Using Plant Stress Experiments to Teach Across Disciplines in Plant Physiology and Soil Chemistry

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Abstract

Hands-on laboratory classes are one of the most effective ways to teach students in STEM (science, technology, engineering, and math) disciplines the analytical skills they need to succeed and to help them integrate concepts from lecture and reading material. However, lab classes are expensive, resource-intensive and time-consuming. Plant and soil experiments are particularly challenging because growing plants need reliable care prior to and during the semester and the changing plant and soil conditions often need to be monitored outside of class time. Salinity and drought stress are common problems in southwestern U.S. agriculture, so a greenhouse experiment was designed to demonstrate the effect of different salinity levels on plant growth and function. Students in the Plant Physiology lab class (BIOL/EPWS 314/514L) induced salinity stress by assembling and applying mixed salt solutions to the plants. Plant growth and yield responses to stress were measured using a variety of specialized research instruments. Students in the Advanced Soil Chemistry class (SOIL 551) measured the soil salinity and other chemical parameters at the end of the experiment. Plant and soil data were analyzed and shared between students in both classes, allowing students to more fully examine the relationship between soil chemistry and plant physiology. Although each class concentrated on the techniques and concepts of its own discipline, the collaboration between instructors and the shared workload and results demonstrated the value of interdisciplinary cooperation by increasing the overall efficiency and relevance of the work. In addition to strengthening the ties between our two labs and departments, we were able to apply the lessons learned in our classroom greenhouse experiments to our research projects.

Introduction and Objectives

In lower level STEM classes, laboratory exercises are often designed and presented as discrete modules to introduce students to specific skills and concepts. If well designed, the lab modules build upon each other and form a logical progression of information throughout the semester. Often times though, the students may not be aware of the larger context in which lab exercises are being done, and, thus, are not able to integrate the lab exercises with lecture and reading material. In upper level courses such as Plant Physiology and Advanced Soil Chemistry, a whole-system experimental approach should be taken, in which the structure of lab exercises challenge students to learn and synthesize more difficult concepts in a larger context, as well as become familiar with analytical techniques and instruments appropriate to their discipline. One way to achieve this aim is to incorporate longer-term experiments spanning several weeks, which build upon the foundation of STEM prerequisite courses and newly-introduced principles, as well as lab analytical tools developed and used in the research setting. A key component of this approach is to integrate research questions that are relevant within the particular discipline. Further, from a pragmatic viewpoint, experiments must be feasible given resource and time constraints.

In this paper, we explore the use of a salinity stress experiment developed collaboratively and incorporated into BIOL/EPWS 314/514L and SOIL 551. Note both labs have been taught for the last three years. The class objectives of this laboratory experiment were: 1) to understand plant-soil relationships by exploring the effects of different soil salinity levels on plant growth and function; 2) to use various instruments and measurement techniques used in both plant physiology and soil chemistry research settings; and 3) to synthesize and discuss data in both written and oral formats. Another practical objective was to obtain preliminary results that could help develop the framework for future research questions related to salinity issues.

Classroom Methodology: "Nuts and Bolts"

Plant Physiology Lab

At the start of the course, students obtained a lab manual. For each weekly lab, the student was required to read through the lab objectives, background material, and experimental lab procedure. An accompanying pre-lab quiz was completed and handed in at the start of the lab, to ensure that the student was prepared. In the context of the salinity experiment, the initial lab detailed soil salinity, its historical and current relevance to plant growth and development, symptoms of salinity stress, and the experimental context, objectives, and procedures to be performed. In addition, a guest presentation about soil salinity and its effects on plant growth and development was incorporated into the laboratory period. For subsequent labs related to specific measurements, an accompanying handout (from the manual) for that week's lab provided pertinent background and procedural details.

The experiment was arranged as a two-way factorial design with three replications of each plant type (barley, bean, corn, cotton, sorghum) by salinity level (1, 2, 4, 8, 16 dS/m) in all combinations. For the first part of the experiment, students prepared mixed salt solutions based on the ionic ratios of the Rio Grande in New Mexico, and applied these solutions every other day to the plants over a three-week time period. Plants were then destructively sampled to determine plant growth and yield responses to salt, including visual ratings of wilting and necrosis, plant height, shoot weight, relative water content, chlorophyll content, and chlorophyll analysis using liquid chromatography techniques.

In addition, a germination study was conducted to ascertain the effect of the different salt levels on germinating seedlings of the five plant types. Students visually observed the seeds over the course of one week, and at the end of this time, noted percent germination. Data measured by each group within the class were entered into an excel spreadsheet during a subsequent lab period, and then made available for the entire class over WebCT.

Advanced Soil Chemistry Lab

As in the BIOL 314/514L lab, a guest presentation detailing the background of the experiment was provided at the start of the lab period. A lecture on soil salinity measurements and responses of plants to various salts was also provided, as well as supplemental readings. To manage our time and resources better, the growing media ("Metro mix" potting soil + sand) from each plant type (5 species) by salinity treatment (5 levels) were combined into one composite sample from three individual pots (for a total of 25 samples). Saturated soil paste extracts were then prepared, and students determined EC, pH, and sodium adsorption ratio (SAR) for each of the soil sample extracts. Students also determined saturation percentage and soil moisture content to evaluate the consistency of the saturation paste method. In addition, students observed the seedlings in the germination study. Data measured by each student within the class were collated and made available to all students via email.

Plant Physiology Lab Synthesis

In the BIOL 314/514L class, students ultimately synthesized the experiment and data collected as a power point presentation prepared by a team. First, part of a laboratory period was dedicated to "walking through" the data at various levels. The significance of results was discussed both as a class and in pre-assigned presentation groups (2-3 people). The class discussion included pertinent tips for giving a power point presentation, exposure to statistical principles like regression by relating chlorophyll data measured to a standard calibration curve obtained with liquid chromatography, as well as relating the target salinity levels to the actual measured soil extract EC data, and understanding observed and measured responses and possible cause-and-effect relationships. In the small groups, students assigned specific roles for each person and discussed presentation ideas. Further, each group was given a unique case study with questions to read and discuss within 30-minutes, in order to encourage application of the salinity experiment to a bigger picture scenario. Each group then shared their case study, along with their synthesis of the questions, with the rest of the class. In a subsequent lab period, students presented their power point talks to the rest of the class, as well as to invited advisors of each of the students.

Advanced Soil Chemistry Lab Synthesis
In the SOIL 551 class, students discussed their findings as a group and then prepared individual written lab reports (10-20 pages) with sections including introduction, objectives, educational goals, theory, materials and methods, results and discussion, suggestions for improvement, references, and accompanying graphics. The lab report instructions provided at the start of the assignment detailed appropriate formatting, objectives and educational goals, and specific questions and answers that were required to be addressed and incorporated into the various sections. The introduction stated the relevance of soil salinity and general background, and the theory section focused on soil salinity measurements. In the materials and methods section, details related to the plant types, growing substrate, and salt solutions, as well as step-by-step methods were expounded, including the preparation of soil paste extracts, and the calibration and use of EC and pH meters. In the results and discussion section, data were presented and interpreted, including trends and consistency of EC, pH, and saturation percentage measurements, as well as impacts of growing substrate and salinity level. Students represented data in graph and/or tabular format, including any relevant statistical analyses performed. In addition, regression data plots showing the actual EC versus target EC for each plant type were provided to each student for inclusion in their discussion. Suggestions for improvement provided students an opportunity to assess the class and personal lab learning experience, as well as gaining input as to how the lab could be utilized at the undergraduate level. Students were also encouraged to provide any relevant supplemental graphics, including appropriate websites, which would support their report presentation.

Conclusions: Benefits of Interdisciplinary Collaboration in Teaching

One of the greatest benefits of collaborating across disciplines, in a teaching context, was that it provided the students an opportunity to gain a larger perspective in the context of specific research questions. The use of a plant stress experiment spanning several weeks provided a strong base on which to expand beyond the context of the immediate plant or soil measurements, and to better understand interrelationships at a whole-system level. The depth of exploration allowed students to be exposed to a variety of measurements and instrumentation, as well as to the principles of experimental design, statistical analysis, and interpretation and synthesis of more complex results, thereby strengthening critical thinking skills. By moving across disciplines, students were also familiarized with faculty/staff outside of their particular discipline, thus building networks within the university community.

As mentioned previously, the experimental design and related salt treatments were developed collaboratively. Thus, results obtained after the first year's lab provided the opportunity for further developing and fine-tuning the methods and experimental design and set-up. Because the labs were approached each year as dynamic and fluid, rather than static, lessons learned from previous year's labs were synthesized and incorporated in subsequent years. Students benefited from this dynamic approach since results from the previous year(s) were shared with students, helping to instill the idea that experiments don't typically work "recipe-perfect", but require work and continual "tweeking" to fine-tune experimental design. Further, students gained valuable lessons in actually *doing* research rather than simply performing techniques. Previous results gave birth to more unanswered questions, providing a foundation on which to discuss and investigate other research questions in the lab context.

From a research perspective, the collaboration strengthened ties between our respective research laboratories, spurring discussions and ideas for possible future joint-research projects. In addition, the experience gained with the experimental salt solutions proffered insight for a current NMSU research project looking at salinity levels along the Rio Grande. Further, a former post-doctoral student at NMSU, now professor, is utilizing the salinity lab protocols for his work with salinity in vegetables. These examples demonstrate that the preparation and time invested in upper-level and graduate labs can be a means for enhancing research activities.