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Case Study Article

On-field Agroecosystem Research Experience: An Undergraduate Perspective

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Abstract: Undergraduate hands-on research can foster innovation and critical thinking among young scholars to delve into real-world challenges. Specifically, exploring the critical nexus between water usage and agricultural yield, can foster academic growth and holds the key to addressing global food security in an era of increasing environmental constraints, where students can unlock insights crucial to enhancing crop yield and sustainability. Investigating the intricate relationship between water management and crop productivity through undergraduate research is exemplified in this article. Undergraduate students acquired hands-on research experience by collecting, processing, and analyzing destructive (crop biomass samples) and non-destructive (plant height, nodes, and leaf chlorophyll content) cropping system data on soybeans under irrigated and dryland production systems, where they worked closely with the farmer. Identifying the current research problem and study site selection, scientific decision-making during the field study, developing critical thinking while ensuring research communication skills, and quality assurance and quality control through technology during data collection and analysis were learning outcomes. The research highlights the observed distinct performance between irrigated and non-irrigated soybeans using non-destructive plant health and growth indicators with plant biomass, following appropriate quality control and assurance steps. Statistically, irrigated soybeans outperformed non-irrigated soybeans in terms of average plant height at maturity (irrigated: 97.0±1.7 cm vs. non-irrigated: 37.4±0.6 cm; $p<0.01$) and number of nodes on the mainstem (irrigated: 19.5±1.2 vs. non-irrigated: 12.6±0.8; $p<0.01$). Findings from this study can help ensure quality control and assurance in future cropping system projects. Through the agroecosystem study, we exhibit the importance and role of undergraduate research opportunities in developing the next generation of problem solvers.

Keywords: *undergraduate research, quality assurance, quality control, non-destructive, destructive, irrigated soybeans, non-irrigated soybeans*

Undergraduates interested in careers in scientific research should have real-world research experience and hands-on training (Thiry et al. 2012). Nevertheless, many students face the challenge of deciding what to do after graduation because they still need the technical skills required in the job market (Fortenberry 1993; Sabatini 1997). The demand for workforce and market skills prompted the development of a research-based course to encourage the involvement of young undergraduate research enthusiasts (Cavanagh et al. 2016). Various student research experiences have enhanced undergraduates' performance and interest in science, technology, engineering, and mathematics (STEM) research across the United States (Bruthers et al. 2021). Researchers and mentors believe that students would benefit from research experience, but they have yet to find the best ways to orient and guide them. It would be

Research Implications

- Undergraduate students benefit from research opportunities in on-field agroecosystem and water use efficiency.
- Soybean health and vegetative growth were significantly greater in irrigated areas of the field than in non-irrigated areas.
- Proper quality assurance and quality control, including photographs and audio recordings, can assist in eliminating errors in agricultural research.
- Learning outcomes from agroecosystem research can shape undergraduates' future research interests and enhance their problem-solving capabilities.

helpful to have an orientation that balances students' attitudes and expectations with the realities of the research experience. As they prepare to transition to graduate study or jobs, enthusiastic students bring an energy of curiosity and eagerness to learn through hands-on training in a real scenario (Adebisi 2022).

The learning activities include discussions with mentors, participation in group meetings, supervised opportunities to explore pertinent research material, and reflection on observations. Students learn scientific techniques such as research planning, modeling scientific breakthroughs, and data analysis through undergraduate research initiatives. Mentors should ideally assist students in assessing the credibility of scientific research and connecting their experiences to their expectations. Undergraduate research advances our understanding of critical issues like optimizing water use for agricultural yield. Hands-on training investigating the intricate relationship between water management and crop yield can become a foundation for understanding the necessity of sustainable agriculture.

Globally, soybean (*Glycine max L.* (Merr.)) is the first-grown legume and fifth most-grown crop (Boote et al. 1998; Kothari et al. 2022). However, climate change, rapid population growth, and high food demand have contributed to the complexity of the agroecosystem, the exploration of natural resources, and their adaptation to global environmental changes (Asseng et al. 2015; Jones et al. 2017). The complexity of agricultural systems related to the change in water use makes it quite tricky to define entire crop system operations in mathematical terms (Jones et al. 2017; Zhao et al. 2019). To fully visualize, represent, and predict the future yield of significant crop growth, crop simulation models have been developed for the past 40 years to assess the ability of farming systems to meet the world's food demand (Zhao et al. 2019). Previous studies highlighted the variation in future soybean yield prediction from different crop models and the limited understanding of soybean biological and mechanical processes in response to climate change (Belcher et al. 2004; Jägermeyr et al. 2021).

Through an undergraduate research opportunity, we collected ground truth destructive and non-destructive soybean data from irrigated and non-irrigated fields to quantify soybean growth and development in response to water usage, where we compared irrigated versus non-irrigated (rainfed) systems. Our undergraduate research-learning goal was to ensure the high quality of generated destructive and non-destructive data through scientific experimental design and developing critical thinking. We hypothesized that water usage can be very critical in crop production. We examined the nexus between water use and agricultural yield, a pivotal area for undergraduate research that can play a transformative role. With the undergraduate perspective linking water and yield through agroecosystem research experience, we had exposure to decision-making. We identify the need for high-quality destructive and non-destructive data with proper control and assurance and the critical role of communication skills for a successful undergraduate research project.

Materials and Methods

Study Area Description

This study collected destructive and non-destructive soybean data from a farmer's field in Sutherland, Nebraska (41.06, -101.15) in 2022 (Figure 1). The research area (56.8 hectares) was chosen to encompass a variety of soil types such that both irrigated and non-irrigated systems were covered (Figure 1A). The irrigated areas covered

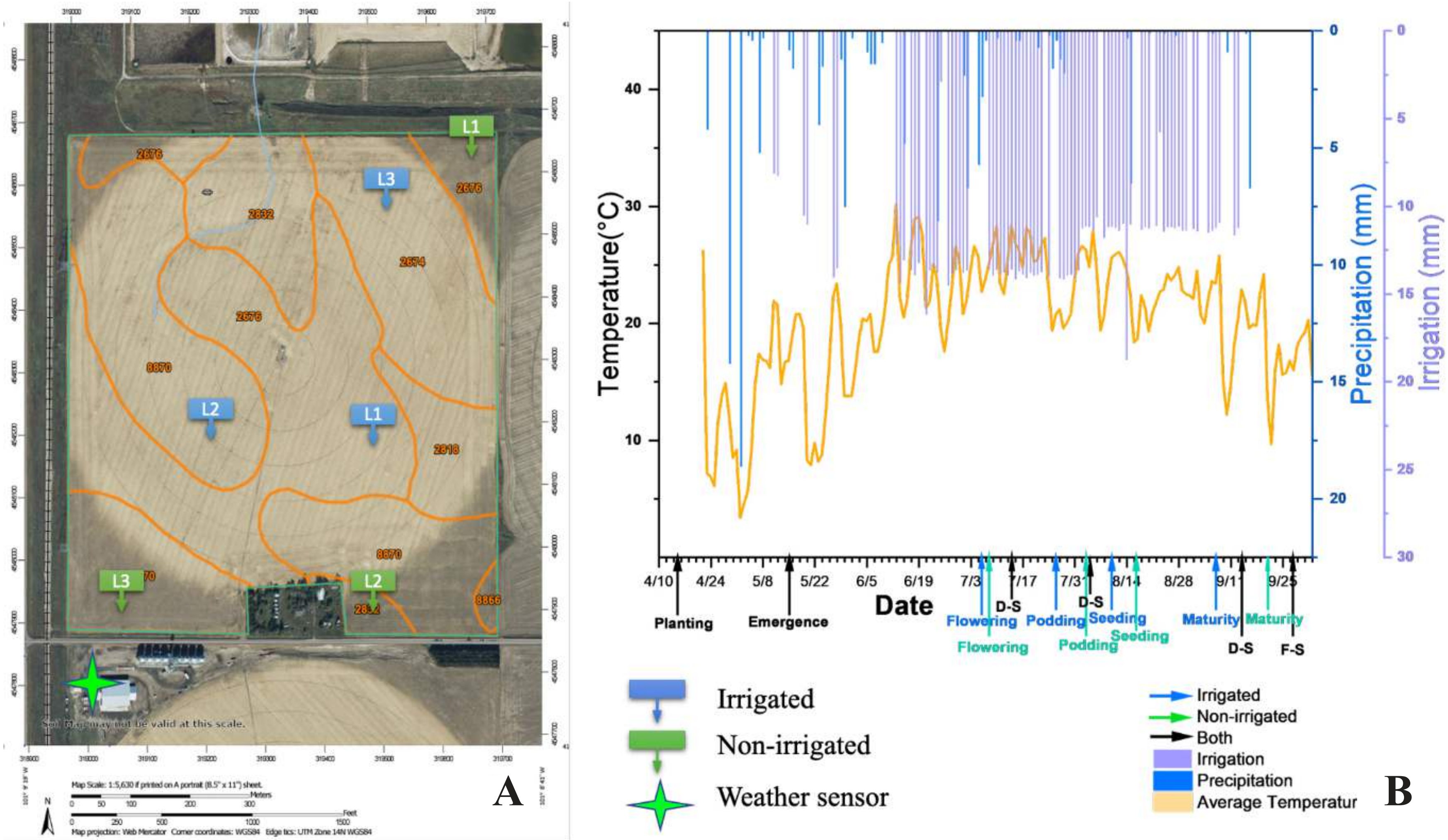

Figure 1. Study area (A) with different soil types (https://websoilsurvey.sc.egov.usda.gov) (left panel), weather and irrigation timeline (B) (right panel).

around 84% of the total field (47.3 hectares). In contrast, the non-irrigated area was the remaining land outside the center pivot radius, which covered approximately 16% of the total field (9.5 hectares). Localized weather stations were installed within 0.8 km from the field's center. Modern and cutting-edge technology, such as the availability of arable sensors (served as weather stations and provided both irrigation and precipitation water depths), soil type variability (Table 1), variable rate irrigation systems, and historical fertilizer and irrigation data, were available at the study sites. These datasets were critical in developing and verifying the cropping system model. However, our role was primarily to collect ground truth data in the farmer's field and link water use with observed yield while ensuring the proper quality of the collected data.

Non-destructive Plant Health and Growth Indicators

Irrigated and non-irrigated separate locations (Table 1) were selected based on soil types to represent experimental replicates. At each location, non-destructive (sampling without causing damage to the plants) data were collected from four randomly independent 1-m rows twice a week. At each representative location and 1-m row, coordinates were recorded, and locations (selected to represent major soil types) were named (location number and row number: e.g., L1-R1; L1-R2; … L1-R3; L3-R4).

For non-destructive sampling events, each calendar date of the visit, the planting date, the plant emergence date (typically takes around ten days, depending on soil temperature and moisture), the beginning pod date (when pods size were 5 mm long at one of the four uppermost nodes), the full pod date (when the pods' sizes were 2 cm at one of the four uppermost nodes), the flowering date (identified when plants have at least one flower on any node), and the full flowering date (identified when plants have an open flower at one of the two uppermost nodes) were noted.

Table 1. Study area map unit symbols with irrigation status, corresponding soil types, and area of interest (AOI) coverage (https://websoilsurvey.sc.egov.usda.gov).

Map Unit Symbol	Map Unit Name	Hectares in AOI	Percent of AOI
2674 (*Irrigated*)	Holdrege silt loam, 1 to 3 percent slopes, plains, and breaks	8.4	14.8%
2676 (*Non-irrigated*)	Holdrege silt loam, 3 to 7 percent slopes, eroded, plains, and breaks	19.3	34.0%
2818 (*Irrigated*)	Uly silt loam, 3 to 6 percent slopes, eroded	3.0	5.3%
2832 (*Irrigated*)	Uly-Coly silt loams, 6 to 11 percent slopes	5.5	9.6%
8866 (*Non-irrigated*)	Hord silt loam, 0 to 1 percent slopes, warm	0.3	0.5%
8870 (*Irrigated and Non-irrigated*)	Hord silt loam, 1 to 3 percent slopes	20.3	35.7%
	Totals for Area of Interest (AOI)	**56.8**	**100.0%**

The number of mainstem nodes in soybeans was frequently counted to evaluate how the plant grows vegetatively. The number of nodes on the mainstem was recorded on five to eight randomly selected plants in each randomly selected row in both irrigated and non-irrigated areas. Node 0 are the two cotyledon nodes, whereas node 1 is where the two unifoliolate leaflets are joined. All other nodes above the unifoliolate leaflets are numbered 2, 3, and so forth and hold trifoliolate leaflets (Kranz and Specht 2012).

Single-sided meter sticks (Eisco™, U.S.) were used to measure plant height from the cotyledonary node to the tip of the apex on five plants within a 1-m row. Portable SPAD 502 Plus Chlorophyll Meters (Spectrum Technologies Inc., U.S.) were used to measure plant leaves' health and nitrogen concentration in SPAD values (Ling et al. 2011), which were later converted into leaf chlorophyll concentration per unit area (Markwell et al. 1995). The calculated chlorophyll concentrations have been reported in Table 2.

Multiple photographs and audio recordings were captured at each stage for quality assurance and quality control (QA/QC) of the collected data. Upon capturing the images and recordings, we conducted a thorough review to identify any errors or typos, ensuring the accuracy and reliability of the data collection. Documenting this information in the field contributed to developing critical thinking skills in managing large datasets generated during agricultural research.

Destructive Plant Sampling

Monthly destructive samples were collected after full flowering from previously identified, marked, non-destructively sampled sites and whole plants were removed from three 1-m rows. At the time of harvest, three 2-m rows were sampled at each of the three locations. There were between 16 and 20 soybean plants in each 1-m row. All plants (including roots, stems, leaves, petioles, pods, and seeds) were entirely removed from the soil and placed in Ziploc® bags to be processed at the University of Nebraska-Lincoln laboratory. The date, location, and row number were meticulously labeled on each Ziploc® bag. Labeled Ziploc® bags containing samples were placed in insulated coolers containing ice packs to ensure sample freshness during travel to the laboratory. All leaves were separated from the mainstems for each plant and placed on aluminum foil. Three randomly selected leaves were taken from each pool of leaves from every plant and photographed alongside a Single Sided Meter Stick. Each leaf was individually folded in a pre-weighed aluminum foil with proper identification. Photographs were taken for QA/QC purposes, and foils were labeled with the date, location number, row number, plant number, and leaf number. The remaining leaves were bagged and folded in large aluminum foil, labeled with the date, location, row, and plant number, and identified as "pooled leaves."

All stems were separated, cut into 10 to 20 cm segments (from soil emergence or where stem color transitions from green to white), then labeled with the date, location number, row number, and plant number. Next, "pooled stems" were placed in a sizeable pre-weighed aluminum foil bag. Roots were discarded as they were not needed in this study. For seeds and pods per plant, the total number of pods and seeds per plant was counted and measured with a weighing balance (NTEP Precision BAL 620G 10MG, U.S.). The samples were bagged separately and identified as "pod samples" and "seed samples," respectively. Pooled leaves, stems, pod samples, and seed samples were weighed for fresh weights and placed in a drying oven (Fisher Scientific Isotemp General Purpose Heating and Drying Ovens, U.S.) at 65 °C. Dry weights were recorded until the constant dry weights (no change in dry weights) were achieved, and dry weights of each sample were recorded while keeping account of the labeling information.

Statistical Analysis

Statistical analyses were done in OriginPro Version 2023b (OrginLab Corporation, Northampton, MA, U.S.). The generated plant height and leaf chlorophyll concentration data were tested for normal distribution using the Shapiro-Wilk test followed by mean significance difference (two-sample paired t-test) between irrigated and non-irrigated. The mean difference in the number of nodes was calculated using the Wilcoxon rank sum test (elimination of normal distribution assumption).

Table 2. Average daily plant height (cm), number of nodes, and SPAD readings for both irrigated and non-irrigated sampling zones.

Sampling Days	Irrigated				Non-Irrigated			
DD/MM/YY	Height (cm)	Number of Nodes	SPAD	Chlorophyll (µmol m^{-2})	Height (cm)	Number of Nodes	SPAD	Chlorophyll (µmol m^{-2})
5/20/22	3.6±0.4	1.3±0.1	36.2±0.6	388.9±7.5	3.3±0.2	1.5±0.2	36.6±0.8	395.7±8.8
5/27/22	5.4±0.4	2.1±0.2	38.3±1.3	425.4±11.8	4.8±0.2	2.0±0.2	37.1±2.5	403.1±18.8
5/31/22	7.5±0.2	2.0±0.2	38.0±1.6	420.0±13.6	7.1±0.5	1.8±0.3	40.0±1.5	454.9±13
6/2/22	9.4±0.1	3.2±0.3	39.2±0.8	440.8±8.8	8.9±0.2	3.3±0.1	40.1±1.6	456.7±13.6
6/10/22	13.2±0.9	5.0±0.0	40.5±0.3	464.2±5.3	10.8±0.3	4.2±0.4	43.6±0.9	524.6±9.4
6/14/22	16.6±0.5	6.9±0.1	41.5±0.7	483.6±8.1	11.8±1.2	5.4±0.3	43.2±0.1	516.6±3.5
6/22/22	21.3±0.8	6.3±0.2	40.3±0.8	461.0±8.8	14.3±0.6	6.3±0.2	41.9±0.8	490.7±8.8
6/28/22	23.5±0.5	6.9±0.1	41.5±0.3	483.6±5.3	19.1±0.1	7.6±0.2	39.9±0.2	453.6±4.5
6/30/22	26.7±0.4	7.5±0.2	38.5±0.7	428.2±8.1	20.2±0.2	8.3±0.4	40.3±0.2	461.0±4.5
7/6/22	36.1±1.2	8.8±0.3	39.4±1.1	445.2±10.6	26.0±0.6	9.5±0.2	40.8±1.0	471.1±10.0
7/8/22	40.2±1.6	9.8±0.3	41.1±0.4	476.7±6.1	29.0±0.7	9.8±0.2	40.3±0.3	461.7±5.3
7/19/22	58.7±1.9	11.2±0.9	41.7±1.0	488.2±10.0	32.9±0.4	10.8±0.1	43.2±0.8	517.4±8.8
7/26/22	72.8±5.2	12.2±0.2	42.4±1.1	500.9±10.6	31.9±2.2	11.0±0.4	43.6±0.3	525.4±5.3
7/28/22	74.5±1.3	13.5±0.3	41.1±0.4	476.4±6.1	34.4±0.3	11.9±0.1	44.5±0.8	543.1±8.8
8/3/22	91.0±4.3	17.7±1.7	42.7±1.4	507.6±12.4	37.0±1.6	11.9±0.7	44.5±1.0	542.7±10
8/24/22	97.0±1.7	16.7±0.8	46.6±0.4	585.7±6.1	37.0±0.7	13.2±0.6	43.5±0.4	522.0±6.1
9/14/22	91.8±4.5	19.5±1.2	19.4±4.8	156.3±32.8	37.4±0.6	12.6±0.8	32.9±2.1	334.0±16.5

Results and Discussion

Increased soybean production has resulted from improved genetic potential (Vogel et al. 2021). However, in many places, production is diminished by water stress as their grain yield is linearly correlated to water usage (Sharda et al. 2019). Soybean water demand and usage have been linked to growth stage, soil type, and weather conditions. Generally, 381 to 635 mm of water is required to grow soybeans (Kranz and Specht 2012). In this study, irrigated soybeans received irrigation and precipitation water (968 and 112 mm, respectively), while non-irrigated soybeans only received precipitation water (112 mm).

Plant Growth and Plant Health Indicators

Seasonally, plant growth indicators (plant height and the number of nodes on the mainstems) were measured to monitor the difference in growth between irrigated and non-irrigated soybeans. Likewise, via SPAD, nitrogen status was measured to assess soybean's greenness as a plant health indicator. Plant height from emergence to harvest day (136 days) varied between irrigated and non-irrigated soybeans, but irrigated soybeans eventually surpassed non-irrigated soybeans, with the difference being significant ($p<0.01$) after day 24 from emergence. Irrigation and precipitation are essential factors in increasing yields and improving plant health. The growth trend for irrigated and non-irrigated soybeans was similar until July 8th, 2022, when the growth height for irrigated soybeans dramatically increased until harvest day (Figure 2A). The variance in plant height was induced by irrigation and precipitation volume received by irrigated soybeans (1,080 mm) and non-irrigated soybeans (112 mm). Overall, mean irrigated soybean plant heights (40.6±1.5 cm) were significantly greater ($p<0.01$) than non-irrigated plant heights (21.6±0.6 cm) for the entire season. Generally, the relationship between irrigation water and sufficiently bringing plants through several growth stages of development explained the variance in plant height.

Irrigated soybeans had more nodes than non-irrigated soybeans, suggesting more vegetative growth. Irrigated soybean nodes ranged from 15 to 20 nodes at maturity, while non-irrigated soybean nodes ranged from 10 to 15 (Figure 2B). The overall mean number of nodes was significantly greater ($p<0.01$) in irrigated soybeans (8.9±0.4) than in non-irrigated soybeans (7.8±0.3).

The SPAD meter, an instrument to measure plant nitrogen content, has been widely used in agricultural and research applications to assess plant nitrogen status (Ling et al. 2011). When comparing irrigated and non-irrigated areas, adequate water supplementation (irrigation and precipitation) benefit irrigated areas over non-irrigated areas in terms of vegetative growth and health (plant nitrogen concentration) (Wang et al. 2021). However, our findings show that soybean leaf chlorophyll concentration, as assessed by a portable SPAD meter, was not influenced by the amount of water applied to the field. Throughout the growing season, chlorophyll content was comparable in irrigated and non-irrigated soybeans, with averages ranging between 391 and 586 µmol m^{-2} before maturity (Figure 2C). Post-harvest, irrigated soybeans' SPAD measurements rapidly declined after maturity, which can be explained by chlorophyll breakdown during leaf senescence (Markwell et al. 1995; Hörtensteiner and Kräutler 2011). Overall, the maturity time difference and growth stages are linked to varying SPAD measurements (Ma et al. 1995). The harvest data concurred with the findings of plant health indices.

Crop Yield Difference between Irrigated and Non-irrigated at Harvest

The average final harvest weight of fresh seed, dry seed weight, and the number of seeds per 2-m row varied between irrigated and non-irrigated systems (Figure 3). Generally, soybean grain yield in the U.S. has increased as the total irrigated land has increased (Irwin et al. 2017). In our study, the total number of seeds harvested was 7.5 times greater in irrigated (5117±409 seeds) than in non-irrigated soybeans (680±180 seeds) ($p<0.01$). Fresh weight of seeds differed considerably ($p<0.01$), with seed weight (972±190 g) from irrigated soybeans being 11.7 times that of non-irrigated soybeans (83±24 g). Seed dry weight followed the same pattern ($p<0.01$), with irrigated soybean seed dry weight (738±72 g) being 12.6 times that of non-irrigated soybeans (58±19 g). The results from this study were expected based on the observed non-destructive plant health indices measured throughout the growing season. We did observe systemic differences in all destructive sampling post-flowering (data not shown here), which predicated the difference observed at harvest. Irrigated soybeans matured two weeks earlier than non-irrigated soybeans, which accounts for the significant difference between the two soybean systems' final harvests of destructive samples.

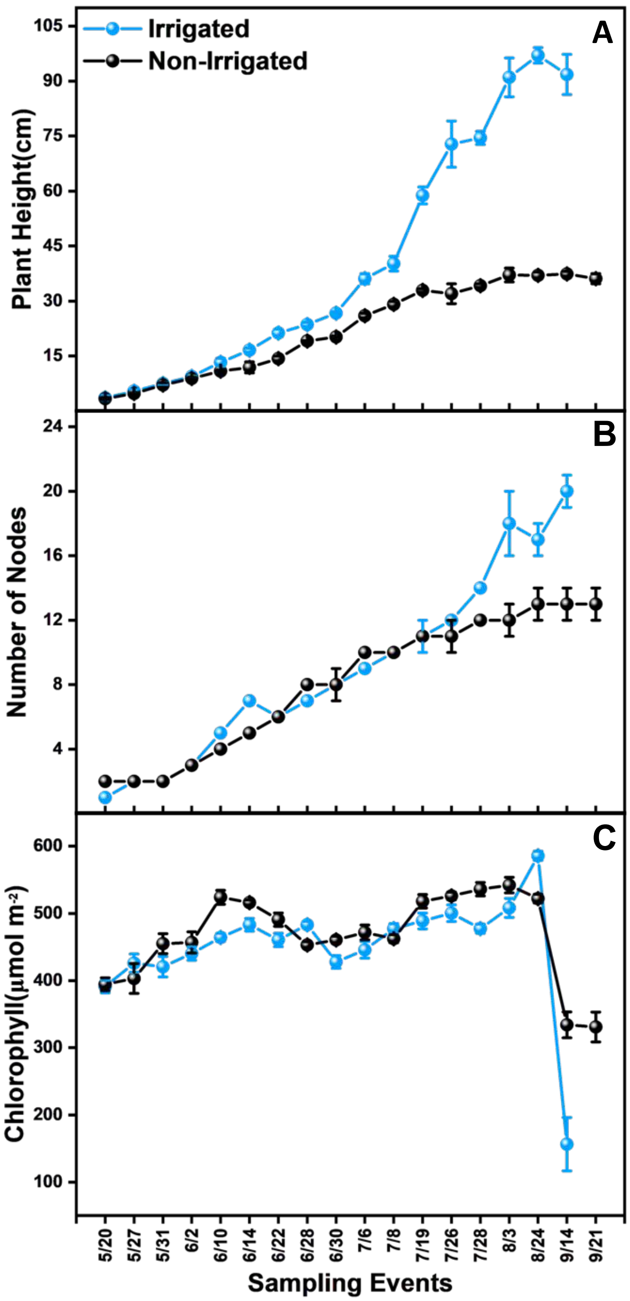

Figure 2. (A) Plant height within a 1-m row in both irrigated and non-irrigated areas, (B) the number of nodes within a 1-m row, and (C) leaf chlorophyll content in µmol m^{-2}.

Undergraduate Perspective in Agroecosystem Research

The job market needs more skilled workers with hands-on experience (Sabatini 1997). In the agricultural field, a lifelong learning experience should involve the active participation of undergraduates in research. Research experience and in-class activities are critical to a learning curve that integrates and provides valuable problem-solving capabilities to next-generation youth. Linking the critical role of water to yield through agroecosystem research, our hands get dirty while gaining the experience and knowledge needed to enter the job market. While few undergraduates see most of the classroom concepts' applications in real life, we gained crucial skills from participating in this agroecosystem research, including proper communication, extensive data handling, on-field data collection, post-processing data analysis, quality assurance, and quality control (Figure 4).

Communication was a critical learning objective among the skills learned from participating in agroecosystem research. Meeting farmers and knowing how they use scientific data, participating in decision-making meetings, and openly discussing project design and data collection objectives were exceptionally useful in solving agricultural issues.

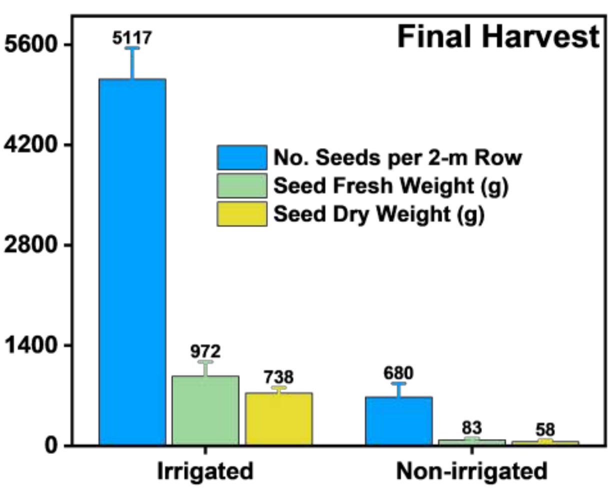

Figure 3. Irrigated and non-irrigated soybeans final harvest number of seeds per 2-m row, seed fresh weight, and seed dry weight (g).

Figure 4. Quality assurance (QA) and quality control (QC) non-destructive (A) number of plants per 1-m row, (B) comparing field pictures with Excel sheet for data transfer errors, (C) nodes and SPAD value pictures in the field, (D) plant height picture, and destructive QA/QC are exemplified in (E) picture of pods in field collected soybean samples, (F) leaf area measuring picture with scale, and (G) ensuring proper temperature of the drying oven.

Being part of the research team, undergraduates can strengthen their research thinking skills with the help of supervision (Craney et al. 2011). Before partaking in field and lab work, undergraduates know what they have learned in class. Working in the field motivates students and is essential to one's academic performance as an undergraduate. Participating in research as an undergraduate promotes critical thinking abilities and decision-making confidence. This study emphasized communication skills through appropriate field data collection.

Quality assurance and quality control are necessary data collection and processing procedures, which were crucial for achieving learning objectives (Sabatini 1997) and ensuring the validity of methods and data being used in research. Undergraduates would benefit significantly from increased opportunities to participate in research since doing research as an undergraduate prepares one for the future. In this study, when inputting data from the field, we would go back to the photographs to confirm the validity of the information entered in the Excel files. Figures 4A and 4B illustrate images captured in a 1-m row, and data entered in an Excel sheet, respectively. There are 18 plants in the image, and the labels L1 and R3 indicate that this sample belongs to location 1 and row 3. The numbers on the picture match the numbers in the Excel file; to ensure that clean data were well recorded, we refer to the picture and the recordings whenever we feel the data may contain certain inaccuracies. The project induced carefulness, eagerness, and preparedness for the job market. In addition, the outcomes of participating in undergraduate research were connecting with farmers and understanding the crucial role of water in agroecosystems. Overall, undergraduate education in agroecosystem research provides a foundation for understanding the complex relationships between agriculture and the environment and prepares students for research, consulting, and policy development careers.

Conclusions

Understanding the intricate dynamics of water management in agriculture is pivotal for addressing global food security challenges. Our research identifies the crucial role of water availability on crop production, reflected by more than a sevenfold difference in yield between irrigated and non-irrigated systems. This research's outcome reflects obtaining high-quality data while ensuring QA/QC by setting up an effective protocol during data collection. The precisely gathered data can support farmers in understanding management practices that boost yield, where effective data collection and analysis can foster decision-making and help verify new crop simulation models. For instance, knowing that irrigated fields have the potential to yield significantly more than non-irrigated fields with evidence and established plant health growth and health indicators would support farmers in making decisions when preparing and planning for their fields. On the other hand, this research provided an excellent opportunity for an undergraduate student to learn about the field data collection, data management, and analysis techniques.

There is a gap in undergraduate research; many students prefer internships, while others do not prefer hands-on studies. They are unaware of the opportunities, and some are not interested in them or think the compensation needs to improve (Tschepikow 2012; Stout 2018). From a larger perspective, undergraduate research dramatically benefits students. For a college student beginning to conduct research, this experience has been of utmost significance. The biggest lesson learned is the correct way to handle and process data. For undergraduates, most of what was learned in classes, in most cases, is not easily experienced in the actual world. Undergraduate research is a solution to help apply classroom lessons and identify contemporary problems and become future problem-solvers.

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Dr. David Fleisher is a USDA-ARS agricultural engineer with over 20 years of experience in interdisciplinary approaches to address critical issues in agricultural production systems. With his team at the Adaptive Cropping System lab, their work focuses on developing mechanistic soil-plant-atmospheric mathematical models, providing computerized decision support, and optimizing crop production in both field and controlled environments. His current research focuses on assessing the impacts of climate change and abiotic constraints on food security using geospatially referenced data and modeling tools. He can be reached at david.fleisher@usda.gov

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