To: Lt Col Mike Potter, SO1 FD

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Hydroponic Vertical Farming - Cost-Benefit Analysis

Issue

1. This report evaluates the applicability of hydroponic vertical farming to the support network when used in forward locations such as Forward Operating Bases (FOBs).

Recommendation(s)

2. SO1 Concepts is requested to note:

a. Hydroponic vertical farming is a modern farming technique (early 21st century), which aims to optimise and increase crop yield whilst using a smaller unit area of land requirement than conventional farming. Hydroponics refers to the process of growing plants in liquid solutions containing macronutrients rather than using soil.

b. Operation and Set-up of Hydroponic Vertical Farm. The biggest hydroponic vertical farm expenditures are energy (more than 50% of total expenditures), and labour (56% of operating budget).

c. Vertical farming is not likely to be able to replace all nutritional requirements for deployed troops and so is judged to be best suited to complementing other sources of nutrition.

d. Complement versus Substitute. If the intention was to fully replace the current FOB Feeding Regime by hydroponic vertical farming, the costs associated with setting-up and operating the indoor farms are expected to be approximately 5 times as high as in the ‘complementary food supply’ scenario.

e. Full Replacement. If it were decided to replace the current FOB Feeding Regime (i.e. ORPs + Fresh Food Contract) by hydroponic vertical farming, the total annual food supply expenses could be reduced by about 33%.

f. Replacement of Fresh Food Contract. If it were decided to only replace the current FOB Fresh Food Contract after D+30 by hydroponic vertical farming, the total annual food supply expenses could be reduced by approximately 20%.

g. Carbon Emissions. If the FOB hydroponic vertical farm is used as a complementary food supply, the carbon emissions for the deployment of equipment and containers are expected to double in Scenario 1 and 2 and to increase by approximately 5% (or £2,087,424) in Scenario 3 if the FOB was in the Middle East.

h. Nutritional Requirements. Although vertical farming might be cheaper than the current Fresh Food Contract, it does not include other food items which are part of the daily nutritional requirements such as meat, dairy, eggs and sweets.

3. And agree:

a. Further investigation is undertaken to break down the Deployed Food Contract costs for a more detailed comparison.

b. Additional analysis is performed to map food shortages around the globe against the specific food options that hydroponic vertical farms can provide.

c. Further research into potential legal challenges to be undertaken. Some vertical farming systems may require the permission of state officials.

Background

4. The defence sector spends more than £15m per year on operational feeding across the globe. This paper aims to analyse whether in-theatre vertical farming is a useful concept for Sp Ops CFD to investigate commercially in order to reduce annual feeding expenditures.

5. The subject of vertical farming has become increasingly popular as global food scarcity rises and the lack of suitable farming land through erosion and continuing infrastructure development.

6. Hydroponic vertical farming is a modern farming technique (early 21st century), which aims to optimise and increase crop yield whilst using a smaller unit area of land requirement than conventional farming. Hydroponics refers to the process of growing plants submerged in liquid solutions containing macronutrients rather than using soil.

7. Containers are the most commonly used facilities for vertical farming systems. Vertical farming containers are often equipped with LED lighting, vertically stacked hydroponics, and smart climate control & monitoring systems to assure optimal plant growth around the clock.

8. In 2016, the U.S. Navy placed a scientific experiment around vertical farming with the mission to test hydroponic gardening at the Natick Soldier Research. The main advantages and difficulties that have been identified during the experiment are.

9. **“One size does not fit all”.** Different plants have different climate and growing requirements, which makes it difficult to facilitate a broader range of fruit and vegetables. Accordingly, some fruit and vegetables did not grow well. Yet, out of 83 different crops, over 50 different crops were successful.

10. **Space Requirements.** Supplying a crew of 130-170 people with fresh tomatoes, cucumbers, and zucchini might require more space than is available on a submarine or any FOB. Even if compact tomato varieties were grown, the energy consumption of lights that make them productive might be a problem for available resources.

11. **Water**. Fresh water is also a limited resource at sea. However, hydroponic gardening uses 90% less water than traditional growing. The military's farm lab has 280 gallons circulating through the system, but the plants only require a maximum of 10 gallons a day.

Aim

12. This project aims to evaluate the opportunities and challenges afforded by introducing container hydroponic vertical farming as complementary and substitutional food supply method to the current FOB Feeding Regime. The idea is to make fresh fruit and vegetables accessible to personnel from D+1 to deliver a healthier and more diverse diet. Hydroponic vertical farms utilising controlled environmental agriculture to optimise plant growth could offer the potential for the farm-to-fork supply chain to be self-sustaining inside the FOB. The project analyses the following aspects:

13. **Financial.** Comparative cost-benefit analysis of hydroponic vertical farming (i.e. start-up and ongoing cost) versus current Operational Ration Pack (ORP) and Fresh Food Contract expenditures.

14. **Deployment, Environment & Health.** Brief analysis of logistical and environmental impact of hydroponic vertical farming. Additional comments on FOB nutritional requirements.

Class I Assumptions

15. This project is based on the following assumptions:

16. **Scenarios.** The project is divided into three separate scenarios: Forces of 200, 1,000 and 30,000 personnel. Each of the forces are at the FOB for 3 months.

17. **Containers.** Spare containers are used in the first scenario (i.e. 200 personnel) to avoid unnecessary expenses. Containers are to be purchased for bigger forces.

18. **ORPs.** Personnel receive 24-hour ORPs everyday between D+1 and D+30 and 10-man ORPs twice per week after D+30, when the fresh food range partly comes into place. For infantry in close combat (i.e. 1/5 of the force) Single Meal Ration per 3 days per person are deployed between D+1 and the end of the operation.

Current FOB Food Supply Regime and Contracts

19. The prime means of feeding FOB personnel are the 10-man ORP, the 24-hour General Purpose ORP and the Single Meal Ration Pack (see Table 1).

Key Findings - Financial

Annual ORP Expenses

20. According to historical Operation Herrick data, 24-hour ORPs and Single Meal Rations are £12 per soldier per day, whilst 10-man ORPs are £59.60 per unit. Considering the FOB ORP distribution outlined in the section above, this translates into the following annual ORP expenditures:

a. Scenario 1: £139,161

b. Scenario 2: £698,808

c. Scenario 3: £10,502,400

Annual Fresh Food Contract Expenses

21. The current Fresh Food Contract was awarded 1 Oct 17 as 5 years with 2 optional years. If these are taken up the contract will end 30 Sep 2024.

22. The Defence Food Programme commits the commercial food supply contractor to provide an operational core range to non-permissive environments after D+30 (i.e. fresh fruit and vegetables enhancing 10-man ORPs) and a full range after D+90.

23. The total annual FOB Fresh Food Contract expenses are estimated to be around £15m per annum (depending on activity), including a set management fee (UK) and the variable costs of food, logistics and fuel.

24. Using the FOB Middle East Fresh Food overseas invoice data from 2019 (excl. fuel and logistics) as a reference, the following annual Fresh Food Contract expenses can be outlined for each of the three scenarios:

a. Scenario 1: £673,641

b. Scenario 2: £3,368,207

c. Scenario 3: £101,046,210

Total Current Food Contract Expenses

25. The current total annual FOB Feeding Regime expenses (i.e. ORPs + Fresh Food Contract) add up to the following total for each scenario:

a. Scenario 1: £812,802

b. Scenario 2: £4,067,015

c. Scenario 3: £111,548,610

Stage of Deployment	Feeding Regime
Standby	Fed in barracks under normal collective feeding arrangements.
In Transit	• Packed meals or transit meal packs • Collective feeding at staging posts • ORP • Meals provided by the carrier (In flight, rail, sea etc)
On arrival in Op Theatre	• Individual feeding – 24hr ORP • Collective feeding – ORP/Fresh/Combination
D+1 to 30	• ORP • ORP + Ambient Supplement (when available) • ORP + Fresh Supplement (when available)
D+30 to D+90	• Fresh and ambient to scale plus ORP
D+90 >	• Fresh to scale[9] or full cash messing (may include compulsory ORP issues)
In Contact	• ORP (supplements if available)

Figure 1: Current FOB Feeding Regime

Set-up and Ongoing Cost Hydroponic Vertical Farm

Energy, Growing Media and Labour

26. Energy. Small vertical farms (i.e. vertical farms below 10,000 square foot) use an average of £2.65 per square foot on energy (electricity, lighting, cooling, fans, pump, etc.), translating into £5,088 per container vertical farm per annum. In other words, any energy-related costs are estimated to account for more than 50% of a vertical farm's expenditures as shown in the diagrams below.

27. Growing Media. Expenses for materials like growing media, seeds, and nutrient solution account for approximately 5-12% of an indoor vertical farm's budget.

28. **Labour.** Container vertical farms typically spend 56% of their operating budget on labour. In the case of a 20-foot container this translates into £2,555 per container.

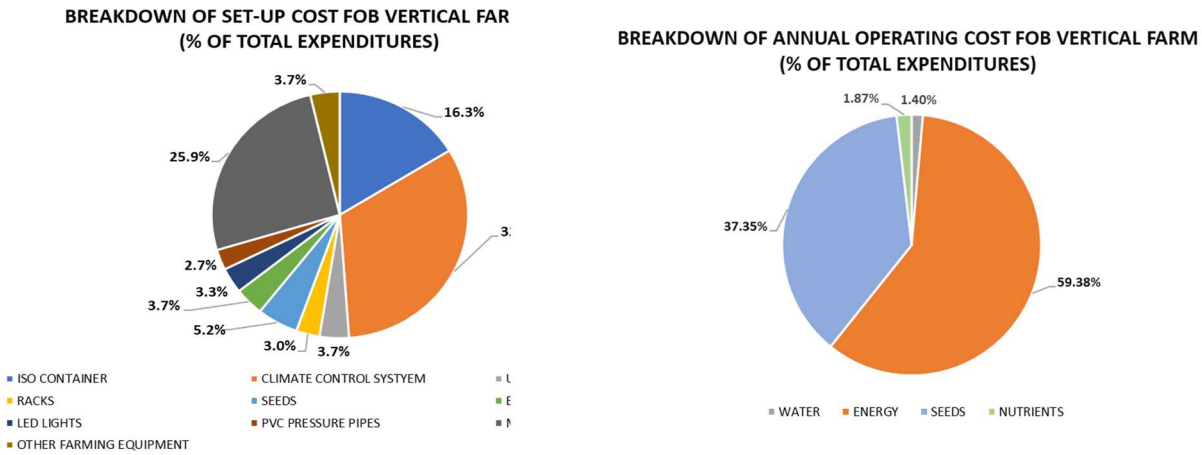

Figure 2: Break-down of Set-up and Ongoing Cost FOB Vertical Farm (% of total Expenses)

Total Cost Findings Vertical Farm

29. The below outlines the total cost of hydroponic vertical container farms as a complementary FOB food supply method. Using vertical farming as a 'complementary food supply source' means that each person is provided with a small plate of in-theatre grown fresh vegetables in addition to the traditional defence Feeding Regime every day. A more detailed cost break-down can be found in the Appendix of the paper.

30. **Scenario 1:** 4 containers are used for vertical farming purposes and 1 container is used as a storage fridge freezer. The set-up cost equals approximately £48,000. The annual operating cost is £52,460 (incl. £10,200 on labour). Total cost hydroponic container vertical farm: **£100,460.**

31. **Scenario 2:** 12 containers are used for vertical farming purposes and 6 containers are used as storage fridge freezers. The set-up cost equals approximately £155,000. The annual operating cost is £172,644 (incl. £30,660 on labour). Total cost container vertical farm: **£327,644.**

32. **Scenario 3:** 150 containers are used for vertical farming purposes and15 containers are used as storage fridge freezers. The set-up cost equals approximately £1,697,000. The annual operating cost is £1,852,770 (incl. £383,250 on labour). Total cost hydroponic container vertical farm: **£3,549,770.**

33. If the intention was to fully replace the current FOB Feeding Regime with hydroponic vertical farming, the total cost (i.e. set-up and operating) of the indoor farms are expected to approximately be 5 times as high as in the complementary scenarios.

34. Additional expenses are expected to occur for the provision of milk, eggs, meat and sweets, which cannot be facilitated by vertical farming but are a strict part of the FOB diet. It is assumed that those three elements correspond for about 2/3 of the FOB Fresh Food Contract expenses listed in the 'Annual Fresh Food Contract Expenses' section.

Comparative Analysis - FOB Vertical Farming versus Current Contract

35. The diagram below shows a comparative analysis between FOB vertical farming (treated as a substitute of the current FOB Feeding Regime from D+1) versus the current total annual food supply contract expenses (i.e. ORPs + Fresh Food Contract).

36. The vertical farming scenario also considers additional cost for meat, egg, milk and sweets (marked as 'miscellaneous'), which cannot be facilitated by vertical farming itself and corresponds to approximately 2/3 of the above listed annual Fresh Food Contract expenses.

37. By replacing the current FOB Feeding Regime (i.e. ORPs + Fresh Food contract) by hydroponic vertical farming, the total annual food supply expenses could be reduced by about 33%.

38. If it were decided to only replace the current FOB Fresh Food Contract after D+30 by hydroponic vertical farming, the total annual food supply expenses could be reduced by approximately 20%.

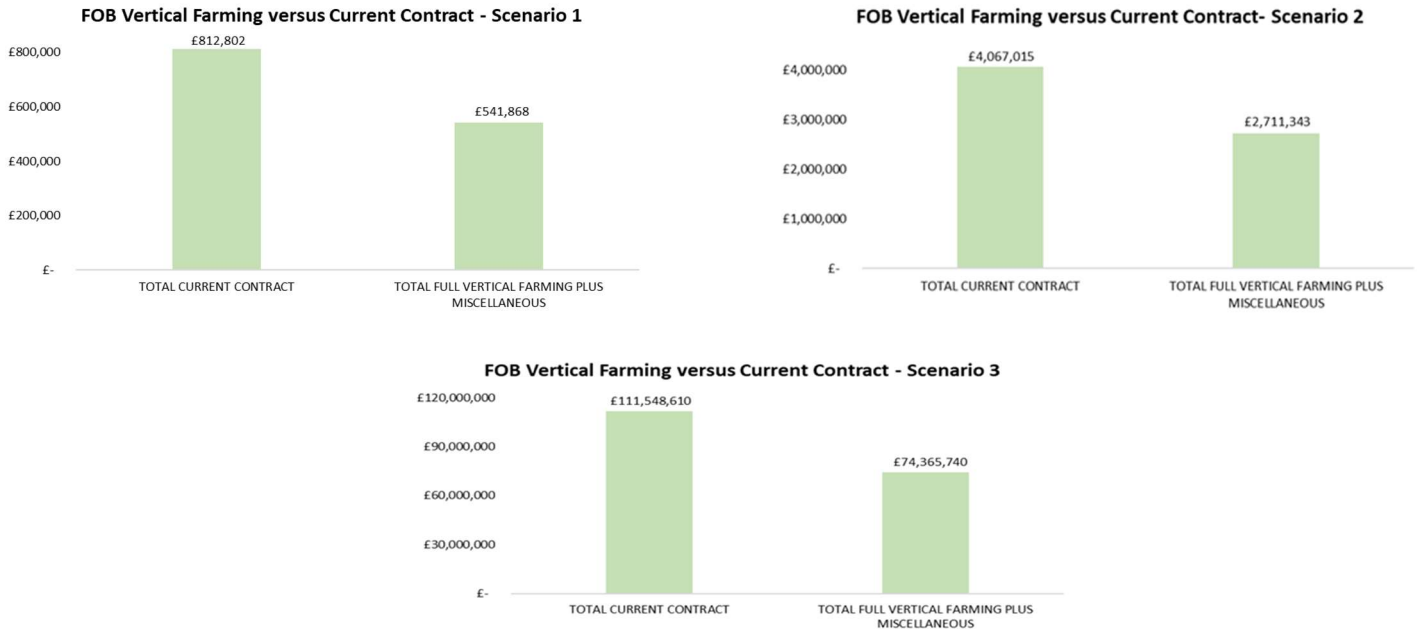

Figure 3: FOB Vertical Farming versus Current Contract – Annual Expenses

Deployment & Carbon Emissions - Vertical Farming as a Complementary Food Supply

Deployment

Carbon Emissions and Environmental Factors

39. **Deployment.** Adding FOB hydroponic vertical farming to the current defence Feeding Regime means that twice as many C-17 Globemaster III return flights to the FOB are required, which translates into a doubling in carbon emissions and expenditures in Scenarios 1 and 2. An additional 27 flights (a 5% flight increase) are required in Scenario 3.

40. **Example:** 27 additional return flights to the Middle East (Muscat) cost £2,087,424 (i.e. £77,312 per C-17 Globemaster III return flight to Oman).

41. **Energy.** Vertical farms also face large energy demands due to the use of supplementary light like LEDs. If non-renewable energy is used to meet these energy demands, vertical farms could produce more pollution than traditional farms or greenhouses.

42. **Water.** However, the advantages of hydroponics include the ability to increase yield per area and reduce water usage. Hydroponic farming could increase the yield per area of lettuce by around 11 times while requiring 13 times less water.

Key Findings – Health and Nutrition

43. The current nutritional standards of 10-man as well as 24-hour ORPs suggest that vertical farms in the FOB would be a good complement to the current diet, since:

a. The government's 'Eat Well' guidelines advice to eat at least 5 portions of a variety of fresh fruit and vegetables every day, since fruit and vegetables are a primary source of vitamins, minerals and dietary fibre.

b. 10- man Ration Packs are suggested to be supplemented with bread, fresh fruit and vegetables where supply allows. Also, 24-hour ORPs are suggested to not be consumed for any longer than 30 days without additional fresh fruit or vegetables

44. Sufficient nutrition in-theatre from D+1 is highly important, since the effects of poor nutrition may result in reduced manning due to absenteeism, reduced operational readiness, decreased retention / morale and increases in injury amongst personnel.

45. However, it may be difficult to cover the whole range of in-theatre nutritional requirements purely through vertical farming. The high daily calorie intake requirements (see figure below) will be difficult to be met by vertical farming considering the high operational cost and the small variety of plants that can be grown in hydroponic containers.

46. **Example:** In order to meet the required daily calories by means of hydroponic vertical farming, approximately 1000 pieces of kale or carrots would have to be prepared per individual.

47. Most types of ORP have a 1 to 4-year shelf life, whilst fresh vertical farming fruit and vegetables must be consumed within a couple of weeks of harvesting. If the harvested fruits or vegetables were to be frozen, it would defeat the purpose of adding fresh food to the FOB diet, whilst some vitamins are lost during processing of frozen produce .

48. Plants that are raised with the help of vertical farming systems may contain fewer nutrients compared to plants that are raised outside on the field.

49. ORPs contain additional operational necessities such as Emergency Survival Rations and Operational Ration Heaters which cannot be not be supplied through vertical farming.

50. Other dietary requirements such as dairy, eggs, meat and sweets cannot be met by vertical farming itself. Hence, ORPs may always have to maintain part of the FOB diet.

Nutritional requirements 24-hour ORP versus Vertical Farming

Per Unit	24-hour ORP	Carrot	Kale
Calories	4500	41	49

Figure 4: Daily Nutrition FOB

Summary of Findings

51. **Operation and Set-up of Hydroponic Vertical Farm.** The biggest hydroponic vertical farm expenditures are energy (more than 50% of total expenditures), and labour (56% of a vertical farm's operating budget).

52. **Full Replacement.** If it were decided to replace the current FOB Feeding Regime (i.e. ORPs + Fresh Food contract) by hydroponic vertical farming, the total annual food supply expenses could be reduced by about 33%.

53. **Replacement of Fresh Food Contract.** If it was decided to only replace the current FOB Fresh Food Contract after D+30 by hydroponic vertical farming, the total annual food supply expenses could be reduced by approximately 20%.

54. **Complement versus Substitute.** If the intention was to fully replace the current FOB Feeding Regime by hydroponic vertical farming, the costs associated with setting-up and operating the indoor farms are expected to approximately be 5 times as high as in the 'vertical farming as a complementary food supply' scenario for each of the three force sizes.

55. **Carbon Emissions**. If FOB hydroponic vertical farm is sued as a complementary food supply, the carbon emissions for the deployment of equipment and the containers are expected to double in Scenario 1 and 2 and to increase by approximately 5% (or £2,087,424) in Scenario 3.

56. **Nutritional Requirements**. Although vertical farming might be cheaper than the current Fresh Food Contract, it does not include other food items which is part of the daily nutritional FOB requirements such as meat, dairy and eggs.

Further Considerations

57. Due to the lack of reliability of the current vertical farming technology, vertical farming may only be considered as a future concept. Vertical farming technology is still at an early stage and it requires further development in order to improve the processes and make vertical farming suitable for the production of fruits and vegetables on a large scale.

58. Calorie allowances vary amongst regiments, corps and injured versus non-injured personnel, which is also strongly influenced by physical activity during operations.

59. Growing times and the strict FOB nutritional requirements make it difficult to treat FOB vertical farming as an effective alternative for short-term operations. Hence, if willing to face high expenditure of setting up and maintaining a container hydroponic vertical farm, plants may be considered to be grown before the deployment to establish a ‘ food supply base’.

60. Due to the high financial set-up cost associated with vertical farming, in-theatre vertical farming may be considered for long term operations or as a complementary form of food supply in permanent in-theatre bases (e.g. Falkland Islands).

61. Once the vegetables and/or fruit have grown, the food still needs to be prepared which might yield additional cost.

62. Within the Forward Operating Base (FOB), containers might be an easy target for indirect fire or other weapons. This could put the harvest and hence the food supply at risk.

63. Some vertical farming systems may also need the permission of state officials. In some states, it may be even forbidden to construct and operate those systems without a certain qualification level.

64. Vertical farming containers require a lot of space which might not be available depending on the size of the FOB.

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APPENDIX

Rough Set Up Cost Hydroponic Farm Containers approx. 200 Personnel

ITEM	COST PER CONTAINER (£)	QUANTITY	TOTAL COST (£)
ISO CONTAINER	2,000	0	-
CLIMATE CONTROL SYSTYEM	4,000	5	20,000
UV FILTRATION SYSTEM	500	4	2,000
RACKS	400	4	1,600
SEEDS	700	4	2,800
EASY TO GROW AUTOPOT	500	4	2,000
LED LIGHTS	450	4	1,800
PVC PRESSURE PIPES	360	4	1,440
MONITORING SYSTEM	3,500	4	14,000
OTHER FARMING EQUIPMENT	500	4	2,000
TOTAL	10,910		47,640

Hydroponic Farm Ongoing Operational Expenses approx. 200 Personnel

ITEM (TOTAL)	ANNUAL COST PER CONTAINER (£)	QUANTITY	TOTAL ANNUAL COST (£)
WATER	150	4	600
ENERGY	5,088	5	25,440
SEEDS	4,000	4	16,000
NUTRIENTS	200	4	800
TOTAL	9,438		42,240

Rough Set Up Cost Hydroponic Farm Containers approx. 1,000 Personnel

ITEM	COST PER CONTAINER (£)	QUANTITY	TOTAL COST (£)
ISO CONTAINER	2,000	18	36,000
CLIMATE CONTROL SYSTYEM	4,000	18	72,000
UV FILTRATION SYSTEM	500	12	6,000
RACKS	400	12	4,800
SEEDS	700	12	8,400
EASY TO GROW AUTOPOT	500	12	6,000
LED LIGHTS	450	12	5,400
PVC PRESSURE PIPES	360	12	4,320
MONITORING SYSTEM	3,500	12	42,000
OTHER FARMING EQUIPMENT	500	12	6,000
TOTAL	10,910		154,920

Hydroponic Farm Ongoing Operational Expenses approx. 1,000 Personnel

ITEM (TOTAL)	ANNUAL COST PER CONTAINER (£)	QUANTITY	TOTAL ANNUAL COST (£)
WATER	150	12	1,800
ENERGY	5,088	18	91,584
SEEDS	4,000	12	48,000
NUTRIENTS	200	12	2,400
TOTAL	9,438		141,984

Rough Set Up Cost Hydroponic Farm Containers approx. 30,000 Personnel

ITEM	COST PER CONTAINER (£)	QUANTITY	TOTAL COST (£)
ISO CONTAINER	2,000	165	330,000
CLIMATE CONTROL SYSTYEM	4,000	165	660,000
UV FILTRATION SYSTEM	500	150	75,000
RACKS	400	150	60,000
SEEDS	700	150	105,000
EASY TO GROW AUTOPOT	500	150	75,000
LED LIGHTS	450	150	67,500
PVC PRESSURE PIPES	360	150	54,000
MONITORING SYSTEM	3,500	150	525,000
OTHER FARMING EQUIPMENT	500	150	75,000
TOTAL	10,910		1,696,500

Hydroponic Farm Ongoing Operational Expenses approx. 30,000 Personnel

ITEM (TOTAL)	ANNUAL COST PER CONTAINER (£)	QUANTITY	TOTAL ANNUAL COST (£)
WATER	150	150	22,500
ENERGY	5,088	165	839,520
SEEDS	4,000	150	600,000
NUTRIENTS	200	150	30,000
TOTAL	9,438		1,469,520

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