Gaps List KSC Space Crop Production Project Scientist:
Interview Evaluation

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The Space Crop Production (SCP) Program at the NASA Kennedy Space Center (KSC) is aimed at achieving nutrient supplementation and moving towards caloric independence from Earth by growing crops for astronauts. However, growing crops outside of Earth's orbit creates many new challenges. The KCS SCP Project Scientists have developed a method of organizing these challenges, called the Gaps List. This Gaps List is a dynamic, taxonomically arranged list of missing knowledge and technologies needed to reach production goals. The purpose of this evaluation was to assess the effectiveness and current research coverage of the Gaps List by using it to document KSC SCP Program research. It was determined that there are several needs within the SCP Program that are not being met, as well as, many deficiencies within the Gaps List. Gaps involving hardware were largely unrecognized by both the KSC researchers and the funding sources that would typically support them. The KSC SCP Project will require more engineering and physical sciences support to fill those gaps. The Gaps List was found to be out of date and in need of rearrangement. A recommendation from this review was that the Gaps List be reassessed at regular intervals to ensure all gaps, and relevant research topics are included. To better understand the gaps within the list, any assessment needs to include a measure of priority, dependency, and breadth. These measures may be included within or alongside the current taxonomical arrangement of the Gaps List.

Nomenclature

AES	=	Advanced Exploration Systems
BPS	=	Biological and Physical Science
CIF	=	Center Innovation Fund
HRP	=	Human Research Program
IR&TD	=	Independent Research & Technology Development
ISS	=	International Space Station
KSC	=	Kennedy Space Center
OSTEM	=	Office of STEM Engagement
SCP	=	Space Crop Production
SBIR	=	Small Business Innovation Research
STMD	=	Space Technology Mission Directorate
STTR	=	Small Business Technology Transfer

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I. Introduction

Space Crop Production (SCP) at NASA's Kennedy Space Center (KSC) is aimed at achieving nutrient supplementation and moving towards caloric independence from Earth. The goal of the program is to create systems that would allow people to live sustainably on the moon and Mars by growing their own food. Growing simple crops, like lettuce, in space, is the first step of many to understanding the unique challenges space brings. Crops are being grown in microgravity through modified hydroponic approaches on the International Space Station. Microgravity produces many obstacles, such as the absence of gravitropic responses in roots, hypoxia from the lack of water and air mixing in space, and the lack of convection that inhibits vascular flow and photosynthesis. These issues are complex and need to be solved systematically. A new method of organization has been proposed by the SCP team called the Gaps List.

SCP research is funded by various NASA sources that focus on supporting research appropriate to their discipline. Biological and Physical Science (BPS) is a funding source that focuses primarily on fundamental biological and physical research. Hardware may be covered if needed to support the science of interest. The International Space Station (ISS) historically funds flight operations and has funded hardware development focused on space station utilization. The Human Research Program is a funding source with an interest in how plants impact human health, well-being, and performance. Advanced Exploration Systems (AES) funds capabilities while NASA's Space Technology Mission Directorate (STMD) funds technologies, students, and early career researchers working on space technologies. There are other mechanisms by which projects can be funded including through Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) grants to small businesses, and Center Innovation Fund (CIF) and Independent Research & Technology Development (IR&TD) awards to NASA personnel. NASA's Office of Stem Engagement (OSTEM) helps to fund research related to student learning and engagement, and funds educational programs, fellowships, and interns that contribute to NASA's needs. Using the Gaps List to understand where these funding sources fit into the SCP research may be important for highlighting areas where new investments can be made.

The Gaps List is a dynamic system of missing knowledge that is organized hierarchically. It was developed by the SCP team members. This method of organizing needed information is meant to showcase the most pressing issues within the project. The gaps on the list are the most attainable research topics needed to be understood such that space crop production can be realized. Some aspects that are too complex to fully understand are not yet included, such as epigenetic changes due to long term solar and space radiation exposure. These more complex issues are documented and are added when they become attainable. That is why the Gaps List is considered dynamic. Gaps close and open as new discoveries are made, and as new technologies are developed. The Gaps List may be useful for scientists when writing proposals and justifying their research through the greater needs of the program for which they work or in identifying potential collaborations. The gaps are organized by an I.D. phrase that has five characters separated by periods. The first character represents the Gap Section. There are three sections (1) Hardware, (2) Crops, and (3) Ecosystem. Within these sections there is separation by Gap Category indicated by the next character which are letters. The following character represents a Sub-Gap or a lesser grouping with numbers and letters. The fourth character represents the Key-word or descriptor. The last character represents the gap itself so that it can be identified uniquely. Each gap has its own I.D., key word, and description. Due to the lengthiness of the Gaps List, data will be organized into graphs by higher levels of organization, Section and Category. The goal of this evaluation was to show alignment and identify disconnects between current SCP research and the Gaps List.

II. Methods

KSC SCP Project Scientists and Post-Doctoral Researchers were selected as the target interview group due to their pertinent knowledge. Each of the 7 scientists went through a 2-step interview process. The first interview involved asking researchers about their current projects and taking thorough notes on the most important points. All notes were recorded in such a way that was uniform and included each project's title, start and end dates, funding sources, and summary. Between meetings the research notes were reviewed, and all related gaps were considered and noted. The second interview involved asking further questions and confirming if the researcher's agreed to the gap alignment suggested. The gaps in which researchers confirmed were recorded. Notes from the interview were condensed into *Table 1: SCP Project Scientist and Post- Doctoral Researcher Gap Frequency Evaluation Chart* in the Data section below.

III. Data

Table 1 *Space Crop Production Project Scientist and Post-Doctoral Researcher Evaluation Chart shows the Gap I.D., Gap Category, Gap Description, Gap Frequency, Funding Frequency and Project Titles associated with those gaps identified during the 2-step interview process of 7 KSC SCP researchers.*

GAP I.D.	GAP CATEGORY	GAP DESCRIPTION	PROJECT FREQUENCY	FUNDING FREQUENCY		PROJECTS
1.A.1.A.1	Environmental Monitoring	Lack effective Ethylene Sensor	0	0		
1.A.2.A.1	Environmental Monitoring	Lack of high TRL multi/hyper spectral imaging sensor	1	BPS	1	Advanced Plant Imaging
1.A.1.B.2	Environmental Monitoring	Lack of effective Root Zone O2 Sensor	0	0		
1.A.1.B.1	Environmental Monitoring	Lack of effective Root Zone Moisture Sensor	0	0		
1.A.2.B.2	Environmental Monitoring	Lack of high TRL Stress Detection technologies other than imaging	0	0		
1.A.3.0.1	Environmental Monitoring	Lack of data sets to identify stress indicators from sensor data streams and respond appropriately	1	BPS	1	Spaceflight Microbiome of a Food Crop Grown Using Different Substrate Moisture Levels
1.B.1.0.1	Environmental Control	Lack ability to effectively provide adequate and uniform delivery of water and nutrients to root zones in relevant space environments	3	BPS	3	Advanced Water Management, Spaceflight Microbiome of a Food Crop Grown Using Different Substrate Moisture, Augmenting Nutritionally-Dense Microgreens in Simulated Microgravity
1.B.1.0.2	Environmental Control	Lack ability to effectively provide adequate and uniform root zone aeration in relevant space environments	3	BPS	3	Advance Water Management, Spaceflight Microbiome of a Food Crop Grown Using Different Substrate Moisture, Augmenting Nutritionally-Dense Microgreens in Simulated Microgravity
1.B.2.A.1	Environmental Control	Need to demonstrate efficient water recovery and recycling to close the water loop partially or fully in relevant space environments	0	0		
1.C.1.0.1	Systems Architecture	Need to determine optimum spatial arrangement of crops to maximize yield per unit volume for each species and for relevant space environments	2	HRP BPS	1 1	Microgreens Nutritional Analysis, Augmenting Nutritionally-Dense Microgreens in Simulated Microgravity
1.C.1.0.2	Systems Architecture	Need to determine optimum temporal arrangement (planting schedule) to maximize yield per unit volume for each crop species in relevant space environments	2	HRP	2	Microgreens Nutritional Analysis, Sustained Veggie
1.C.2.0.2	Systems Architecture	Need to define needed activities to be automated under different mission scenarios and operational scales	0	0		
1.C.3.0.1	Systems Architecture	Need to define and optimize interfaces with growth system and vehicle/habitat	0	0		
1.C.2.0.3	Systems Architecture	Need to develop/elevate TRL on soft robotics and specialized end effectors	0	0		
1.D.1.0.1	Sustainability	Lack space flight ready non-edible biomass management	0	0		
1.D.1.0.2	Sustainability	Elevate TRL for hardware solutions and CRL for crop solutions to recovering nutrients from vehicle waste streams, including selective sodium removal	0	0		
1.D.2.0.1	Sustainability	Need to determine and achieve minimum failure rates and spares for subcomponents to achieve life safety levels of reliability	0	0		
1.D.2.0.2	Sustainability	Need to determine cleaning and maintenance protocols to maintain yield over successive grow cycles	1	STMD	1	Alternative Plasma Sources for Space Agricultural Applications
1.D.2.0.3	Sustainability	Determine how to manage plant environments in the event of system malfunction such that the integrity of the crops and hardware is maintained	1	BPS	1	Spaceflight Microbiome of a Food Crop Grown Using Different Substrate Moisture Levels
1.D.3.0.1	Sustainability	Need to develop ISRU approaches to grow crops	1	BPS	1	Fit Annex
1.E.1.0.1	Food Safety	Lack of non-invasive food safety monitoring technologies	0	0		
1.E.2.0.1	Food Safety	Lack of sustainable space flight approved food sanitation systems and techniques	1	CIF	1	Alternative Plasma Sources for Space Agricultural Applications,
2.A.1.0.1	Plant Environmental Response	Lack of adequate data of gravity threshold and effects on plant physiology for candidate crops	1	BPS	1	Augmenting Nutritionally Dense Microgreens in Simulated Microgravity
2.A.2.0.1	Plant Environmental Response	Lack of adequate data of radiation threshold and effects on crop physiology	2	BPS 2		Effect of simulated solar particle events and galactic cosmic rays on plant growth and development, Effect of Long Duration Space Exposure on Seeds- MISSE Seeds, Effect of Long Duration Space Exposure on Seeds- SEER
2.A.3.0.1	Plant Environmental Response	Need to define and validate universal light treatment recipes.	1	BPS 1 HRP 1		Pick-and-Eat Salad-Crop Productivity, Nutritional Value, and Acceptability to Supplement the ISS Food System
2.A.3.0.2	Plant Environmental Response	Need to define DLI and appropriate PAR range for all candidate crops	1	BPS HRP	1 1	Pick-and-Eat Salad-Crop Productivity, Nutritional Value, and Acceptability to Supplement the ISS Food System Growing Beyond Earth

2.A.3.0.3	Plant Environmental Response	Need to define photoperiod tolerance/requirements for crops of interest	1	OSTEM BPS	1 1	Growing Beyond Earth
2.A.3.0.4	Plant Environmental Response	Need to define primary drivers of crop light treatments (i.e. are we targeting nutrient production, biomass optimization, calories, flavor, etc.)	0	0		
2.A.4.A.1	Plant Environmental Response	Incomplete data sets on CO2 level effects on plant physiology for candidate crops	6	HRP BPS ISS	1 4 1	New Crops Testing Collaboration: IBMP and KSC, VEG-03 Veggie Series Proof of Concept Flights, PH-04 Hatch to ISS, New Crop Testing, Augmenting Nutritionally Dense Microgreens in Simulated Microgravity
2.A.4.B.1	Plant Environmental Response	Incomplete data sets on pressure level effects on plant physiology for candidate crops	0	0		
2.A.4.C.1	Plant Environmental Response	Incomplete data sets on airflow behavior in different gravity levels and effect on plant physiology for crops with different canopy architectures	1	BPS 1		Photosynthesis and Ventilation in Low Gravity, Microgreen Root Zone and Shoot Zone Separator Box, PH-04 Hatch to ISS-Ventilation Study
2.A.4.D.1	Plant Environmental Response	Incomplete data sets for temperature tolerance of candidate crops in space environments	0	0		
2.A.5.A.1	Plant Environmental Response	Need to advance understanding of crop physiological disorders and stress responses of interest to space crop production.	3	BPS 3		Spaceflight Microbiome of a Food Crop Grown Using Different Substrate Moisture Levels, New Crop Testing, Augmenting Nutritionally Dense Microgreens in Simulated Microgravity
2.A.6.A.1	Plant Environmental Response	Incomplete data sets of water uptake and thresholds for candidate crops in space environments (including air flow and humidity).	1	BPS 1		Spaceflight Microbiome of a Food Crop Grown Using Different Substrate Moisture Levels
2.B.1.0.1	Crop Performance	Incomplete data sets on yield of candidate crops in space environments	7	HRP BPS OSTEM ISS 1	2 5 1	Pick-and-Eat Salad-Crop Productivity, Nutritional Value, and Acceptability to Supplement the ISS Food System, Non-traditional Crop Tests – PECASE, Growing Beyond Earth, VEG-03 Veggie Series Proof of Concept Flights, PH-04 Hatch to ISS, New Crop Testing, Microgreen Nutritional Analysis
2.B.1.0.2	Crop Performance	Need to select/breed/engineer improved yield crops for space environments	3	BPS HRP OSTEM	2 1 1	Non-traditional Crop Tests – PECASE, Growing Beyond Earth, New Crop Testing
2.B.1.0.3	Crop Performance	Need to select/breed/engineer self-fertilize parthenocarpic fruit for space environments	0	0		
2.B.2.0.1	Crop Performance	Incomplete data sets of nutritional content for candidate crops for space environments	8	BPS HRP AES ISS	4 3 1 1	Spaceflight Microbiome of a Food Crop Grown Using Different Substrate Moisture Levels, Non-traditional Crop Tests – PECASE, New Crops Testing Collaboration: IBMP and KSC, Crew Health and Performance Exploration Analog (CHAPEA) – Crop Growth, PH-04 Hatch to ISS, New Crop Testing, Microgreens Nutritional Analysis, Augmenting Nutritionally-Dense Microgreens in Simulated Microgravity
2.B.2.0.2	Crop Performance	Need to select/breed/engineer improved nutritional content crops for space environments	8	HRP BPS AES	3 5 1	Pick-and-Eat Salad-Crop Productivity, Nutritional Value, and Acceptability to Supplement the ISS Food System, Non-traditional Crop Tests – PECASE, New Crops Testing Collaboration: IBMP and KSC, Crew Health and Performance Exploration Analog (CHAPEA) – Crop Growth, VEG-03 Veggie Series Proof of Concept Flights, New Crop Testing, Augmenting Nutritionally-Dense Microgreens in Simulated Microgravity
2.B.3.0.1	Crop Performance	Incomplete data sets of plant size (needed volume) for candidate crops in space environments	7	BPS HRP OSTEM ISS	5 1 1 1	Non-traditional Crop Tests – PECASE, New Crop Testing, Sustained Veggie, Growing Beyond Earth, VEG-03 Veggie Series Proof of Concept Flights, PH-04 Hatch to ISS, Microgreens Nutritional Analysis, Augmenting Nutritionally-Dense Microgreens in Simulated Microgravity
2.B.3.0.2	Crop Performance	Need to select/breed/engineer more appropriately sized crops with high harvest index for space environments	2	BPS	2	Non-traditional Crop Tests – PECASE, New Crop Testing
2.B.4.0.1	Crop Performance	Incomplete data sets on organoleptic considerations for candidate crops in space environments	7	HRP AES BPS ISS	4 1 3 1	Pick-and-Eat Salad-Crop Productivity, Nutritional Value, and Acceptability to Supplement the ISS Food System, New Crops Testing Collaboration: IBMP and KSC, Crew Health and Performance Exploration Analog (CHAPEA) – Crop Growth, VEG-03 Veggie Series Proof of Concept Flights, PH-04 Hatch to ISS, New Crop Testing, Microgreens Nutritional Analysis
2.B.4.0.2	Crop Performance	Need to select/breed/engineer more palatable/pleasing crops for space environments	3	BPS HRP AES	1 2 1	New Crops Testing Collaboration: IBMP and KSC, Crew Health and Performance Exploration Analog (CHAPEA) – Crop Growth, New Crop Testing
2.B.5.0.1	Crop Performance	Incomplete data sets on degradation rate for candidate crops for space environments	0	0		
2.B.5.0.2	Crop Performance	Need to select/breed/engineer crops with more easily degradable inedible biomass for improved resource recovery in space environments	0	0		
2.C.1.A.1	Horticultural Practices	Lack of understanding of radiation effects on stored seeds, clonal material etc. and appropriate radiation protective storage systems	2	HRP	2	Effect of simulated solar particle events and galactic cosmic rays on plant growth and development, Effect of Long Duration Space Exposure on Seeds- MISSE Seeds, Effect of Long Duration Space Exposure on Seeds- SEER
2.C.1.A.2	Horticultural Practices	Lack of sustainable seed handling and planting methods to ensure viability appropriate to space environments and various mission parameters	2	BPS	2	VEG-03 Veggie Series Proof of Concept Flights, Augmenting Nutritionally-Dense Microgreens in Simulated Microgravity
2.C.1.A.3	Horticultural Practices	Lack of sustainable in-situ seed production strategy	0	0		
2.C.1.A.4	Horticultural Practices	Lack of understanding of appropriate seed sanitation methods for candidate crop types in space environments	1	CIF	1	Alternative Plasma Sources for Space Agricultural Applications,

2.C.1.B.1	Horticultural Practices	Lack of method for storing and handling clonal materials in space environments	0	0		
2.C.2.0.1	Horticultural Practices	Lack of methods and technology for transplanting in soilless growth systems in space environments	1	BPS	1	VEG-03 Veggie Series Proof of Concept Flights
2.C.3.0.1	Horticultural Practices	Incomplete datasets on optimum fertilizer strategies for candidate crops in space environments	3	OSTEM BPS ISS	1 2 1	Growing Beyond Earth, PH-04 Hatch to ISS, Augmenting Nutritionally-Dense Microgreens in Simulated Microgravity
2.C.4.0.1	Horticultural Practices	Lack of automated pollination methods applicable to various gravity levels and space environments	0	0		
2.C.4.0.2	Horticultural Practices	Lack of data on significance of pollination problem	4	HRP BPS OSTEM ISS 1	1 3 1	Pick-and-Eat Salad-Crop Productivity, Nutritional Value, and Acceptability to Supplement the ISS Food System, Growing Beyond Earth, VEG-03 Veggie Series Proof of Concept Flights, PH-04 Hatch to ISS
2.C.5.0.1	Horticultural Practices	Lack of adequate and sustainable method for harvesting from candidate crops in space environments *consider moving to hardware.	1	BPS IR&TD	1 1	Microgreen Root Zone and Shoot Zone Separator Box
3.A.1.0.1	Microbiome	Lack of knowledge on effects of plant-human biome interactions in spaceflight environment	4	HRP AES BPS	1 1 3	Pick-and-Eat Salad-Crop Productivity, Nutritional Value, and Acceptability to Supplement the ISS Food System, Crew Health and Performance Exploration Analog (CHAPEA) – Crop Growth, Seed Microbiome Time Course, VEG-03 Veggie Series Proof of Concept Flights
3.A.2.0.1	Microbiome	Lack of knowledge on effects of plant-hardware biome interactions in spaceflight environment	5	BPS CIF	3 2	Spaceflight Microbiome of a Food Crop Grown Using Different Substrate Moisture Levels, Alternative Plasma Sources for Space Agricultural Applications, Effect of Long Duration Space Exposure on Seeds- SEER, Effect of Long Duration Space Exposure on Seeds-MISSE Seeds, An in-depth characterization of a multispecies biofilm relevant to the Water Processor Assembly (WPA) under microgravity
3.A.3.0.1	Microbiome	Lack of knowledge on microbiome evolution over time in spaceflight environment	1	ISS	1	PH-04 Hatch to ISS
3.A.4.0.1	Microbiome	Lack of microbiome baseline knowledge and augmentation strategy	4	BPS CIF	3 1	Spaceflight Microbiome of a Food Crop Grown Using Different Substrate Moisture Levels, Alternative Plasma Sources for Space Agricultural Applications, Effect of Long Duration Space Exposure on Seeds- SEER, Effect of Long Duration Space Exposure on Seeds-MISSE Seeds
3.B.1.0.1	Multi-Crop Interaction	Lack of knowledge of specific crop type interactions in space flight environment, both beneficial and harmful	2	BPS HRP	1 1	VEG-03 Veggie Series Proof of Concept Flights, Sustained Veggie
3.C.1.0.1	Human Plant Interaction	Lack of scientific/validated behavioral health data beyond anecdotal evidence regarding effects crew by having plants present	4	HRP AES BPS ISS	1 1 2 1	Pick-and-Eat Salad-Crop Productivity, Nutritional Value, and Acceptability to Supplement the ISS Food System, Crew Health and Performance Exploration Analog (CHAPEA) – Crop Growth, VEG-03 Veggie Series Proof of Concept Flights, PH-04 Hatch to ISS
3.C.1.0.2	Human Plant Interaction	Lack of an automation/crew time strategy to maintain plant environments	0	0		
3.D.1.0.1	Stability	Lack of knowledge of ecosystem stability during planned mission durations	0	0		
3.E.1.0.1	Food Security	Lack of biosafety plan to prevent and manage crop pathogens in space environments	0	0		
3.F.1.0.1	Food Safety	Lack of Hazard Analysis Critical Control Point Plan for candidate crops types in space environments	6	HRP BPS ISS	2 4 1	Non-traditional Crop Tests – PECASE, Pick-and-Eat Salad-Crop Productivity, Nutritional Value, and Acceptability to Supplement the ISS Food System, Microgreens Food Safety Analysis, Space Crop Production HACCP Plan, VEG-03 Veggie Series Proof of Concept Flights, PH-04 Hatch to ISS
3.F.1.0.2	Food Safety	Lack of clear process for approval of crew consumption of crops.	1	BPS HRP	1 1	Study on Crew time use in Greenhouse in Analog Facilities and in Veggie on ISS

IV. Results and Discussion

The culmination of interview data shows that the majority of KSC Project Scientist and Post-Doctoral research is concentrated primarily in the Crops Section, with the Ecosystem Section being second most represented and least in the Hardware Section, as seen in Figure 1. The most frequent funding sources for all projects were BPS, HRP, and ISS, in decreasing order. Funding sources AES, OSTEM, and CIF all had the same frequency while IR&TD had the least overall. In reference to funding sources, it is important to note that it is the frequency of funding not the amount of funding.

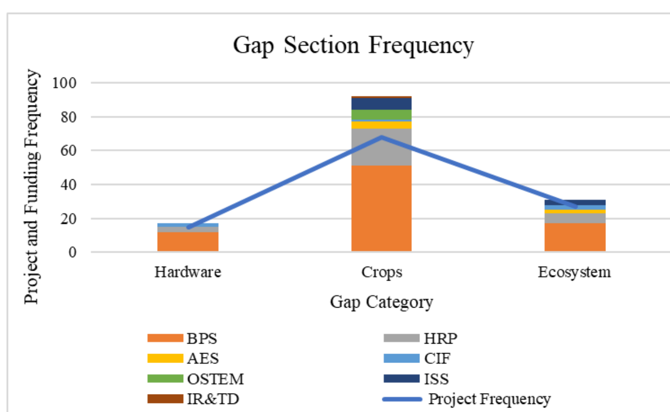

Figure 1 *Gap Section Project and Funding Frequency*

The lowest frequency of research alignment lies in the Hardware Section seen in the left on Figure 1. In Figure 2, the Food Safety and Food Security categories within the Hardware Section have 0 frequency, or no projects identified that align to these topics. The Hardware Section also has the highest number of gaps without any aligned projects. This likely has adverse effects because hardware capabilities are needed to make progress in the steps toward research for producing crops at a larger scale in space environments. Historically, BPS has been the main funding source for the SCP Project due to its focus in fundamental biology and applied crop science. Today, SCP is shifting towards production. To support this shift, the SCP Program will need more engineering and physics support from other funding sources that focus on hardware and capabilities. Few Project Scientists were aware or had any knowledge on these gaps. *To emphasize the importance of gaps in areas such as hardware, it may be helpful to have a measure of priority.*

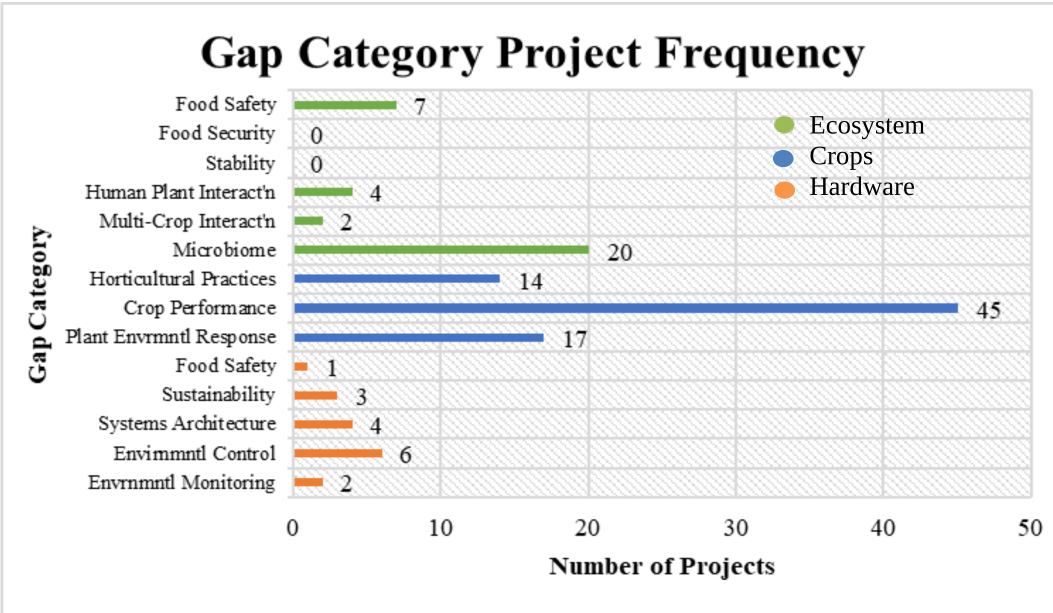

Figure 2 *Gap Category Project Frequency*

An intermediate frequency was found in the Ecosystem Section, represented in the center of Figure 1. The low frequency in this section is not unexpected considering these gaps are related to system sustainability over time and multi factor interactions. These aspects are hard to study and require considerable funding and time. Some of the gaps in this category depend on knowledge or technologies that are not yet available. Gaps in other categories may contribute to the completion of the gaps in this section. *It may be beneficial to create a list of dependencies or gaps that rely on others to be complete before they can then be completed.*

The section of the Gaps List most emphasized in current research is the Crops Section on the right in Figure 1. The Crops Section categories consist of Plant Environmental Responses, Crop Performance and Horticultural Practices. In Figure 2, it is evident that Crop Performance is the most frequently researched category in the Crops Section. The density of this category is most likely due to the large scope of Crop Performance and support from the funding sources BPS and HRP. In Figure 1 this section has the greatest frequency of BPS funding. This is expected considering BPS focuses on fundamental science and it is the main contributor to the SCP Program. Crop Performance encompasses the growth factors of all the crops currently being considered for space crop production. Many of the gaps in Crop Performance require extended effort versus other gaps that may be more straight forward. For example, several gaps in the Hardware Section talk about one single sensor. It would be simpler to close a gap that includes one technology advancement versus many ongoing and extensive experiments. *In this example, we can see the importance of scope or breadth in which a gap encompasses. It may be important to portray these differences within the gap description, taxonomy or in another list.*

During the interviews, it became evident that there are varying perspectives on the important topics within crop production. While all the current research is important, it may be beneficial to prioritize or to combine perspectives to close gaps more efficiently. It was difficult to make evaluations about the SCP research without a greater understanding of the priorities, dependencies, and breadth of the gaps. It may be beneficial to reorganize the taxonomy of the current list or to create new lists that include priority, dependency, and scope. Once these changes have been made, data can be reorganized, and specific evaluations can be made at the individual gap level.

Because the data from this evaluation were self-reported during interviews, there is potential bias. It is possible that scientists did not report all their projects or that they had bias towards gaps within the scope of their interest and knowledge. The contents of the Gaps List were not up to date. During interviews, it became evident that many aspects of KSC research were not represented in the Gaps List. Discussions were held to make these changes. Several gaps were reworded or added to accommodate all current KSC research questions. The gaps that were changed may be underrepresented as these changes were made after the interview process was completed.

V. Conclusion

The goal of this evaluation was to show alignment and identify disconnects between current SCP research and the Gaps List. The Gaps List and the methods of collecting data that are outlined in this report are an effective way to assess the overall focus of a project. The interview process was effective in its intended purpose--to document current SCP research, but also in improving the Gaps List. It became evident that there are varying levels of funding and project frequency across the Gaps List. *To address less frequent gaps such as Hardware and Microbiome, support from funding sources that focus on these disciplines may be necessary*. An efficient rate of progress will likely be achieved if adequate support is given to all sections of the Gaps List.

The dynamic nature of the Gaps List was utilized, and several future and current gaps were added. *For the Gaps List to remain effective, it needs to be evaluated at regular intervals to ensure all gaps are included, the proper gaps are closed, and future gaps are added*. During the interview process, it became evident that there is currently no consensus within the SCP Program of gap priority, dependency, and breadth. It may be most effective for the Gaps List to include a measure of these three aspects. *Making a new list may be helpful to reorganize the gaps into a taxonomy measuring priority. Creating a roadmap of gaps to be completed in succession is adequate for measuring dependency. Rewording gap descriptions such that they portray their scope, may be necessary*. If these recommendations are implemented, scientists will be able to see where their expertise aligns with the highest priority gaps, and how much effort is required to close the gap.

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