Cultivating Future Leaders in Sustainable Agriculture: Insights from the Digital Agriculture Fellowship Program at the University of California, Riverside

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Abstract.

Funded by USDA's National Institute of Food and Agriculture's Sustainable Agricultural Systems Program and housed at the University of California, Riverside (UCR), the Digital Agriculture Fellowship (DAF) aims at equipping undergraduate students with the knowledge and experience necessary to meet the agricultural challenges posed by climate change and sustainability concerns. The program was established in 2020 and will be funded through 2026. Activities span over fifteen months for each participating fellow and are structured to provide students with a multifaceted education and training path. Throughout the fellowship, participants engage in networking activities, fostering connections with fellow students and gaining access to a community of experts in the agricultural domain. Furthermore, students are exposed to real-world research experiences, allowing them to explore and understand current and future agricultural challenges. They receive mentorship from UCR faculty. This talk summarizes success stories and challenges in the first two cohorts of the fellowship. As part of the funding for the DAF, the program leadership has collaborated with an external evaluation team. The evaluation focused on various student and program outcomes, including student understanding of digital agriculture and interest in digital agricultural research and related careers. The findings from the evaluation indicated that students from both cohorts (2021-2022 & 2022-2023) generally increased their interest and understanding of digital agriculture. In the 2021-2022 Cohort, students expressed that their participation in the program influenced their desire to pursue a related Ph.D. and introduced them to applications of technology in agriculture. For the 2022-2023 Cohort, in addition to an increased interest in obtaining a graduate-level degree, trainees also expressed interest in teaching in digital agriculture and exposure to career pathways they would not have otherwise been aware of. While both cohorts generally reported satisfaction and an increased interest and understanding of

agriculture, there was a notable difference in interest and feelings of preparedness. This presentation will discuss various challenges in program implementation, including program timelines, and highlight noted differences between cohorts and student outcomes. In summary, in its first two years, the Digital Agriculture Fellowship Program has played a pivotal role in planting the seed for a new generation of agricultural professionals capable of addressing the evolving agricultural challenges precipitated by climate change in a scientific and data-driven manner.

Keywords.
Student-led research; undergraduate students; digital agriculture; Research Experiences for Undergraduates.

Introduction

Funded by USDA's National Institute for Food and Agriculture, the "Artificial Intelligence to Increase Sustainability of Water, Nutrient, Salinity, and Pest Management in the Western US" (also known as AI4SA, https://ai4sa.ucr.edu/) is a multi-institutional research project (Grant Number: 2020-69012-31914) led by the University of California, Riverside (UCR). The project seeks to be instrumental to the long-term adoption of precision agriculture across the study region, particularly where the shift in management would bring significant environmental benefits. The project has three components: applied research, extension, and education.

Through education efforts, the project aims to prepare undergraduate students for careers within precision agriculture and agricultural data sciences. Fewer young people choose agriculture as a career (USDA-ERS, 2019). However, the ongoing fourth industrial revolution (Klaus Schwab et al., 2018; Schwab, 2016) offers to empower young people to invent and sustain fulfilling careers. The USDA and state agencies have highlighted the need to recruit more young people into the agricultural workforce because the US agricultural workforce has been aging for decades (Vilsack and Clark, 2014). Interviews, roundtables, and focus groups were carried out with industry stakeholders during the conceptualization of DAF in 2019 and previous years at UCR. Most commonly, it emerged that there was a lack of multidisciplinary expertise in agriculture and data science in the pool of recent graduates looking for jobs in the ag tech industry. The AI4SA project has presented the opportunity to recruit a new generation of students, including data science-oriented undergraduate students, into careers in agriculture. To accomplish this, a *Digital Agriculture Fellowship* (DAF) for undergraduate students was established in 2020 and started enrolling students in 2021. The objective of this manuscript is to summarize the success stories and challenges in the first two cohorts of the fellowship. The manuscript aims to discuss generalizable takeaways from the UCR DAF experience to help other institutions that may desire to establish a similar educational program.

Materials and Methods

The Digital Agriculture Fellowship (DAF)

Between June 2021 and November 2023, the first two DAF cohorts were supported at UCR. UCR is a Hispanic-Serving Institution with a highly diverse student body. Eligible DAF students were US citizens or permanent residents in their sophomore or junior year with a minimum GPA of 3.2. They were enrolled in majors aligning with data science, environmental science, agricultural sciences, and engineering. Efforts were made to encourage a diverse pool of participating students. Because most attrition from STEM majors occurs before upper-division courses, recruitment efforts were primarily directed to students in their second year to promote retention in their major (Chen, 2013). The first two DAF cohorts included 8 students each. The DAF activities included a full-time summer research and career development program, part-time academic-year research, conference attendance, student club activities, and industry externships.

The five-year (four cohorts) timeline for the DAF appears in Figure 1. This timeline was greatly

affected by the COVID-19 pandemic and related employment challenges at UCR. The first cohort started in June 2021 and carried out virtual activities until the spring of 2022, when the UCR campus resumed in-person activities. The second cohort started in September 2022 and carried out their summer programs in the summer of 2023 concurrently with the third cohort (which is not discussed here). A description of DAF is provided in the sections below.

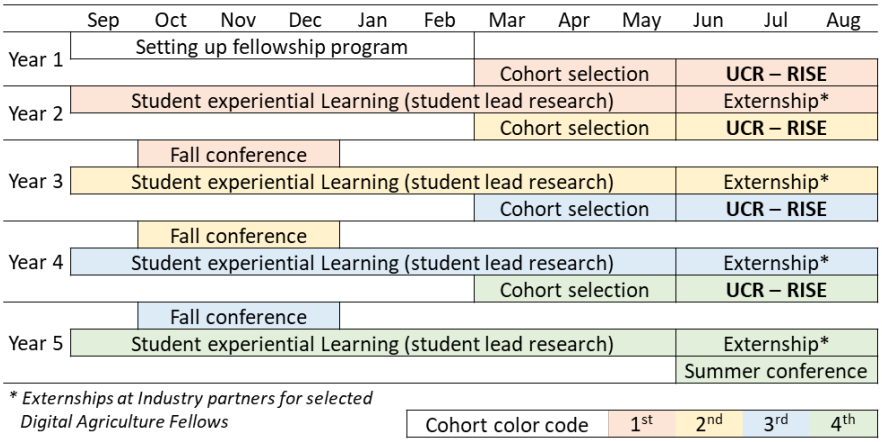

Fig 1. The Education and training path for the Digital Agriculture Fellowship

Research in Science and Engineering (RISE) Program

Established at UC Riverside in 2010, RISE (https://cnasscholars.ucr.edu/research-opportunities#rise) has been supporting and developing STEM students since its inception through summer research programs. RISE is a 10-week program designed for rising sophomore, juniors, incoming transfers, and seniors from varying backgrounds. Participants work under the supervision of a faculty mentor on the mentor's research project. RISE aims to increase the number of outstanding students from diverse backgrounds to become acquainted with one of the most essential traits of a scientific career: Research. Additionally, RISE aims to increase the population of students who pursue graduate and/or professional degrees. It provides an opportunity for them to develop a competitive profile with which to advance their educational, professional, and career goals. The primary objectives of RISE are: *i*) shaping undergraduate students' research and professional identity; *ii*) enhancing scientific communication and literacy; and *iii*) developing a sense of belonging within UCR. In the summers of 2021 and 2023, RISE was offered to around 80 to 100 students per year, belonging to different programs and fellowships, including DAF.

In addition to mentored research, students participated in workshops, which included: Maximizing your internship; Understanding and Analyzing Scientific Articles; Team Building Challenge Course; How to Write a Scientific Abstract; How to Give an Oral Scientific Presentation; Conquering the Imposter Phenomenon; How To Give a Poster Scientific Presentation; Mastering LinkedIn; Elevator Pitch & Scientific Communication; Ethics 101: Research Ethics; Graduate School Programs & Opportunities; Study Abroad in STEM; Student Practice Presentations for Symposium. At the end of each summer program, a RISE symposium was held where students shared their research findings through posters and talks. Eight students in the first cohort participated in RISE in 2021. Six students from the second cohort participated in RISE in 2023, because two students did industry internships instead (see below).

Academic year research & activities

From September 2021 through May 2022 (first cohort) and September 2022 through May 2023 (second cohort), each student was paired with an AI4SA investigator and engaged in part-time student-led research projects over nine months. Typically, students were under the daily

supervision of a graduate student or postdoc. Each student participated in the laboratory meetings to which they were assigned. The DAF project titles are reported in Table 1.

Table 1. The Digital Agriculture Fellowship projects for the first two cohorts in the program at the University of California, Riverside (UCR).

Student	Cohort	UCR Mentor	Project Title
W. Burgess	First	H. Ajami	Groundwater Response to Drought is Defined by Evapotranspiration, Antecedent Conditions, and Precipitation Characteristics
I. Morales	First	V. Papalexakis	Tensor Decomposition for Hyperspectral Image Analysis
C. Ho	First	R. Anderson	Machine Learning in Crop Classification
K. Urrutia Avila	First	K. Karydis	Autonomous Soil Moisture Mapping
H. Dingilian	First	A. Putman	Detecting Damage from Nematodes in Crops Using Remote Sensing
K. Lincoln	First	M. Rivera	Use of Artificial Intelligence for Asian Citrus Psyllid Detection on ACP Sticky Traps
S. Ahmed	First	M. McGiffen	Big Satellite Data Analytics on Crop Growth in California
V. Gajjewar	First	A. Eldawy	Increasing the Efficiency of Geospatial Data Processing
A. Barajas	Second	A. Putman	Weed Detection through Drone Imaging in an Onion Field
M. Nolasco	Second	E. Scudiero	Using Gamma-Ray Spectrometry to Study Plant Soil Relationship in Ten Lettuce Fields in the Salinas Valley
V. Gonzales	Second	H. Ajami	Understanding Surface Water and Groundwater Chemistry Variability in the Sierra Nevada
S. Singh	Second	M. McGiffen	Weed Discrimination using YOLOv8 deep learning algorithm
J. Guillroy	Second	R. Anderson	LSTM Neural Network for Crop Classification in the Yuma Valley Region of the Lower Colorado River Basin
H. Patel	Second	V. Papalexakis	Semantic Segmentation for Crop Type Prediction
N. Jimenez	Second	R. Anderson	Proximal Remote sensing of soil texture in relationship to gamma rays within Arid Zones
W. Bryant	Second	A. Eldawy	Big Satellite Data Query

The students formed UCR's Digital Agriculture and Agronomy (DAA) Club. The club has operated during the in-person stage of DAF, meeting at least once a month for brown bags, field trips, and career development roundtables. The DAA organized activities for the broad UCR community to increase awareness of careers and research opportunities in precision agriculture and related disciplines. Each DAF student was enrolled in the Soil Science Society of America. The first cohort of students petitioned the SSSA for the DAA club to qualify as a *Students of Agronomy, Soils, & Environmental Sciences* (SASES) chapter (soils.org/undergrads). SASES membership provides many career development opportunities, including access to contests for student-led research, national recognition, awards, and scholarships (SASES, 2017).

In the spring of 2022 and 2023, the students presented their research at UCR symposia, including the UCR Undergraduate Symposium and the 2023 UCR Inaugural Precision Agriculture Workshop. Additionally, the students had the opportunity to present their research at the ASA-CSSA-SSSA Meeting in Baltimore, MD (2022) and in St. Louis, MS (2023); and at the 2023 California Plant and Soil Conference in Fresno, CA.

Expected outcomes and program evaluation

Prior studies have documented that student engagement in research correlates with increased retention in STEM (Lopatto, 2004). One of the short-term goals that the DAF aimed to achieve was to increase the participation of undergraduates in digital agricultural research. Other goals include increasing the number of undergraduates applying to digital agriculture-related careers and graduate programs. From the first two cohorts who participated in the DAF, the evaluation team from the University of California, Santa Barbara Evaluation Center conducted pre-and post-test surveys to learn about several aspects of trainees' experiences. Generally, items utilized Likert scales (Joshi et al., 2015) with a range of 1 to 7, 1 representing strongly disagree with

statements to 7, representing strongly agreeing with a statement. The evaluation design was an explanatory mixed methods design (Creswell & Clark, 2017), where the quantitative survey data collected from students (e.g., ratings of the quality of the educational activities) was analyzed, with quantitative patterns then used to inform the development of interview or focus group protocols that aim to explain these patterns. This design typically offers the best opportunity to understand the broader effectiveness of the implementation and use the qualitative data to explain the successes and challenges.

For the first cohort, the pre-test had n=8, and three students were engineering majors, three were computer science majors, and two were math majors. The post-survey had n=5, with two fewer students from engineering majors participating in the survey. The second cohort had n=8 for the pre-test (Majors: one Statistics, two Mathematics, two Computer and Data Science; one Environmental Sciences; one Physical Sciences, and one Undeclared). A mid-year survey was carried out (n=7), but the student from the Statistics Major did not participate. Finally, the post-test (n=5) with the Mathematics and Data Science Majors students not participating.

Results and Discussion

The students from both cohorts generally carried out their research project with interest. The scientific output from the 16 students was remarkable, especially considering that the COVID-19 pandemic hindered activities for the first cohort. In addition to presentations at UCR events, the DAF students contributed to two posters at the 2022 ASA-CSSA-SSSA International Meeting (Kayad et al., 2022; Scudiero et al., 2022); four posters at the 2023 California Plant and Soil Conference (https://ucanr.edu/sites/calasa/files/362812.pdf); four posters at the 2023 ASA-CSSA-SSSA International Meeting (Barajas et al., 2023; Guillroy et al, 2023; Jimenez, 2023; Nolasco et al., 2023), and at two international conferences in the field of Computer Science (Gurav et al., 2023; Singla et al., 2021).

Notably, DAF students received state and national awards, including the ASA-CSSA-SSSA National Student Recognition Award in 2023 (CSA News, 2023a) and 2024 (CSA News, 2024), the 2023 ASA, CSSA, and SSSA Golden Opportunity Scholar (CSA News, 2023b); and Third Place at the Plant/Undergraduate poster competition at the 2023 California Plant and Soil Conference.

Program evaluation overview

The DAF program impacted both cohorts' career aspirations and understanding of digital agriculture. Cohort 1 participants (n=5) generally reported an increased interest and understanding of digital agriculture. Students expressed that participation in the program influenced their desire to pursue a Ph.D. and introduced them to how to use relevant technology in agriculture. Cohort 2 fellows (n= 7) displayed a similar increase in understanding of digital agriculture, as well as interest. In addition to mentioning their pursuits of obtaining a graduate-level degree, trainees also expressed interest in teaching in digital agriculture and exposure to career pathways they would not have otherwise been aware of. Both cohorts were generally satisfied with their faculty mentorship and enjoyed collaborating with both peers and faculty (Cohort 1 mean=6.91; Cohort 2 mean= 6.89). Some challenges that have emerged are the program's structure, meeting with faculty, and research steps. Other challenges also include the various experiences of trainees' interest in digital agriculture. To combat this, the evaluation team has worked with the UCR team to rethink student recruitment and add additional measures for emerging outcomes, such as career preparation.

First Cohort Detailed Survey Reports

Trainees described the benefits they gained from their participation in the Summer RISE Program, explaining that it allowed them to develop their research skills and the opportunity to connect with others interested in their area of interest. Responses ranged from exposure to the research

process, insight into what it means to be a researcher, and how to conduct research either on a team or individually. A typical quote included, *"The summer RISE program helped me develop the skills necessary to effectively evaluate the research of others as well as conduct research of my own in an academic setting."*

Developing research skills, conveying findings, and providing insight towards writer research papers and tools to present research were the main themes that emerged when trainees were asked about how the Summer RISE program contributed to their academic pursuits. A participant reported: "*I got a taste of what conducting academic research is like, which helped me make up my mind about deciding to pursue a Ph.D. and work in research. Having lab experience and a strong connection with my faculty mentor will also make me a stronger applicant to graduate school*"

Trainees said that the Summer RISE program provided them with the opportunity to develop a clearer goal of their career trajectory, how they could apply what they learned to the real world, and the confidence to pursue higher education. A meaningful quote was "*Because of this summer program, I was able to decide to pursue a Ph.D. and conduct research. Having lab experience and strong professional connections with my faculty mentor will also aid me in my future career*."

The DAF students found the faculty mentoring to be a particularly helpful and formative component of the program, with an overall satisfaction score of 6.91.

Overall, the first cohort saw an increase in knowledge and interest in digital agriculture, see Figures 2 and 3. On average, student understanding of digital agriculture increased from pretest to post-tests (Fig. 2).

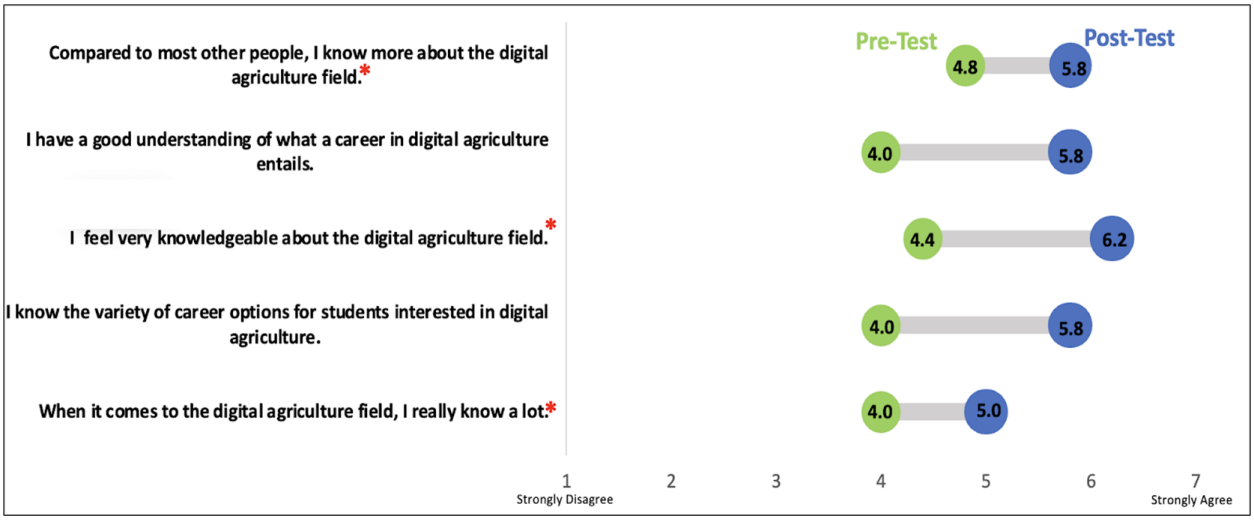

Fig. 2. Current Understanding of Digital Agriculture for the first cohort: Pre-test (green) and Post-test (blue). The asterisks indicate that the questions are reverse coded.

With the exception of the item "I will graduate with a college degree in a major area needed for a career in Digital agriculture, on average, trainee interest in digital agriculture increased from pre-test to post-test (Fig. 3).

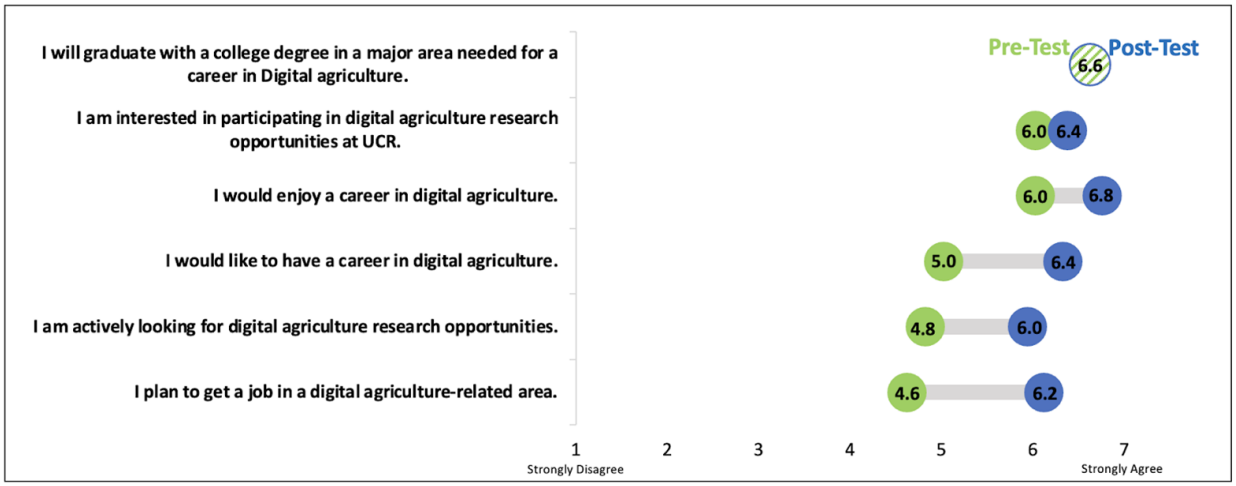

Fig. 3: Interest in Digital Agriculture for the first cohort: Pre-test (green) and Post-test (blue).

Second Cohort Detailed Survey Reports

Students highlighted that the program would contribute to their academic pursuits as it would help them when applying to a graduate program and, overall, seeing beneficial outcomes: "*The summer internship will allow me to work closely with my grad student and PI which will enhance my relationships with them. This is vital for me as I plan to attend graduate school. I also expect this program to engage and challenge my understanding of what I have learned in my classes to practical applications.*"

DAF trainees expressed that the program would contribute to their academic pursuits as they hope to gain clarity, knowledge, and experience. One student commented: "*I am still unsure whether or not to do pursue higher education like applying to grad school so this could help solidify my choice*."

The students highlighted that the summer industry internships would contribute to their future careers as they would provide experience and insight into industry expectations.

The second cohort carried out RISE entirely in-person. All trainees expressed that the program contributed to their future careers through experience, insight, and exploration of pathways/career choices. Selected quotes from the surveys include: "*From being in the Summer RISE program, I gained very useful information from the workshops available to us. The graduate schools panel was very helpful since it allowed me to gain a head-start of knowledge on grad school and learn about it*." "*I will use the resources introduced to me through the RISE workshops, and I will also use the connections that I made. This includes my connection to my PI, whom I will ask to write me a letter of recommendation for graduate school." "I know what it takes to commit to a research project. I know that failing in research is common, and it's okay as long as I keep trying and move forward. The people around me have lots of resources to offer if I simply ask*."

Similarly to the first cohort, the opportunity to work closely with a UCR faculty mentor was an important program feature for the students, who gave an overall satisfaction score of 6.89 to the faculty mentoring questions.

The second cohort showed some decreases in pre to post-test interest in pursuing digital agriculture jobs and research, as some students remarked that while they enjoyed the program and had a beneficial learning experience, they did not intend to pursue digital agriculture as their main focus topic (Figs. 4 and 5). Relevant quotes from the students included: "*DAF was great for me it allowed me to explore the field of digital ag and soil science, and although it showed me that this field wasn't for me in the future, I'm thankful it allowed me to discover this early on*." "*I only ever thought about teaching mathematics, but I stepped my toes into agriculture and actually liked*

it, so I may end up teaching agriculture as well."

Except for the questions "I know the variety of career options for students interested in digital agriculture" and "I have a good understanding of what a career in digital agriculture entails", on average, the students' understanding of digital agriculture increased from pre-test to post-test (Fig. 4).

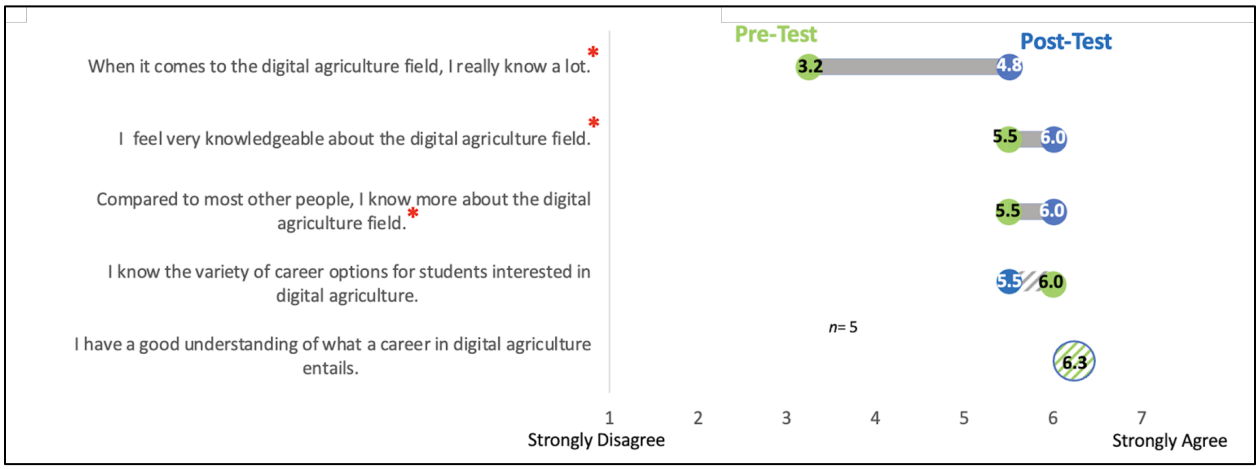

Fig. 4. Current Understanding of Digital Agriculture for the second cohort: Pre-test (green) and Post-test (blue). The asterisks indicate that the questions are reverse coded.

On average, trainee interest in digital agriculture increased from pre-test to post-test (Fig. 5)

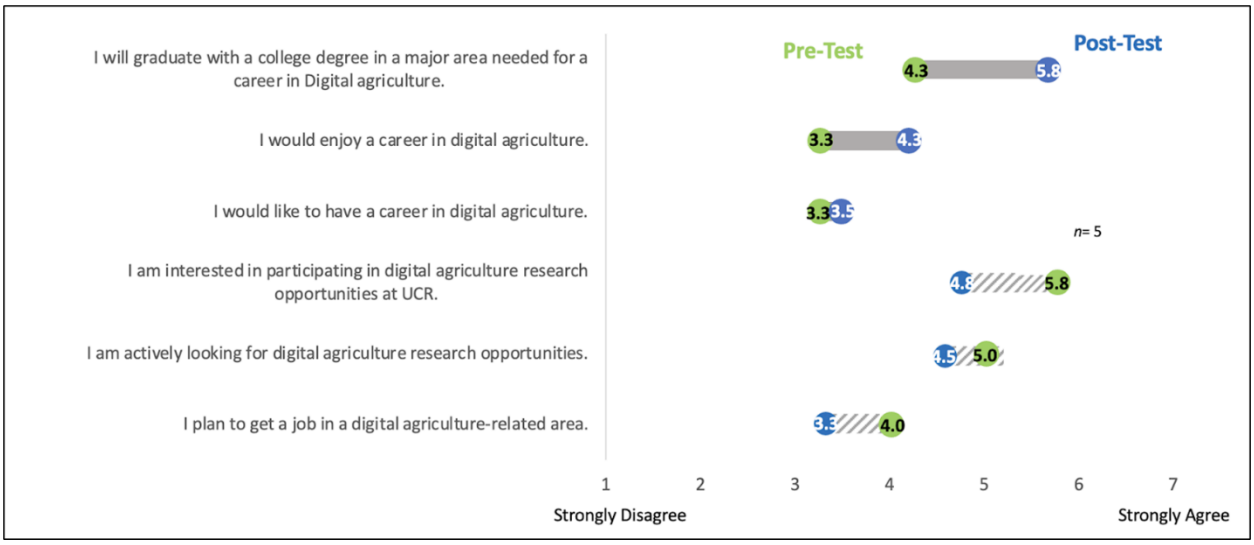

Fig. 5. Interest in Digital Agriculture for the second cohort: Pre-test (green) and Post-test (blue).

Conclusions

The Digital Agriculture Fellowship (DAF) program at the University of California, Riverside (UCR) increased students' knowledge and interest in digital agriculture. Participants gained a better understanding of the field, and many became more interested in pursuing graduate studies and careers in this area. The program helped students develop research skills through the Summer RISE program and provided valuable experience and mentoring from faculty, which students

rated highly. However, some challenges were noted, such as program structure, coordination with faculty, and varying levels of student interest. These challenges suggest a need for better recruitment strategies and more career preparation support. Multi-year undergraduate curriculum-enrichment programs, such as DAF, are very resource-expensive. Identifying students with a high initial interest and commitment to the program topic may help continued engagement, retention, and program success. It is recommended that preliminary activities targeted to a large student audience are carried out to select potential participants to any long-term program.

The DAF also promoted diversity and inclusion, reflecting UCR's commitment to broadening participation in STEM fields. These findings provide valuable insights for other schools looking to create similar programs, emphasizing the importance of hands-on research, good mentoring, and targeted recruitment to keep students engaged in STEM and agriculture careers.

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