FACILITIES & RESOURCES APPENDIX 3

External Review of University of Nebraska–Lincoln Plant Growth and Phenotyping Facilities April 2 - 4, 2019

External Review Team:

Bettina Berger, The University of Adelaide
Julie Hochhalter, North Dakota State University
Kevin Reilly, Donald Danforth Plant Science Center
Pedro Andrade Sanchez, The University of Arizona
Yang Yang, Purdue University

FACILITIES & RESOURCES APPENDIX 3

Introduction:

We commend the University of Nebraska Agricultural Research Division for encouraging a thorough and transparent review, bringing together key staff and stakeholders in the Plant Growth and Phenotyping facilities. It is clear that UNL is diligently working to position itself at the forefront of innovation in these areas. The UNL team has wisely embarked on the process of consolidating facilities, which will serve to promote operational efficiency and heightened quality of facilities and service offerings.

Our observations clearly demonstrate that the UNL controlled-environment facilities (greenhouses and growth chambers) have been well-operated and maintained by highly dedicated and professional staff, and that UNL PIs with excellent expertise in biology as well as engineering have been actively leveraging the world-class phenotyping systems in their research. In other words, UNL is rich in building blocks in terms of expertise and experience in controlled-environment facility operation and plant phenomics, and is well on its way to establishing itself as one of the leading institutions in plant phenomics not only in North America, but in the world.

To best serve UNL in identifying opportunities to improve on what has been accomplished, we have focused our observations primarily on the following: status of the facilities and opportunities for improvement and/or renovation, the policies and procedures in facility operations and management, safety and regulatory issues, management and professional development opportunities, the overall phenotyping system management and operation, as well as the long-term sustainability of the overall phenomics-related investment and research.

Below we discuss a number of observations and recommendations that we hope will aid UNL in its goals to provide users with state-of-the art facilities, as well as expert and attentive service to more rapidly advance research, teaching and extension efforts.

1. Plant Growth Facility

In terms of the greenhouses and growth chambers across the campus, we strongly recommend UNL to invest time and financial resources in developing a master plan for PGF expansion, and to establish a clear vision for future development of greenhouses as well as growth chambers.

1.1. Greenhouses (GHs)

We agree with the recommendation from a private construction firm that the East campus and teaching facilities need to be replaced. For the East Campus facilities, there are significant safety risks for staff and users and to the facility itself. Upgrades and renovation plans must be done with strict adherence to electrical installation code. The concerns over user and staff safety cannot be overstated, and we strongly recommend an immediate risk assessment to help prevent disaster if the facilities will continue to be operated. The lack of consistent lighting conditions, antiquated HVAC and limited sensors and control systems also indicate that significant investments and upgrades are needed in order to improve the quality of research in the facilities. To improve the lighting conditions in the GHs, additional light fixtures, and/or new lighting technologies (such as LEDs, double-ended HID, etc.) should be considered, taking into account the ageing electrical installations (facility should not operate at upper limit of allowed load). We recommend UNL GH staff team consult with GH lighting experts to establish the appropriate light intensity requirements, light distribution, light quality/spectrum, and photoperiod that best accommodate the research in the GH facilities. We also encourage UNL GH staff to collect preliminary test data on the impacts of new lighting technologies, such as LEDs, in order to avoid unintended consequences in research. To improve the capability and consistency in GH temperature control, the fan-coil units in the air-conditioned greenhouse should come with bimodal capability (i.e. equipped with both a cooling coil and a heating coil). Also, the HVAC equipment should be recessed in ground to minimize excessive shading. Humidity control was not mentioned by staff during the interview. We strongly recommend UNL staff take serious consideration in GH humidity control.

Attention is also needed to the (lack of) isolation among current greenhouses. The current GH configuration is not able to facilitate the needs to prevent insects and diseases from transferring among GHs.

The teaching greenhouses should be replaced because the current facilities can no longer provide adequate teaching resources and student experiences, and is obviously deficient in support and instruction spaces. The next generation of horticulturists needs to be exposed to computer-controlled facilities, sensor-based operations, urban and precision agriculture techniques, etc., which the current teaching greenhouse is not able to provide. We suspect that the poor teaching GH facilities and the lack of support spaces could be contributing factors to the significant drop in horticulture program enrolment since the 1990's.

The GH compound at NIC is the only greenhouse facility we would consider "research-grade", but to our knowledge it is not available for non-phenotyping-related research. Increased supplemental lighting in NIC for improved light consistency is indicated. In hindsight, recessing the large HVAC equipment in the ground would have decreased shading - a consideration that can be applied for future greenhouse builds. Other than NIC, Beadle is the highest quality GH across the UNL campus; however, we would not recommend using the Beadle GHs as a basis of design for future greenhouse expansions. Instead, we recommend UNL to consider benchmarking against other research-grade facilities such as UNL's NIC, Danforth Center, NDSU, University of Missouri-Columbia, University of Arizona Controlled Environment Center, etc. (could conduct site visits), and to consult with companies like Nexus on current standards for state-of-art, research-grade GH.

1.2. Growth Chambers

The growth chambers at the East Campus could be better consolidated in a new space. We are concerned about investing more money into placing chambers in this area, which may be torn down in the near future. Is there a plan for a centralized, long-term growth chamber facility? If so, that would lead to enhanced efficiencies in terms of operations and maintenance, etc. We recommend UNL perform a cost-analysis for moving chambers if the head-house is decommissioned. If the chambers are to be moved, a well-conceived plan should be developed around the physical logistics of how this would be accomplished, whether local mechanical contractor be hired or done in-house, potential risk to equipment, labor costs, and similar aspects. It would be helpful if Conviron, UNL Facilities, or other experts could be consulted on the risks to equipment during transportation. Consideration should also be extended to the downtime to researchers while relocating the units. For several reasons, it may be better to strategically plan a new chamber facility/area before purchasing more chambers.

2. Policies and Procedures

Consolidation was a prudent decision and provides opportunities for improved coordination of services, staffing, materials acquisition, maintenance needs, customer communication, facility/equipment upgrade decisions, etc. This also can promote consistency in services and uniform application of policies and procedures. Some improvements can likely be made to the consistency aspect. During the interviews, we were uncertain if policies and procedures are being applied and enforced similarly between greenhouse facilities, so that users can expect similar service quality and procedures between facilities.

Some policies, such as the ones related to the safety protocol for working in GHs, are not always well followed by users, and staff have found it difficult to enforce these policies at times. This is due to the fear of pushback from faculty. There also has been challenges with user compliance in using the online space request form, which is an important tool and has been well-developed by the PGF. To better enforce the operations and safety policies across the controlled-environment facilities, we recommend that each user be required to complete a walk through orientation which would include:

- General procedures (how to book space, where to find supplies/equipment, GH contacts, etc.)
- General hygiene and labelling requirements

- Safety standards (escape routes, fire extinguisher location, assembly point etc.)
- Regulatory compliance (how to handle and dispose of transgenics and other regulated materials)

A positive cultural change and top-down support from UNL leadership would facilitate the enforcement and compliance of all the policies regarding working in the GHs. It cannot be overstated that the Professors/Department Heads need to realize expectations of overseeing safety and regulatory compliance for their groups. The GH staff have been doing their best to provide a safe and efficient working environment, but it takes everyone's cooperation for the solid policy enforcement. As part of the cultural change, we recommend inviting an external representative to join the Advisory Committee in order to provide outside perspective and serve as a resource for PGF director/managers. Ideally, this would be someone with strong experience in controlled environment facility operations and management. This could be someone who conference-calls in for meetings.

Writing SOP's should be a constant exercise and sustained effort to create a culture of documentation. SOP's should apply to multiple levels, including a) greenhouse management practices such as handling materials, identification of container/plant materials, lighting, temperature/RH settings or controls, irrigation, pest control, etc., and b) electronic scanner operations, error logs, maintenance logs, repair history, calibration, etc.

The lack of a plant tracking system in the greenhouse for individual large containers and/or trays is a concern. The current protocols do not provide a way to quickly identify and locate users, transgenics, labs, species, etc. within the facility aside from what the manager has "in their head". This creates a risk for service/information continuity in the event of staff turnover, extended leave, etc. A policy should be established to appropriately label containers. More importantly, information on each experiment (owner, species, transgenic/GE, emergency contact info, etc.) needs to be readily available (perhaps on the entrance door of each greenhouse if the whole house belongs to one experiment; or on the benches if multiple experiments in one GH). Pot stake printers are economical and make labelling easy. This policy can also help to better handle biosafety compliance (signage, clear colour coding and labelling).

Integration of beneficial insects / IPM measures is strongly recommended. IPM is the current industry standard for pest control. Pest management, user and staff safety, keeping facilities open, reduced risk of plant phytotoxicity, etc. are important benefits of biocontrol use and a true IPM program. Exposing students to IPM is also important for training and career success. Understandably, it will require the ability to devote a significant amount time. Some areas may be more conducive to biocontrols than others, but the program could be implemented slowly over the course of a few years. Educating greenhouse users about IPM is key to success and should be part of orientation and training. Cost-wise, there would likely be an initial increase in labor and spending, but the return on investment could be realistically achieved within a few years.

We would also like to see a centralized online list of all growth chambers with location, specifications/capabilities, square footage, and contact details for staff in charge provided. There currently appears to be some lack of awareness of chamber availability from faculty/users.

3. Safety and Regulatory

The current state of the facility on the East Campus greenhouses is a life safety concern, with electrical issues and ageing infrastructure (two recent fires!). We recommend immediate safety risk assessment and actions to reduce the risk of disaster/ fatality (e.g. installation of smoke detectors, heat sensors, sprinklers, and/or other fire suppression equipment).

EPA-WPS training is a priority of staff, though they expressed concerns with user compliance and buy in. GH staff and users should use appropriate footwear, gloves and eye protection when required.

We recommend a greenhouse user orientation related to safety as well as use (supply location, key personnel and contact information, do's and don'ts, etc.). This could be combined with WPS training (even just 10-15 minutes), so everyone gets some training. The online space request should include a question relating to whether user training has been completed. We also would like to raise the question on how much the Biosafety Office is involved in compliance in the GHs. This should be a shared responsibility with PGF Management. Are the Institutional Biosafety Committee (IBC) procedures, responsibilities and project approval processes clearly defined and well-communicated to Professors/PI's?

4. Staff/Management

The skill and experience of PGF/Phenomics staff is a major asset for UNL. The dedication and care shown by staff members for their work and responsibilities is strong. The PGF Faculty Advisor Committee also voiced their agreement with this assessment.

There seems to be some disconnection/misunderstanding between how PGF staff are valued by faculty and users, and how PGF staff perception of how they are valued. A dominant majority of UNL Faculty/Users we have been in contact with feel the GH managers and staff are doing a good job, and are essential assets to their research, therefore they would not want to lose them. However, multiple PGF staff are worried about their job security and being penalized for enforcing operational and safety procedures.

We recommend UNL to consider revising job descriptions if needed to more formally communicate GH Managers' authority and the expectation to enforce approved policies and procedures. The Facility Director and Managers should have a reasonable level of authority over all operational aspects. UNL leadership should back these positions with sufficient authority and formal support. PGF staff need support from administration and the PGF committee to enforce policies and bring faculty/users into compliance. At the same time, PGF staff and management should be diligent in communicating issues, challenges, successes and other important topics to the Committee and Leadership. This will improve the culture of the facility and improve research quality & results. PGF staff morale may be improved by upper administration thoughtfully and intentionally implementing staff appreciation initiatives.

Some PGF areas appear to be understaffed and current staff overworked, perhaps especially in Beadle GH where there is one manager and 1.5 FTE Technicians, but occupancy is highest, quality expectations are higher, and is mostly full-service. An increased staffing level with more dedicated technicians for Beadle GH to support day-to-day operations should be considered. The Beadle GH Manager may need some training/coaching on effective delegation and given time to properly train new staff. This would in turn free up time for the GH Manager to dedicate toward IPM implementation and other priorities.

The PGF team dynamics appear to be good. The team should investigate integrating working teams, cross-training (operational redundancy), professional development, and other aspects to make them even stronger.

5. Professional Development

The review committee has found tremendous personal benefit from training in leadership, managing conflict and client-relationships, transitioning from individual contributors and technical experts to leaders, and team development. Training of collective PGF/Phenotyping Management Team could empower, enhance confidence and show UNL's willingness to invest in staff development. We strongly recommend UNL to allocate funds in order to encourage attendance at conferences/workshops. Individual training for PGF/Phenotyping Director and Managers may be beneficial as well to increase professional and soft skills.

Membership in organizations, such as AERGC, AHS or NCERA-101, are especially good options for PGF Director/Managers - with an understanding that attendance of GH Managers at meetings would likely need to be rotated. We encourage yearly conference attendance for the PGF Director to keep updated on state of industry, networking, and brainstorming with others in similar positions. For the phenotyping team (technical

and scientific), there is also an abundance of phenotyping conferences to learn about latest developments and establish important networks with similar facilities.

6. Phenotyping

UNL has all the components to become a world-leader in plant phenotyping: excellent hardware, world class crop scientists, complementary expertise in engineering, statistics, data management and computer vision. Turning those components into an effective phenotyping program only requires some fine tuning.

The phenotyping center rates may have to be reviewed. We suggest to consider a scaled pricing, i.e. per pot rates drop as number of pots in the experiment increase. If rates are lower but higher usage is gained, the current income level could be maintained or possibly increased. A flow-on from this would be an increased science output, especially from internal users who already contribute to the academic excellence of UNL. Too high rates run the risk of staff not using the facility, becoming less competitive in grant funding, or compromising the science due to budget constraints, e.g. smaller, shorter experiments than ideally required.

Basic image analysis needs to become part of phenotyping service portfolio. There currently appears to be parallel development and duplication of efforts, with image analysis being dependent on individual collaboration amongst faculty. The basic image analysis needs to be handled by a staff employed in a service/professional role and with a service attitude, not an academic appointee with their own research focus; the staff also needs to be embedded in the phenotyping team, not separate from the technical team and plant scientists.

NOTE: Due to key staff for the image analysis being on sick leave during the review process, the review team could not obtain a complete picture of the image analyses processes in place and recommendations are based on the information obtained from other staff.

The appointment of a director for phenotyping should be revisited. This person should have oversight of the whole phenotyping process, bring the team and disciplines together and be the go-to person for the plant scientists undertaking the project. In effect, the person would be an 'interpreter' with sufficient domain knowledge of the different disciplines required for phenotyping to communicate effectively with all team members and collaborating faculty.

In order to build an effective team, consideration needs to be given to the following aspects

- Conflicting demands between expectations in service provision and academic career progression;
- Technical skills and professional soft skills (a lack of some soft skills can be excused in classic academic roles, but is a major issue in an interdisciplinary team - recruitment needs to focus on those skills and extra training may be required)

The process map for the phenotyping workflow should also outline to users and facility staff who's responsible for what step and if the responsibility is dependent on the project (e.g., who grows plants initially), the responsibility needs to be agreed on beforehand and documented. The phenotyping policy should include a requirement for the PI or user (if local) to inspect their plants at least once per week and consult with operating staff on progress and any issues that may need to be addressed. There should be a checklist in place for users and the phenotyping team before a phenotyping experiment gets taken on; e.g. statistical support and consultation with statistician has to be a requirement.

Creating a service-based system tailored to private sector users has the potential benefit of increasing revenue, but careful consideration should be given to find mechanisms for prioritization of usage. External use should not be seen as a conflict to internal demand but the possibility to cross-subsidies internal rates. UNL faculty should not have the impression that these state-of-the-art facilities are out of reach.

The HTS system is grossly underutilized and options for increasing uptake should be pursued or sale of the system, if it is no longer required

- Could it be leveraged to foster external collaboration with industry partners or other universities, international centers? (basic image analysis needs to be in place)
- Understand research needs of staff and students and explain how HTS system could benefit their research project
- Perform detailed analysis of current limitations of HTS hardware/software, and identify potential modifications for repurposing

7. Long Term Sustainability

UNL should develop a solid plan towards achieving financial health after all external subsidies start to wind down. This statement is true even with the understanding that a public institution will always provide a level of subsidy/backing for their state-funded programs. For the phenotyping capability, UNL should investigate if partnering with other institutions is an option (e.g. other universities, research centers and facilities). There is a good argument that can be made to potential partner universities for buy-in, since maintenance of a phenotyping facility is a large investment and staffing requirements are considerable (e.g. "instead of building your own, buy time on our system"). For external use by collaborators, service level (basic image analysis) needs to be addressed first though.

It needs to be kept in mind that if industry partners are to be attracted to cross subsidize internal user fees, the only greenhouse space suitable is at NIC, other areas would not meet industry standards and expectations (stewardship and EHS etc.) unless refurbished or replaced.

Integrating more engineering expertise and pursue close collaboration with UNL College of Engineering faculty in the area of mechatronics can ensure long term relevance of equipment and keeping pace with latest technological developments, customized solutions, avoiding obsolescence and increasing flexibility of applications.

There should be a master plan developed for long term replacement of growth facilities. I.e. is it financially sound to install new growth chambers in a building that may need replacement in the not too distant future?

- Future facilities should be designed flexible and modular wherever possible to allow for layout changes, retro-fitting, upgrades
- The infrastructure planning should be closely aligned with the long-term research and teaching strategy; i.e. what type of research will UNL be doing in 10-20 years' time? What courses will be offered in the future (e.g. vertical farming? Digital agriculture?) - this will ultimately drive what facilities will be required and further develop UNL's brand.