AG2PI SEED GRANT PROPOSAL

Title of Proposal:

Developing robust imaging platforms for routine plant phenotyping

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Keywords:

Plant breeding, phenotyping, data collection, image analysis

1. Objectives/aims:

Phenotyping is a critical step for plant and animal research, both in practical applications such as the selection of superior individuals in breeding programs or for research applications like the precise dissection of the genetic architecture of important traits[1]. One of the main challenges of phenotyping is the sheer amount of data that must be collected, analyzed, and stored[2]. Traditional methods of phenotyping are time-consuming, labor-intensive, and subject to human error. Additionally, researchers are limited in the number of phenotypes they can collect in a growing season, often resulting in uncollected traits or reduced population sizes[3].

Imaging provides a solution to many of these issues, allowing researchers to quickly and easily capture large amounts of data with a standardized collection process to ensure accuracy and consistency[4]. Modern image processing techniques can provide quantitative measures for complex traits and images can be asynchronously processed, allowing researchers to extract more detailed information from larger populations and reprocess data as new techniques are developed[5]. However, many imaging approaches available to plant and animal scientists result in unlabeled data, complicating analysis or even resulting in unusable data.

Field Book is an open-source Android app for phenotyping used in the breeding community with more than 6,000 users worldwide[6]. Multiple databases including BreedBase and the Breeding Information Management System have built in direct support for syncing with Field Book for data collection[7,8]. The app allows users to collect trait data with an optimized user interface and features to ensure data integrity and continuity. While Field Book currently includes a feature that allows users to capture images linked to specific entries, this setup is currently limited in that: 1) it can only use the integrated device camera, restricting opportunities for fixed camera phenotyping that is common in plant and animal research and 2) it uses a non-optimized file storage, slowing performance and restricting the ability to collect and utilize large amounts of data. **The work outlined in this proposal aims to address both issues.**

The goal of this project is to improve the image capturing capacity within Field Book to further enable high-throughput imaging capabilities for plant and animal scientists. This will be achieved by improving the Field Book codebase, testing compatible hardware, conducting a case study in citrus, and providing hardware recommendations. Developing the capacity to rapidly

collect standardized high-quality images will further the adoption of image-based phenotyping, making these techniques widely available to a diverse range of plant and animal scientists.

Specific objectives:

A. Improve Field Book code to facilitate high-throughput and external image capture.

To improve the ability of plant and animal scientists to capture organized image datasets, we will extend the current image-related feature set in Field Book. Specifically, we will improve the existing image data type by adding support for USB-compatible cameras and DSLR cameras, as well as integrate an open-source camera stack into the codebase to increase future flexibility.

B. Test specific hardware for performance and durability in repeated imaging.

Integrating hardware and software into a single workflow is one of the biggest challenges of software development. With the sheer quantity of phones, tablets, and cameras available, ensuring that all of these devices cooperate and are compatible is impossible. Through the development and validation of the code for this project, we will test popular mobile devices and cameras to identify suitable combinations that target specific phenotyping challenges.

C. Conduct a case study with citrus to evaluate the effectiveness of the improved software for mobile-based image capture and phenotyping.

Figure 1. Example of citrus diversity. Quarter shown for scale. Size and color have not been adjusted.

To further validate the suitability of specific hardware for phenotyping, we will perform a case study utilizing citrus fruits as a model. The citrus genus has enormous amounts of diversity (Figure 1) that often goes understudied due to a lack of high-throughput phenotyping tools. The USDA-ARS citrus breeding program has nearly 40,000 trees in its collection. While most trees can be visually assessed each season, it is currently not feasible to collect actionable phenotypes that can be used for improvement at this scale. With the improvements to Field Book image capture, we will collect the images necessary to extract important fruit traits including height, width, area, perimeter, shape, color, peel thickness, and seed number.

D. Create specific hardware and workflow recommendations for the Field Book community.

To ensure the results of this project can be adopted by diverse plant and animal research programs, we will publish all developed code, testing results, and hardware recommendations in open access journals and on the PhenoApps website (www.phenoapps.org).

2. Furthering the aims of the AG2PI

Robust imaging pipelines are foundational to the success of many of the AG2PI aims. The proposed project will substantially improve the image capture capacity in Field Book, a widely used mobile application among plant breeders. These improvements will support image capture pipelines that can be used across multiple species, including those that are being improved specifically for increased carbon capture and livestock feed. Additionally, this project will work to develop strategies for handling and integrating disparate data sources, addressing research challenges and method gaps prevalent in plant and animal scientific communities.

The deliverables of this project will directly impact thousands of plant breeders and therefore supports AG2PI's goals of communicating and disseminating findings across the scientific community. However, the proposed work is not limited to breeders and can be utilized by any researcher interested in collecting image-based data. We will utilize in-app usage metrics to determine the success of this project by measuring how and how often the developed features are used. This will support the goals of the AG2PI by making these tools and technology more accessible and scalable, particularly to research programs with limited resources.

3. Expected outcomes & deliverables

Many of the current phenotyping methods used in breeding and research programs do not allow for the organized collection, analysis, and storage of image-based data. For many crops and species, advanced high-throughput phenotyping technologies are not an option due to the cost, complexity, or limited applicability for specific traits of interest. These research programs are forced to rely on inadequate data capture methods or miss out on the opportunity to routinely collect and utilize image-based data. The proposed project has the potential to directly improve how thousands of plant and animal scientists capture image-based data for research.

To make this vision a reality, we will improve the Field Book app with the necessary code to support external cameras and improve the current image capture capabilities. These

changes alone, when released, will be available to the more than 6,000 current users of the app. However, to ensure the smooth adoption of these features, we will test different combinations of devices to identify and solve potential compatibility issues. The results and recommendations from this testing will be published and freely available.

The potential impacts of this project are enormous. By lowering the barrier to collecting organized images, we are facilitating the adoption and utilization of new technologies into plant and animal research. Moreso, since additional phenotypic characterization of biological samples is already supported in Field Book, we are essentially simplifying the process by which scientists can capture the robust and labeled datasets necessary to train deep learning models and develop new image analysis algorithms. Long term, these algorithms will be directly integrated into Field Book, allowing for the real-time extraction of complex phenotypic measurements from collected images, further catalyzing the ability of scientists to rapidly capture and subsequently utilize phenotypic data in their research programs.

4. Qualifications of the project team

Dr. Trevor Rife leads a lab at Clemson University that focuses on phenomics and crop improvement and has been working to improve how data is collected in plant breeding programs for more than a decade. Dr. Rife directs the PhenoApps project which includes Field Book. His lab includes expertise on plant genetics, image analysis, algorithm development, mobile app deployment, and data organization and storage. **Dr. Adrian Percy** has more than 30 years of experience in the agricultural sector and is the inaugural Executive Director of the NC Plant Sciences Initiative (NC PSI) at North Carolina State University. The NC PSI promotes interdisciplinary science and technology through public private partnerships to advance the plant sciences. **Dr. Amanda Hulse-Kemp** is a Computational Biologist with USDA-ARS focusing on genomics and phenomics of various crop species. Dr. Hulse-Kemp specializes in genetics and genomics of diverse crop systems and works to modernize the tools that are available to breeding programs with limited resources through the Breeding Insight OnRamp project (BI OnRamp). **Dr. Heather Manching** is a Postdoctoral Fellow at North Carolina State University currently supporting BI OnRamp. Dr. Manching has performed the seminal work in understanding the phenotyping approaches needed to make improvements related to citrus breeding.

5. Proposal timeline

Objective	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.
Extend Field Book app to improve image capture												
Test hardware for performance and durability												
Conduct a case study in citrus trees and fruit												
Publish specific imaging hardware recommendations												

Milestones:

A. Release a version of Field Book that can connect to DSLR and USB cameras.
B. Development of a dynamic testing environment to rapidly test hardware combinations.
C. Collection and analysis of data from a citrus case study to validate project effectiveness.
D. Presentation of findings and recommendations with the plant and animal research communities through conferences, workshops, and publications.

6. Engaging AG2PI scientific communities & underrepresented groups

To adequately engage with the AG2PI scientific communities and underrepresented groups, we will work to involve members of these communities in the research development, design, and deployment process. We will invite input and solicit feedback on the architecture of the proposed features from breeders and geneticists throughout the research process. The case study to validate the development work will be performed at satellite research stations that generally have limited resources needed to complete research, further ensuring that the project outputs are relevant to the broader AG2PI scientific community. We will present the project outcomes at conferences and workshops, publish articles in scientific journals, and participate in outreach events to engage with breeders and other scientists from underrepresented groups.

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