

**MARS BASE ZERO:
SUMMER 2002 PRODUCTIVITY***

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ABSTRACT

The International Space Exploration and Colonization Company (ISECCo) has been committed to the advancement of space colonization since 1988. Critical to the human habitation of space is life support technology which includes sustainable food production. ISECCo has built a semi-Closed Ecological Life Support System (Semi-CELSS) facility in preparation for designing a fully closed system. We are currently operating the semi-CELSS, named Mars Base Zero, to achieve a balanced diet that minimizes crop area and maximizes yield. Mars Base Zero uses strictly soil based techniques such as one would use on Mars. The 2002 operation of Mars Base Zero and crop yield are discussed at length.

Keywords: CELSS, agriculture, Mars, greenhouse, ISECCo.

INTRODUCTION

Long-duration space missions and future colonization will rely on closed ecological life support systems (CELSS) to provide most of the needed food, air and water. With this in mind, the International Space Exploration and Colonization Company (ISECCo) began its experiments into developing closed ecosystems in 1988. Our current test platform, named Mars Base Zero, is a 24 x 36 foot (about 7.3 meters by 11 meters) greenhouse with an 8 foot (2.4 meter) wide apartment attached to one end.

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RESULTS

Mars Base Zero is a semi-closed ecosystem designed to provide food for up to one person. While the structure is not yet complete, we have been doing some preliminary experiments with productivity. In the spring of 2002 we planted about 485 square feet (45 square meters), which is a little more than half of the eventual maximum crop area of 864 square feet (80 square meters). The total available crop area is broken into 6 equal squares, each square being 12 feet (3.6 meters) on a side; currently only 3 of these are filled with dirt. We also had potted plants and planting trays in a square that was not filled with dirt.

During the 2002 season we did not close the structure, which is to say that the south half was completely open to the weather. This means that, for the most part, the climate inside Mars Base Zero was the same as the local weather, with the possible exception of the back corners where some heat would be retained by the sheltering structure overnight. Unfortunately for us, 2002 turned out to be an unusually cool summer. June and July were 2° F (1° C) colder than average, and August was 2.5° F (2° C) colder. A couple degrees may not seem like much, but it really clobbered the wheat and some of our other warmer-weather crops. The open structure also caused some problems with the soil getting too wet in the potato square. It started wet from snow melt, and never really dried out because it rained enough to keep it soggy.

On September 28, 2002 Ray Collins moved into Mars Base Zero. The next day he closed himself inside and for the following week he lived exclusively off Mars Base Zero produce. The trial run ended on October 6 in mid-afternoon. For the nine days Mars Base Zero was occupied, and the 166 hours Ray was closed inside, the only food available in Mars Base Zero was what was harvested (on the days Ray was not closed inside the entire day—i.e. the first and last day—he did not eat exclusively from Mars Base Zero). The diet was primarily potato, though there was a practically unlimited supply of carrots, cabbage and turnips. Other foods that were in high demand, like onions and peas, were strictly rationed to assure they would last. Although never really hungry (he always ate whenever hungry), Ray reported a low average calorie consumption (averaging 1675 calories a day) with some minor symptoms of calorie restriction: weight loss (2 pounds over the 9 days) and difficulty keeping warm when inside temperatures ranged down to 25° F (-4° C)—Ray normally does not get cold at these temperatures. (Note: the furnace was not set up for this trial, so the inside temperature was basically the same as outside, in spite of the fact that plastic was put up closing the south side of the structure.)

During the 2002 season we had some notable successes, such as a broccoli plant with a 4.5 pound (2 kilogram) head and potato plants producing 5.5 pounds (2.5 kg); and some notable failures: the beans didn't produce at all; the wheat did very poorly. Overall the crops we would consider to be completely successful were the potatoes, carrots, cabbage, cauliflower, broccoli, lettuce and the herbs. The crops that did the worst were beans, peas and wheat. Intermediate crops were onions, spinach and turnips. Potatoes have almost always proven to be our most productive crop so we planted an entire square—the single largest area for any crop—in potatoes. Wheat is probably the most useful crop one can grow, so we devoted quite a bit of area to it (83 square

feet—7.7 square meters) but it failed. In order of increasing area we also planted Early Scarlet Globe radishes, self-blanching cauliflower, Salad Bowl leaf lettuce, spinach, Bloomsdale long standing spinach, Miracle Sweet tomato, soy beans, red beans, Royal Chantenay carrots, black beans, pinto beans, navy beans, dry onion bulbs, Purple top turnips, Green Arrow tall peas, and Provider bush green beans. We planted tomatoes, Lemon Balm spice, Candy mint, Siam Queen Thai Basil, and celeriac in pots. Shogun broccoli, Mid-season cabbage, and self-blanching cauliflower were planted in both the planting squares and pots. (See also Table 1.) The following is a description of each plant, with comments and a description of next year's plans.

Green beans

We planted the green beans in what turned out to be the worst spot in the garden. During the winter of 1999-2000 Ray and Frances spent the winter living in Mars Base Zero, and we had an emergency space heater set up in the area we planted the beans. In the process of fueling the heater small amounts of diesel fuel got spilt. This may be why the beans (and also peas) did poorly. The location is also shaded in the early morning. Since beans grow quite well here in Alaska their failure was probably a combination of the soil contamination and the lack of sun in the morning. Though we did get a few pods, yield was basically 0.

Next summer we'll put the beans in a different location that has more sun. We may also dig out some of the contaminated soil so what we do plant will grow better! Green beans should be planted by June 15 to harvest in the middle of September.

Peas

Although we did get a few peas, we were overall very disappointed in their productivity. The plants got about 3 feet tall (1 meter), which is a great deal shorter than they normally get to in Alaska (6 feet—2 meters—is common). They were planted against the back wall so we could use the wall to attach the fence for them to climb. Possible causes for their slow growth: lack of *Rhizobia* bacteria (a bacteria which fixes nitrogen for plant use); shading (like the beans, the peas were planted in the very back of Mars Base Zero); lack of water (planted along the very back edge, which may not have gotten properly watered on a regular basis) and possibly some of the soil was contaminated, since some of the peas were planted near the area the fuel spills occurred.

Next summer we will probably plant the peas in the same location. To insure they grow better we may pre-germinate them; dust them with *Rhizobia* bacteria; and make a better effort to keep them well watered. We may also remove some of the possibly contaminated soil. Peas should be planted by June 15 to harvest in the middle of September.

Onions

Onions are one of the most productive crops that can be grown (in terms of calories produced per square foot per day). Unfortunately that isn't so in Alaska. We've grown onions many times,

but in general we've had very low productivity. This summer Mars Base Zero did not prove any different. Though they did grow, the largest wasn't much more than 2 inches (5 cm) in diameter, and the total yield was fairly low. Onions are sensitive to low fertility, and it is possible we didn't have fertile enough soil. Alternatively, the soil may not have been warm enough for optimum growth. By late August temperatures were cool enough so the onions started to senesce for the winter, so we harvested them.

Next summer we'll try growing onions in pots and trays, to try to get the soil warmer to encourage faster growth. We can also plant them earlier in the spring, to extend the season. It may be worthwhile to start a few in April, to see if we can get full sized onions before it gets too cold for them.

Tomatoes

Tomatoes do not grow very well outdoors in Alaska. We planted them, but they frosted before we got any harvest.

Next year we'll start the tomatoes a little earlier, probably the middle of March, and attempt to keep them a little warmer.

Turnips

Turnips usually grow very well in Alaska. Unfortunately they are sensitive to bolting. We planted our turnips in the middle of a back square, in what may be one of the warmest areas. This turned out to be a mistake, because the turnips tended towards bolting rather than growing large tubers. Though we did have a fair harvest, it is nothing like we were expecting.

Next summer we will plant the turnips closer to the outer edge of the greenhouse, and try to keep them a little cooler. Late may planting should yield a good harvest by the middle of September.

Lettuce

The lettuce grew nicely at the south end of one of the troughs. From a little more than 1 square foot (0.3 square meter) we harvested lettuce leaves for 6 weeks totaling 50 oz (1350). After the 4th week we started a second planting of lettuce and spinach in the open space that had been growing spinach (see spinach). The second planting had a good yield but by the time the lettuce really began to mature, the cooler temperatures set in and continuing harvest slowed down. The first harvest was at 7 weeks, with a more robust harvest the following weeks for the first planting. The second planting (planted at the 8th week) yielded the first crop at week 14.

Next year we want to plant about the same area. To have a harvest in the middle of September we will want to have a planting in the middle of July. Naturally we'll plant some earlier so we can have fresh lettuce for our volunteers during the summer!

Spinach

We planted equal amounts of spinach and lettuce in the front of the greenhouse. Unfortunately, spinach tends to bolt due to the long daylight hours here in Alaska. We first got spinach about week 7. By week 8 it had started to bolt, and by week 9 it had nearly all bolted. Even so, we did harvest 12.6 ounces (340 grams) from 56 plants from our first planting. The second planting also bolted but we managed to get 2.3 ounces (64 grams) over 3 weeks of harvesting. Timing of the plantings were the same as the lettuce.

Next summer we'll plant our spinach much later in the summer, and we'll plant it in the back of the greenhouse to reduce light and hopefully inhibit bolting. We'll also try other varieties and we hope to find a bolt-resistant one. Another variety of spinach (mustard spinach) grows more like lettuce and Debi-Lee has grown it in an Alaskan garden more successfully than the taller varieties. Seven weeks before the middle of September is late July, so we should plant our spinach in late July.

Cauliflower

We harvested 4 lovely and tasty heads of cauliflower yielding about 12 cups (about 3 liters) per head. Interestingly, the 3 plants in pots did better (they could have been harvested 2 weeks sooner) than the one plant in the regular square. It was situated three quarters of the way to the back (to the north, which is shaded in the morning and evening) and may have done better farther south, where there was better sun. Also the pots probably had better soil temperatures. All the cauliflower heads yielded very close to 2.5 pounds (about 1 kg) each. The first three heads were harvested at week 13—though the other two of them could have been harvested at week 12: we didn't have anyone available to do harvesting then. This number of weeks refers to the length of time since they were transplanted into Mars Base Zero; the plants were about a month old when transplanted. Total growth time was 16 weeks.

Next year we will plant all our cauliflower in pots. To have a harvest during the middle of September, we will need to plant our cauliflower (from seed) in the middle of May. Four to six plants will probably be adequate again.

Broccoli

Conversely, the broccoli plant grew better in their corner of the 12 foot by 12 foot (3.6 meter) squares than the 1+ square foot (1/3 meter) pot. However, only one of two plants in the square survived. These were started four weeks early (in pots) and one did not survive the transplant, possibly because of not enough water. The first broccoli (all 4 pounds—1.8 kilograms—of it!)

was harvested at week 11. Since the broccoli was from pre-plants (like the cauliflower, 4 weeks old), total growth time was 15 weeks.

Next year we will plant all our broccoli in the squares. We'll want to plant four to six plants from seed in the 3rd week of May to harvest in the middle of September.

Dry Beans

We experimented with black beans, navy beans, pinto beans and red beans and soy beans. We planted them in the middle back crop square. Most of the beans were pre-sprouted in ragdolls (a rolled paper towel, kept moist). They all grew very well, reaching 3 to 5 feet (1-1.5 meter) in height and climbed nicely around the posts. They did not have enough warm weather time to produce beans but did have a few flowers. We had a number of freezing nights that slowly killed them back in the last month (September) of operation. The soy beans did well compared to earlier experiments which indicated that they need a hot climate; with better summer weather and starting them early enough in the spring we may coax a crop from them.

Next summer we'll plant beans again, but we intend to start them very early (April?) in the hopes that we'll get a long enough season to actually have something to harvest in September. Keeping the greenhouse heated in the fall will help.

Cabbage

We planted 2 cabbage pre-plants (4 weeks old) in the 12 foot (3.6 meter) squares and 2 in pots. Like the broccoli, only one grew in the squares but it outgrew the potted ones. Cabbage is a good Alaska crop since it both grows well and survives a hard frost. Although not as large as we've seen it grow in gardens, our cabbage was a good size, weighing 6 to 8 pounds (3+ kilograms) each.

Next summer we'll plant the cabbage from seed in early May to have a harvest in the middle of September.

Carrots

Actually the carrots did better in total yield per day at one ounces (28 grams)*per square meter per day over the full 19 weeks of operation than the potatoes at 0.8 ounce (23 grams) per square meter per day: calories per square meter per day is the most important factor for Mars Base Zero. Since carrots have fewer calories per ounce (or gram) than potatoes, their productivity is actually a lot less in terms of calories produced per square meter per day. See Table 1.

This carrot variety yielded small 1 to 6 inch (2.5-15 cm) carrots, but normal diameter that were very sweet. Early harvest is determined by crowding. We actually had a terrible germination rate; only half the carrots planted came up (67 of 145) though most of the carrot patch looked full. Very likely germination failure was due to insufficient water. Next year we will put a layer

of plastic over them until they sprout, which will not only keep the soil moist, but it will heat the soil as well (encouraging faster germination).

There should be no change in how we plant carrots next summer; we'll plant them as soon as the greenhouse is warm enough. We do want to see how well they grow in trays, however. So we'll plant them both in squares and in trays to compare growth rates and yield.

Celeriac

We planted one stalk in a pot and harvested a root ball almost the size of a softball. Celeriac can be used somewhat like celery, and is a good source of selenium—a mineral that is very hard to get enough of on the Mars Base Zero diet.

Next summer we'll plant another pot of celeriac, probably using a pre-plant again.

Wheat

Wheat is a very marginal crop in Alaska, and any summer that is even slightly cooler than normal will cause the wheat to fail. We had a cooler than normal summer this year, and with the open structure our wheat did very poorly. The poor overall health of the wheat led to serious aphid infestation, which only aggravated the situation. If we'd been relying on wheat for food we'd have gone pretty hungry!

Although wheat is such a marginal crop for us, it is so useful as a food that we'll try again next year. We expect to increase our total area planted by 30% so we'll have the area to try the wheat again. We'll also try a few other grains like oats and barley for variety.

Potato

In the past, potatoes have been our best crop. They did not disappoint us this year either. We planted 138 square feet (11.14 square meters) in potatoes. The most productive potato plant yielded nearly 6 pounds (2.6 kilograms) of potatoes. We were a little worried that the soil was too wet (it started wet, and never really dried), but they grew well anyhow. We will probably plant the same amount of area next year, with no change in fertilization or watering schedule. Total yield in potatoes was 68 pounds (31 kilograms). If the entire planting area had been planted in potatoes we would have been producing an average of 2,600 calories a day, which is marginally enough to support a person.

This year we planted 3 different varieties of potato. The white potatoes (Yukon Gold) out-produced the others with a total yield for the season of 0.8 pounds per square foot (4 kg/m^2); red potatoes produced second best with a yield of 0.4 pounds per square foot (2 kg/m^2) and the purple did worst with only 0.2 pounds per square foot (1 kg/m^2). The Yukon Gold variety produced 3.2 calories per square foot per day (35 calories per square meter per day). If all 864

square feet (80 m²) were planted in these potatoes the yield would be 2,800 calories per day—continuously.

We were careful to keep the potatoes in the front half of the greenhouse to prevent the soil from getting too warm since potatoes fail to set if the soil temperature is more than 68° F (20° C). The soil temperature in the back parts of the greenhouse never exceeded this, so it may be an option to plant them further back.

Next year we'll plant about 50% more potatoes that we did this year, and we will use only white potatoes, though we may try a few different varieties of them, such as Yukon Gold and Bake King. We'll also try to keep the soil somewhat dryer. We want to try some experiments with crowding, for some of our data indicated that the potatoes were getting too crowded because the margins did far better than the centers. However this could also be due to warmer soil temperatures, so we will also experiment with planting potatoes in trays and farther back in the greenhouse, to see how well they grow in warmer soils. Some of the data indicated the boardwalk (a board which runs over the center of the potato patch to assist in weeding and watering—the entire 12 foot by 12 foot (3.6 meter) square was a solid bank of potatoes) may have reduced productivity of the plants immediately beside it (due to shading). We need to investigate this possible effect too. (The plants seemed to be growing unimpeded by the plank, but we need to justify this observation quantitatively).

CONCLUSION

Mars Base Zero was not fully operational in the summer of 2002. In spite of that, we had a crop sufficient to support a person for more than the week we actually had someone closed up inside. The crop was lacking in certain dietary aspects, partially due to the failure of certain crops. (For example vitamin E consumption was less than 20% of RDA; calcium was around 35% and riboflavin was 40%.) However we feel the trial was a complete success since we managed to close the door this early in our experiments. Further trials will stretch our operating capabilities, and as we work toward getting the structure finished with all the available crop areas planted we will be able to have longer and longer closed periods.

For Mars Base Zero to support a person it needs to continuously produce food. Our current method of operation does not allow continuous production, but it will allow us to build the operational skills needed to run Mars Base Zero continuously when the structure is complete. Although our planting techniques are different now than they will be when under continuous operation (for example, with continuous operation new plants can be planted before the old ones are harvested) we can get a general idea of total productivity. If our goal is to have Mars Base Zero support a person (though we don't really expect it to, it may come close), we need to harvest around 2,500 calories per day. This year we had about 55% of the total area planted for about 120 days. About 40 days of this were probably not very productive (plants don't tend to do very well when nearly frozen), so our probably growth period was 80 days. 55 percent (the percent of Mars Base Zero we planted) of 80 days is 44 days; in order to support a person for

44 days we should have harvested around 110,000 calories. Our actual harvest was closer to 40,000 calories—far short.

During the summer of 2003, we will expand our crop area by around 144 square feet (11 square meter) nearly doubling the potato area and adding a number of crops. We are already experimenting with peanuts, and we hope to have a successful crop (good for vitamin E). We may also try rice. These hot weather crops will require a sheltered area and a lot of extra work, but, if successful, they will significantly improve the diet. We will also try less radical crops such as sunflower seeds (also a good source of vitamin E), barley and oats. In the fall of 2003 we hope to run Mars Base Zero closed for longer than the week we did this fall.

TABLE next page

Table 1: Crop yield data

Crop	Area planted m ²	Growing period, plant-harvest (in days)	Total yield in grams	Total yield/m ²	Grams yield/m ² -day (yield/m ² divided by days)	Calories per m ² per day
Broccoli – in pots	0.56	5/25-9/15 119	1020	3642	30.6	9
Cabbage in Pots	0.28	5/25-9/30 128	6519	8809	34	16
Cabbage-Mid Season	0.74	5/25-9/29 128	3261	4407	34	9
Carrots –Royal Chantenay	0.93	5/26-10/1 129	3371	3664	28.4	12
Cauliflower in Pots	0.28	5/26-8/19 91	2762	9864	108	27
Cauliflower-Self Blanching	0.12	5/26-9/2 105	1156	9632	92	23
Celeric	0.09	6/2-8/26 91	280	311.6	31.8	12
Lettuce-Salad Bowl	0.14	5/28-8/26 98	1297	9267	94.6	17
Lettuce – 2 nd crop	0.14	7/13-9/6 56	133.1	951	17	3
Onions-Dry Bulbs	1.53	5/26-9/2 105	2125	1389	13.2	5
Potatoes --All	11.14	6/2-10/1) 121	31.03	2,785	23	24
--Purple	4	121	4.33	1,080	8.92	9
--Red	1.14	121	2.4	2,087	17.25	18
--White	6	121	24.3	4,050	33.47	35
Radish – Early Scarlet Globe	0.56	5/26-7/13 49	189.8	340.7	6.95	1
Spinach-Bloomsdale	0.28	5/28-7/13 56	357	1275	22.76	5
Spinach (2 nd crop)	0.14	7/13-9/6 56	65.15	465.4	8.31	2
Turnips-Purple Top	1.86	5/26-9/28 128	3279	1763	13.8	4