Iceland test bed was located at the Keilir Institute of Technology in Reykjanesbaer (63°58'06.3"N 22°34'11.1"W). The municipal geothermal hot water that traditionally heats homes and buildings is used for the working fluid. The test bed has 5x20 meter test bed and a 2x20 meter control plot.

There is also a fourth test bed on the roof of the Foundation Building at the Cooper Union in NYC. This test bed has been studied in past papers and will be referenced for comparison of energy consumption and growth rates.

The experimental and the control plots were contiguous at all three location and they received the same amount of sunlight and precipitation. The control beds did not have any working fluid.

The initial soil temperature profile measurements were made using an Omega HH309 Data Logger thermometer with k-type thermocouples. Most of the subsequent temperature readings came from Winco TMR-DG4 digital thermometers. A depth of 8 cm at 5 cm intervals were taken perpendicular to the pipes. The surface temperatures of the beds were verified with a Mikron 7200 infrared camera. The measurement's basic accuracy is ± .1°C. The water flow rates were measured with Blue-White vertical float type flow meters at Olfus and at Reykjanesbaer. The flow rate numbers were determined by visual inspection, with a projected accuracy of .2 liters per minute. Watts dial temperature gages were used to monitor the hot water working fluid's temperature. Measurements were again made by visual inspection and are accurate to .5°C.

The NLFI flow rates were measured by manually timing how long it took to fill 5 liter pails. The NLFI temperatures were measured with the Winco thermometers used to measure soil temperatures.

The specific cultivar selections for each plot and their locations in the heated and control plots were determined by using assigned numbers drawn from a hat in a double-blind process.

Plant growth, stem spread, and stem diameters were recorded and placed in excel files. The plant growth at all the heated gardens was measured by total plant height and width using Mitutoyo digital calipers and meter measuring sticks. A rigid 4x4 cm by 3 mm thick plastic square was placed near the plant stems during measurements to serve as a level surface for measuring the plant's vertical dimension and stem diameter at 2 cm height was recorded.

All heated and unheated test beds were treated the same, with no special watering frequencies. No fertilizers or artificial lighting were used. A typical plant distribution plan is shown in Figure 1.

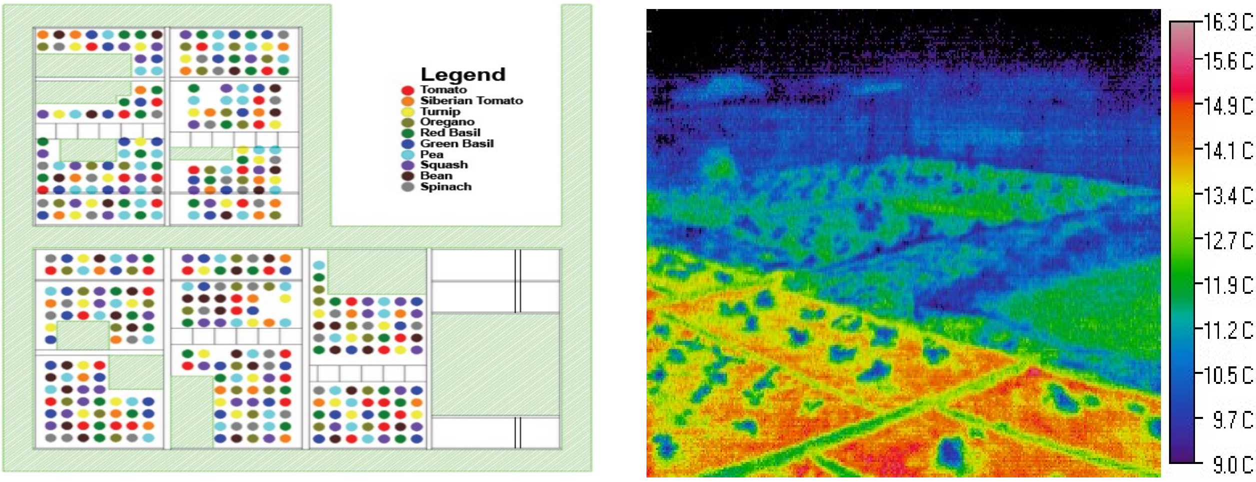

Figure 1: Plant locations schematic at the Agricultural University of Iceland. The top area is the 5x5 meter control plot and the bottom area is the 5x10 meter heated plot.

The first Iceland test bed at the Agricultural University of Iceland has a geothermal bore hole heat source that produces steam and steam condensate at temperatures that range from 100-125°C. The borehole working fluid is piped to a traditional shell and tube heat exchanger as shown in Figure 2 (Dell et al.; 2013a). The system then generates a working fluid at controllable temperatures between 45°C in the summer and 65°C in the winter. It uses a pump to circulate hot water at a flow rate of 8-10 liters per minute throughout the year in a closed loop.

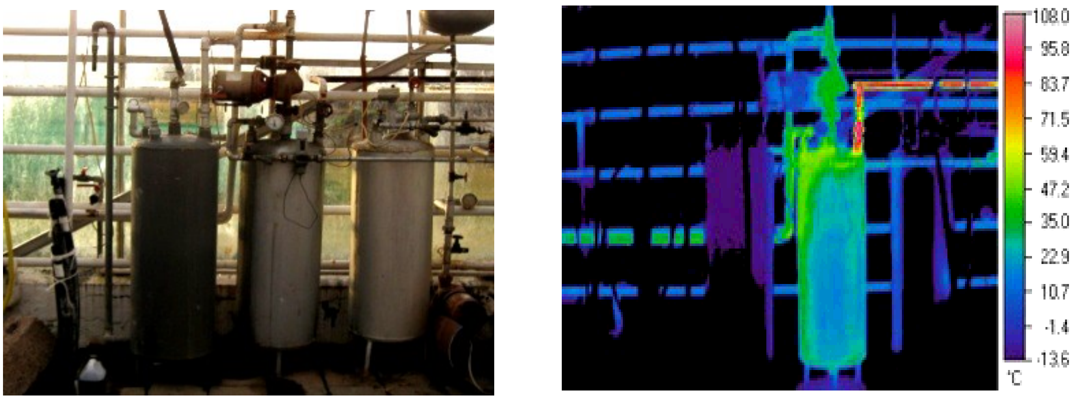

Figure 2: Agricultural University of Iceland's first heat exchanger (left), and infrared image (right)

At the first Iceland test bed at the Agricultural University of Iceland, shown in Figure 3, 15-25 cm beds of compacted sand were prepared for the control and experimental garden beds. Polybutylene plastic pipe (2.5 cm diameter) was installed in a spiral pattern at 25 cm centers and then covered in 4-5 cm of compacted sand (Dell et al.; 2011). The soils were prepared on top of this at depths of 10 and 20 cm.

The heated test bed measures 5 x 10 m and the control bed measures 5 x 5 m. The test bed has been operational since 2007 and serves as a student platform for experimentation and data collection.

The second Iceland test bed at the NLFI Rehabilitation and Health Clinic in Hveragerdi has its own borehole, which heats a swimming and rehabilitation pool, small green houses, and buildings. It pipes the geothermal grey waste hot water into the adjoining Varma

River. The main discharge point has a concrete cooling pit where it is mixed with potable water from a dedicated line (Dell et al.; 2014b). The grey water enters the pit at about 60-85°C and is discharged at 45-60°C. The author's 6 x 16 square meter heated garden intercepted about 8-10 liters per minute of the grey water. The gravity feed cooled the water to the same 45-60°C temperature. In addition to reducing the need for potable water for cooling purposes, as shown in Figure 4, the waste hot water was used in a classic cascade utilization to heat the soil for agricultural purposes.

Figure 3: Piping layout (left), heated garden test bed at the Agricultural University of Iceland (middle), and in progress construction detail showing the pipes and the gravel drainage layer (right).

Figure 4: NLFI swimming pool heat exchangers (left) and the garden pipes before the gravel layer and the top layer of soil were added (right).

The waste hot water from the NLFI greenhouses served as an additional heat source. The working fluid varied in temperature from 40-85 °C. The intermittent flow rate varied from 0-25 liters per minute. The higher flow rate had the highest temperatures. A reservoir tank for storage and thermal stability would need to be designed and built before this heat source could be viable. This student-built garden functioned from 2011- 2015. All the water for this test bed was gravity fed.

A third Iceland heated garden shown in Figure 5 was installed at the Keilir Institute of Technology in Reykjanesbær. It was like the other Icelandic gardens except that it was heated by the municipal hot water that heats the building. This garden functioned from 2010-2019 and incorporated student research projects. It measured 5 x 20 meters.

Figure 5: Keilir garden hot water distribution and monitoring system (left) and the finished heated garden (right).

3. RESULTS AND DISCUSSION

Temperature profiles taken at a depth of 8 cm indicate consistent ΔT's of approximately 10°C every 25 cm as shown in Figure 6. This coincides directly with the location of the heating pipes that are at 25 cm intervals

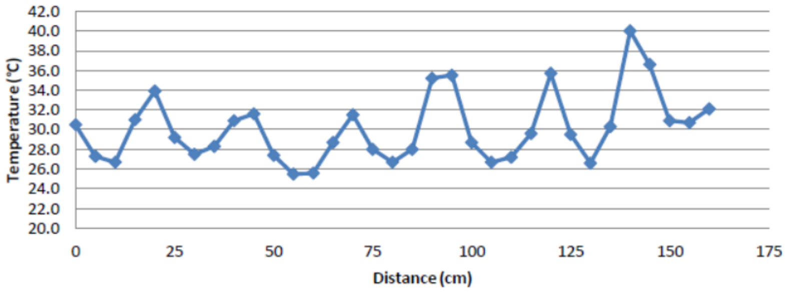

Figure 6: Typical temperature profile showing regular temperature fluctuations every 25 cm.

The energy consumption per square meter of each heated garden was calculated from the mass conservation equation:

$$\dot{q} = \dot{m} C_p (T_h - T_c) \tag{1}$$

where $\dot{q}$ is the rate of heat exchange, $\dot{m}$ is the mass flow rate, T_h is the garden inlet temperature, T_c is the garden outlet temperature, and C_p is the specific heat. The working fluid in the other gardens was water, with the density assumed to be 997 kg/m^3 and the specific heat 4.186 kJ/kg·K. All the gardens had a flow rate of approximately 0.16 kg/s, except the Keilir gardens, which had a flow rate of 0.10 kg/s. The water entered the gardens between 39-55°C, with ΔT's between 5-14°C. Table 1 shows the data collected for each of the gardens.

Using Equation 1, the heat exchange rate for each of the gardens was calculated. The results are shown in Figure 10. The Foundation Building had the greatest heat exchange rate of 0.33 kW/m^2, about double the average heat exchange rate of 0.16 kW/m^2 at three Iceland gardens. This could be in part because of the raised insulated platforms of the New York City test beds. It should also be noted that the New York City test beds use green roof growth medium which is porous to enable water sequestration. It also lacks smaller particulate matter, which also adds to the air permeability, thus enabling convection air flow from the medium's interior.

Table 1: Heat exchange data for the experimental heated gardens.

	$\dot{m}$	T_h	T_c	ΔT	A
	kg/s	°C	°C	°C	m^2
Agricultural Univ.	0.16	55	41	14	50
NFLI top line	0.16	50	43.4	6.6	50
NFLI bottom line	0.16	50	42.8	7.2	50
Keilir first line	0.10	49	38	11	60
Keilir second line	0.10	45	36	9	60
Foundation Building	0.16	48	43	5	10

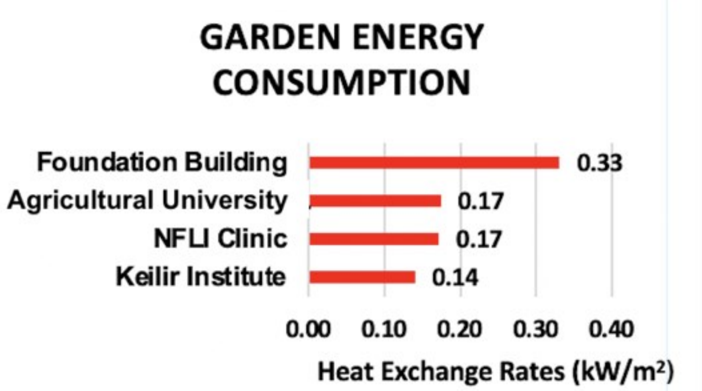

Figure 7: Heat exchange rate per unit area in each of the Iceland gardens and the completed New York City garden.

In the thermal image in Figure 8 below taken of the Agricultural University of Iceland's geothermal heated garden, the pipes are not visible, but the soil depth is clearly delineated. The red areas in the foreground are in the 10 cm heated bed indicating surface temperatures around 20-21°C, the other beds have a soil depth of 20 cm shown in cool colors (blues and greens), indicating surface temperatures 18-19 °C. The bed dividers are the blue and black lines. The black unheated perimeter areas are less than 17°C.

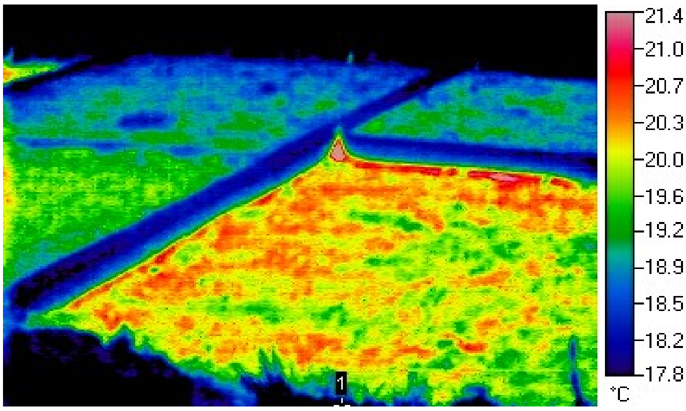

Figure 8: Thermal image of the heated 10 cm bed (front) and 20 cm (rear) heated gardens in Iceland.

As shown in Figure 9, the tomato plants in the heated beds all had one or two main roots that grew following the underground heat pipes in the New York City experimental gardens. The unheated beds had normal root systems. The proximity to heat pipes can have significant effects on plant growth. `

Figure 9: Roots follow the heated pipes in the New York City gardens.

The experimental heated gardens often displayed dramatic differences in growth when compared with the control unheated gardens, as can be seen in Figures 10 and 11.

Figure 10: Heated experimental (left) versus unheated control (right) turnip, oregano, and oak tree gardens in Iceland.

Figure 11: Heated experimental (left) versus unheated control (right) gardens in Iceland.

Figure 12: Harvestable bolls from New York City Cotton Plants in October 2014.

Cotton, which is typically only harvestable in southern parts of the United States, was grown outdoors and yielded harvestable bolls at the Cooper Union in New York City (40°43'46.2"N 73°59'25.7"W), as can be seen in Figure 12. No open bolls occurred in the unheated control gardens (ASHRAE, 2015).

In 2017, Oregano plants at the Agricultural University of Iceland established approximately four times the span in the heated versus the unheated gardens. Growth measurements are plotted in Figure 10 and 13.

As shown in Figure 13 the average spread of the heated oregano was four times the spread of the unheated control plot. None of the unheated zucchini plants survived, as was to be expected because the Icelandic climate is too cold for zucchinis. The average tomato stem diameters were almost double in the heated bed. The average spread of the heated tomato plants was 40% greater in the heated plants. This number is deceiving because tomato plants leave sag as they increase in weight.

Harvestable crops have been produced at the test gardens at the Agricultural University of Iceland. Figure 14 shows the displayed turnips at Frú Lauga, an organic food store in Reykjavik. In this first attempt to commercialize, all proceeds were donated to local charities.

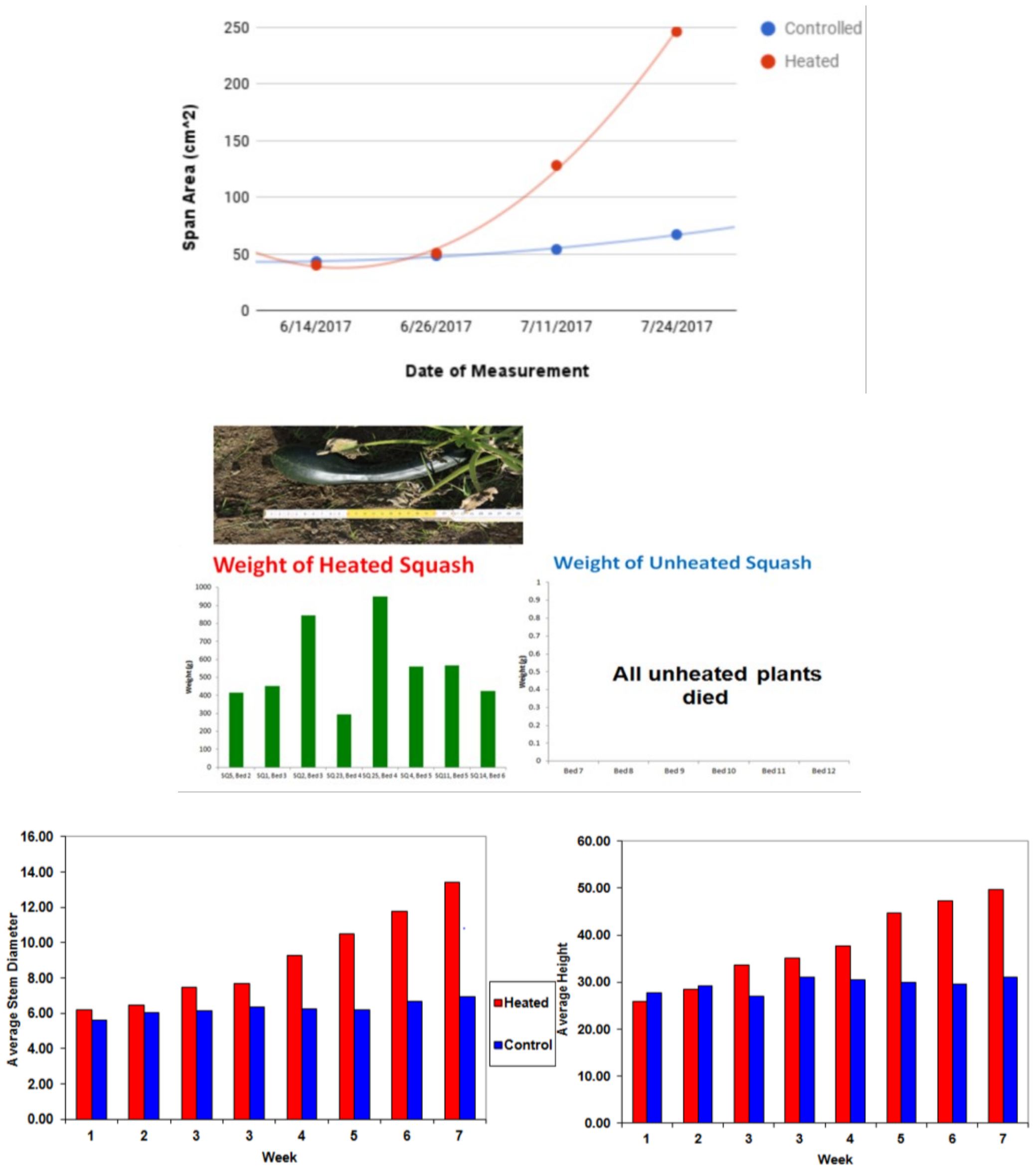

Figure 13: Typical heated versus unheated growth data from the Agricultural University of Iceland geothermal heated gardens. 2017 oregano plants (top), 2012 zucchinis (middle), and 2009 tomato plants (bottom).

4. CONCLUSIONS

In the year 2018, the gardens in Iceland produced a small, marketable harvest of non-indigenous oregano and turnips (Figure 14). The heating system has been installed since 2007 with no maintenance needed for the 12 years of operation of the underground system.

The five test beds demonstrate the adaptability of heated gardens in a variety of waste heat scenarios. The Agricultural University garden uses a standard shell and tube system and works off waste condensate. The NLFI garden uses a gravity feed from a heated swimming pool and shows possibilities of using the waste hot water from greenhouses. The Keilir garden uses municipal hot water in a direct or waste configuration. The New York City heated green roofs have produced enhanced crops and out of region cultivars including cotton.

Tomatoes are usually only grown in greenhouses in Iceland. The results demonstrate the 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 (Dell et al.; 2014b). 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 recorded to be more than 20% of the average plant growth in the control gardens in some instances.

All heating scenarios could be accomplished without the sophisticated monitoring and control systems that are used in typical heated greenhouses. All four systems were proven to be reliable and practical. The cost savings from the additional expense of purchasing and installing heated greenhouses are significant. Although the authors do not contend that this system will replace heated greenhouses, the research does indicate its economic viability as a low-cost alternative for domestic production of some cultivars.

This cascade utilization can create enhanced agricultural production from thermal pollution.

Figure 14: Harvested turnips in a test market setting at Fru Lauga, a local organic food store in Reykjavik. Anecdotal remarks and requests for more turnips indicate public approval of the taste of our product.

Further research and refinements should include a larger scale test bed to serve as a guide for potential commercial development and testing on additional cultivars.

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