2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering
Education for 130 Years
ASEE
Paper ID #37950

Peanut Trials on Raised Beds with Indoor and Outdoor FarmBot Setups

Dr. Abhijit Nagchaudhuri, University of Maryland, Eastern Shore

Dr. Abhijit Nagchaudhuri is currently a Professor in the Department of Engineering and Aviation Sciences at University of Maryland Eastern Shore. He is a member American Society for Mechanical Engineers (ASME) and American Society for Engineering Education. He is actively involved in teaching and research in the areas of robotics/mechatronics, precision agriculture and remote sensing, and biofuels/renewable energy.

Dr. Madhumi Mitra, Ph.D., University of Maryland, Eastern Shore

Dr. Madhumi Mitra is a tenured full professor of Biological and Environmental sciences in the Department of Natural Sciences at the University of Maryland Eastern Shore (UMES). She is the coordinator of biology and chemistry education programs at UMES. She has received her doctoral degree in Plant Biology from North Carolina State University, Raleigh, NC, USA. Her B.S. and M.S degrees are in Botany from the Presidency College (now Presidency University) and University of Calcutta, India respectively. She is also the recipient of a master's degree in the nation's first-degree program in Medical Cannabis Science and Therapeutics from the School of Pharmacy from the University of Maryland Baltimore (UMB) in 2021. Two of her students in Biology Education have been the recipients of the Presidential Awards for Excellence in Mathematics and Science Teaching (PAEMST), which is the highest honors bestowed by the United States government specifically for STEM teachers. One of her students was awarded the Maryland Teacher of the Year award in 2019. Her research interests and expertise include micro and macroalgal ecology; seaweeds in human health and nutrition; biomonitoring and biosorption potential of seaweeds and seagrasses; bioenergy from algae; water quality; and sustainable robotic farming with applications of seaweeds as biostimulants. She is the recipient of various research and teaching awards, and has published in many peer-reviewed journals and proceedings, and presented her research at national and international conferences. She also co-edited and coauthored a book on Bioenergy with Springer Academic Publishers in 2020. She is currently working on her second book on Artificial Intelligence in the 21st Century for CRC Press (a Taylor and Francis group). Dr. Mitra has given keynote addresses at international conferences on Bioenergy and related disciplines in the STEM areas. She holds a strong record of competitive funding from federal and state agencies. She has been a recipient of more than 15 million dollars grants as a principal and a co-principal investigator. She has served in various leadership roles for many professional organizations. She was the Division Chair of the Energy Conversion and Conservation Division (ECCD) of the American Society of Engineering Education (ASEE). She has also served on the Board of Directors for Assateague Coastal Trust (ACT) for more than five years; serves as a member of the commission on Diversity, Equity, and Inclusion of ASEE; and have been an advocate for renewable energy and climate change.

Mr. Jesu Raj Pandya, University of Maryland, Eastern Shore

Currently a doctoral student in Food & Agriculture Sciences, University of Maryland Eastern Shore (UMES), MSc - Applied Computer Sciences at UMES, BSc - Electrical and Electronical Engineering (JNTU).

Interest in robotics and automation in food production and food safety.

Peanut Trials on Raised Beds with Indoor and Outdoor FarmBot Setups

Abstract

FarmBots are three-axis Cartesian robots quite similar to 3D printers that run on Raspberry Pi 3 and Arduino-like microprocessor boards. These machines can seed, kill weeds, sense soil-moisture content, and irrigate plants individually over the raised bed area they serve. FarmBots can be manipulated using web applications over smartphones. The Raspberry Pi Camera (Pi-Cam) integrated with the machine can be used for weed detection and time-lapse photography.

FarmBot efforts on campus are integral to the ongoing “Smart Farming” project. The “Smart Farming” project leaders at the University of Maryland Eastern Shore (UMES) have engaged undergraduate engineering and computer science students with graduate students in the Food Science and Technology (FDST) program to promote education and research efforts aligned with the land grant mission of the campus, regional priorities of the eastern shore region and objectives outlined in extramurally funded projects supported by National Institute of Food and Agriculture (NIFA/USDA). As part of the project, students have engaged in growing specialty crops using FarmBots (**http://farm.bot**) in an outdoor 10ft by 20ft raised bed inside a tunnel house powered by solar and wind energy, as well as an indoor setup on a 5ft by 10ft bed with LED-grow lights. Rainwater harvesting capability is being developed for the outdoor set-up for the irrigation needs of the crops served by the robot. The setup is envisioned to be a novel demonstration platform for a small-scale autonomous sustainable food production system that uses a robotic device, as well as renewable energy and rainwater harvesting suitable for a variety of settings including urban and suburban regions. The indoor set-up allows changing the photoperiod for growing specialty crops.

For the field trials outlined in this paper, “peanuts” were chosen as the specialty crop to grow in both the outdoor and indoor FarmBot beds. This allowed the project leaders to discuss the contributions of and the legacy of Dr. George Washington Carver an eminent African American scientist who developed more than 300 products from peanuts. The field trials involved studying the effects of inoculating the peanut seeds with *rhizobium leguminosarum* bacteria and different irrigation levels on the harvest.

1.0 Introduction

UMES is a historically black, 1890 land-grant institution. Agriculture and water quality issues are paramount in the eastern shore region. The “Smart Farming” project utilizes advanced technologies integral to modern digital agricultural practices to promote education, research, and community engagement efforts aligned with the campus mission and regional priorities. The

“Smart Farming” project has been ongoing at the campus for over a decade under the leadership of the principal author. The project promotes student involvement with production agricultural practices on UMES farms for growing corn, soybean, and wheat utilizing advanced farm machinery and drones to promote sustainable intensification through best practices in the growing area of “precision agriculture” at a somewhat larger scale. Integration of advanced digital agricultural tools such as the FarmBots (http://farmbot.io) for growing specialty crops on small raised beds is also central to the overall scope of the project [1-3]. Since its inception, the project has adopted the experiential learning [4] paradigm and involved undergraduate students from engineering and other STEM disciplines on campus to engage with one another in a vertically integrated [5] team setting along with the graduate student (s) in the Food Science Technology (FDST) doctoral program on campus. Along with the principal author who is a faculty in the engineering program other faculty members from the School of Agricultural Natural Sciences (SANS) have collaborated on the ongoing efforts and advised the student team.

This paper will largely focus on the FarmBot set-ups on campus in both outdoor and indoor settings and recent trials for growing peanuts in these settings. As mentioned earlier, at the university a FarmBot has been installed in an outdoor high tunnel house [3] and a smaller one in an indoor setting with overhead grow lights (see Figures 1a, 1b, 2a, & 2b). FarmBots are computer numerically controlled (CNC) robots developed for smart farming practices at a small scale. It

Figure 1a : Outdoor FarmBot set up in high tunnel with solar and wind turbine

Figure 1b: View from inside the high tunnel with a inset of a solar powered robotic weeder

Figure 2a : Indoor FarmBot with Growlights, the Farmbot bed is on a mobile table

Figure 2b : Indoor FarmBot with students collecting data with FarmBeats Kit utilizes popular Raspberry Pi and Arduino micro-controller boards and can seed, weed, irrigate, and take time-lapse images with appropriately coded “sequences” and “regimen”. FarmBots are also cloud accessible, which allows the robots to be operated remotely from any smart device with a web browser and network connectivity. At the university and Farmbot Genesis XL V1.4 has been set up outdoors to serve a 10ft. by 20 ft. raised bed while the smaller Farmbot Express V1.1 serves a 5ft. by 10 ft. mobile bed and is set up indoors in the Food Science and Technology building on campus. The outdoor Farmbot is housed in a tunnel house to extend the growing season for the plants. In addition, the outdoor Farmbot has been set up to be powered by renewable energy using a wind turbine and solar panels. The irrigation needs for the outdoor Farmbot will be met by a rainwater harvesting system to demonstrate an independent platform for sustainable farming practices. The indoor set-up has overhead grow lights that allows changing the photoperiod for cultivating specialty crops such as peanuts, radish, turnips, and carrots.

Students are also testing a solar-powered robotic weeding system in the outdoor set up as shown in Figure 1b [6]. Preliminary trials have also been undertaken by students involved with the project to collect relevant data during the growth of selected peanut plants using the FarmBeats student sensor kit as shown in Figure 2b (https://aiforteachers.org/resource/farmbeats-for-students). These efforts will be expanded in the future and will not be elaborated further in this paper.

2.0 Why Peanuts?

Peanuts (*Arachis hypogaea)*, also known as groundnuts, are an important crop that has a variety of unique features that make them an ideal crop for study and experimentation. It is a type of legume that grows underground. The peanut is unusual because it flowers above the ground, but the pods are below the ground. Peanut seeds (kernels) grow into a green oval-leafed plant about 15-20 inches tall. It develops delicate yellow flowers around the lower portion of the plant. The flowers pollinate themselves and then lose their petals and fertilized ovary begins to enlarge. The budding ovary grows down away from the plant, forming a small peg that extends into the soil. The peanut embryo is at the tip of the peg, which penetrates the soil. The embryo begins to mature taking the form of a peanut and from planting to harvesting; the growth cycle takes about four to five months, depending on the variety. Peanut plants need 1.5 to 2 inches of water per week during kernel development; it should however be noted its water needs are about 1/9th for an ounce compared to almonds. Targeted irrigation can help with kernel growth. Depending on its care, one peanut plant may produce up to 25-50 peanuts [7]. In addition, peanuts fix nitrogen in the soil and it has been observed by other researchers that the use of inoculant containing *rhizobium leguminosarum* bacteria during planting is beneficial [8].

George Washington Carver, an eminent African-American scientist and educator is widely regarded as the "Father of the Peanut Industry [9]." His work has also inspired countless students, researchers, and scientists to continue exploring the full potential of peanuts and other crops. Overall, the unique features and historical significance of peanuts make them an ideal subject for study and experimentation, particularly for students at historically black institutions.

3.0 Field trials, growth, and, harvest

Understanding the unique growth stages of peanuts is essential for successful cultivation, and using technology such as FarmBots can provide students with valuable insight into how to optimize peanut development in various growing environments both indoors and outdoors. For the field trials reported in this paper, the two treatments that were used were inoculants and irrigation levels. Two batches of peanut seeds were prepared, one was inoculated using *rhizobium leguminosarum* bacteria and the other was left non-inoculated. To inoculate the peanut seeds, *rhizobium leguminosarum* granules were ground into a fine powder and applied to water-moist peanut seeds. For the outdoor set up a 12-volt submersible Seaflo bilge pump was connected to the FarmBot for precise irrigation according to the designed sequence. The water was pumped from a 275-gallon tank placed outside the high tunnel. In the future, the tank will be filled with harvested rainwater. It was determined by conducting preliminary testing that the pump took 2 minutes and 27 seconds to deliver one gallon of water. For irrigation treatment I (I1) the Farmbot was programmed to activate the pump for 50 seconds, and for irrigation treatment II (I2) for 20 seconds twice daily over each plant. Farmbot was also programmed to take a picture of the entire farm bed once a week. Similar trials were conducted for both the outdoor and indoor setup with the FarmBots at the university. In the indoor setup, the FarmBot was directly connected to a water tap in the building with a hose and a pump was not necessary, the solenoid valve was just programmed to open and close for the appropriate duration to perform the irrigation. The appropriate duration worked out to be 30 seconds over each plant twice a week for the irrigation treatment I1 (3.5 in/week) and 12 seconds twice a week for the irrigation treatment I2 (1.5 in/week). The farm designs for the indoor and outdoor trials are shown side by side in Figures 3a and 3b. Since the bed is smaller for the indoor FarmBot only 32 seeds were planted with 16 seeds in each zone, the outdoor FarmBot had a larger bed but some space was left out at the edges and only 40 seeds were planted with 20 seeds in each zone as shown. 20 plants for the outdoor Farmbot and 16 plants in the indoor setup received 1.5 inches of irrigation (I1) each week whereas plants in the other zone received 3.5 inches of irrigation water (I2). During the middle of the growing season, there was a malfunction with the pump so the irrigation schedule was disrupted which may have had some effect on the harvest data. In the indoor FarmBot, the photoperiod was set up to be 18 hours of light and 6 hours of darkness before flowering, thereafter the photoperiod was changed to equal amounts of light and darkness for each day. In the future, the project team plans to conduct experiments with other variations of photoperiod. General observation of the trial indicated that the longer photoperiod helped the peanut plants to grow more vigorously with the increased photoperiod. The seed inoculation was randomized for each zone in Figures 3a and 3b, locations designated as A indicates inoculated seeds, and B indicate non-inoculated seeds. For both trials, gypsum was added to the soil after the flowering of the plants. The peanuts were hand harvested roughly five and a half months after planting for both FarmBot beds (April/May – September/October timeframe). The harvest from each plant was counted and weighed.

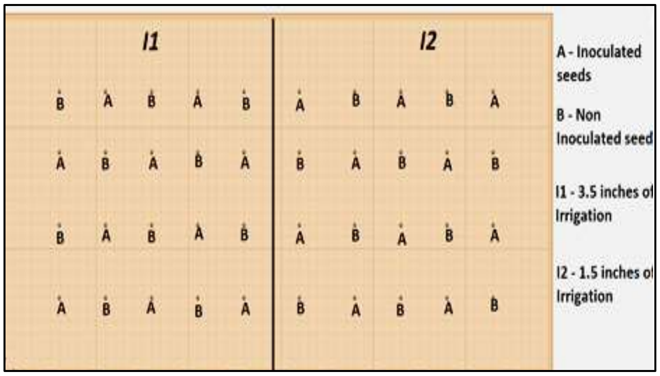


Figure 3a: Farm Design for theOutdoor FarmBot

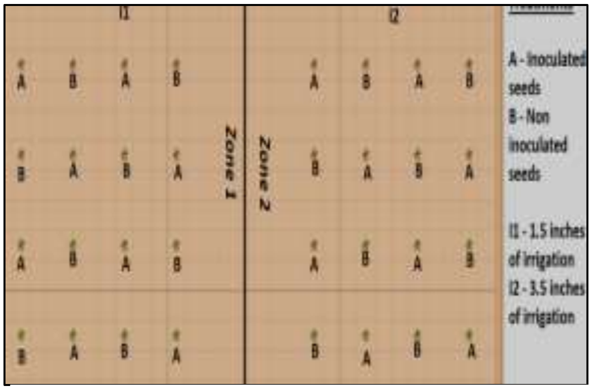
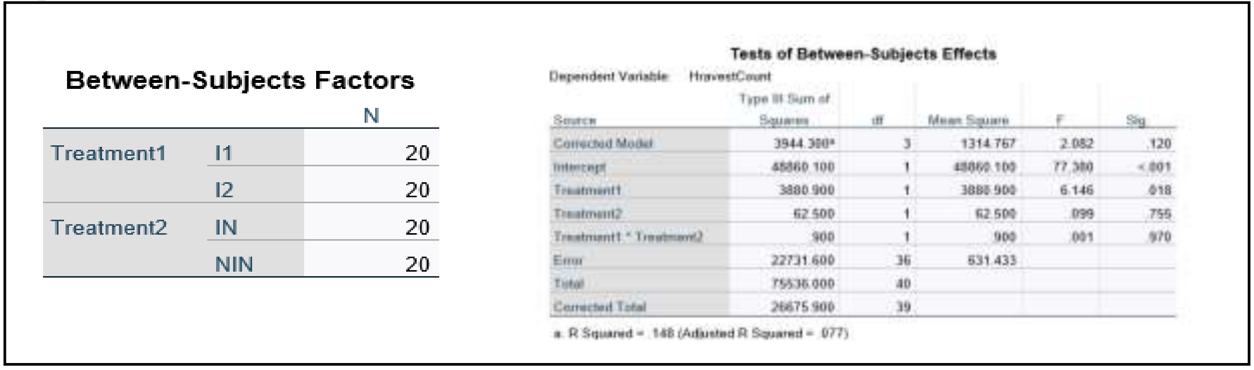


Figure 3b: Farm Design for the Indoor FarmBot

4.0 Harvest Data Analysis

Irrigation was discontinued two weeks before the harvest. Each plant was hand harvested and allowed to dry for a few days. The yield from each plant was tabulated for both count and weight for inoculated and non-inoculated plants for each zone. The data clearly showed irrigation increased the yield both in the indoor and outdoor setups. ANOVA analysis was performed using IBM SPSS with irrigation and inoculation as treatment variables and the count and weight as the dependent variable separately. The results were statistically similar for both outdoor and indoor trials, but the average yield per plant was higher in the outdoor trials. ANOVA results indicate irrigation had a significant effect but the inoculation did not in both the indoor and outdoor setup. The trials will be repeated with different inoculants at a future date. The ANOVA results for the outdoor and indoor trials are shown in Figures 4a and 4b for the peanut count per plant as the dependent variable.



Between-Subjects Factors

		N
Treatment1	I1	20
	I2	20
Treatment2	IN	20
	NIN	20

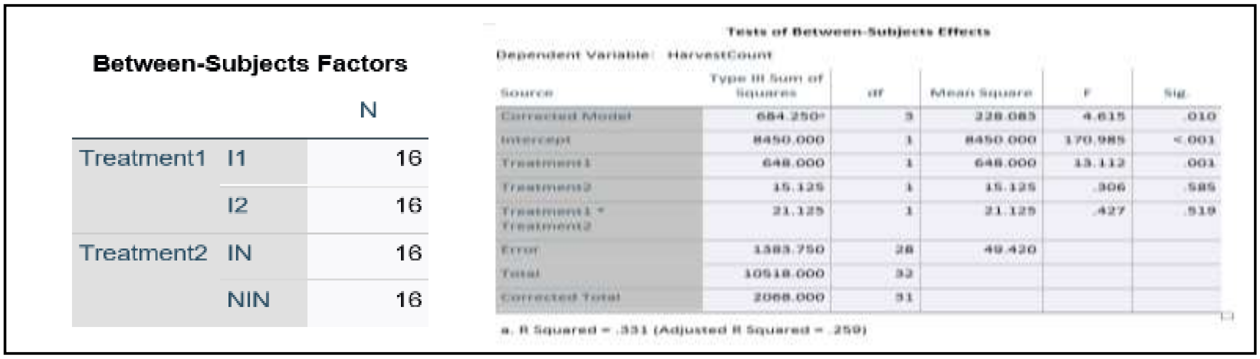
Tests of Between-Subjects Effects

Dependent Variable: HravestCount

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3944.300ᵃ	3	1314.767	2.082	.120
Intercept	48860.100	1	48860.100	77.380	<.001
Treatment1	3880.900	1	3880.900	6.146	.018
Treatment2	62.500	1	62.500	.099	.755
Treatment1 * Treatment2	.900	1	.900	.001	.970
Error	22731.600	36	631.433		
Total	75536.000	40			
Corrected Total	26675.900	39			

a. R Squared = .148 (Adjusted R Squared = .077)

Figure 4a: ANOVA ANALYSIS Outdoor FarmBot Trial (Two factors- Treament1: Irrigation I1& Irrigation I2, Trearment2: Inoculated seeds IN & Non-Inoculated seeds NIN)



Between-Subjects Factors

		N
Treatment1	I1	16
	I2	16
Treatment2	IN	16
	NIN	16

Tests of Between-Subjects Effects

Dependent Variable: HarvestCount

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	684.250ᵃ	3	228.083	4.615	.010
Intercept	8450.000	1	8450.000	170.985	<.001
Treatment1	648.000	1	648.000	13.112	.001
Treatment2	15.125	1	15.125	.306	.585
Treatment1 * Treatment2	21.125	1	21.125	.427	.519
Error	1383.750	28	49.420		
Total	10518.000	32			
Corrected Total	2068.000	31			

a. R Squared = .331 (Adjusted R Squared = .259)

Figure 4b: ANOVA ANALYSIS INDOOR FarmBot Trial (Two factors- Treament1: Irrigation I1& Irrigation 2, Trearment2: Inoculated seeds IN & Non-Inoculated seeds NIN)

5.0 Problems and Challenges

Although most of the early issues with the FarmBot installation has been resolved, the students involved with the trials had to deal with several concerns during the peanut trials reported in this paper. FarmBot had some network connectivity issues during the trials, which forced the project team to pause the variable irrigation treatment for more than 2 weeks. The submersible water pumps (Seaflo Marine water pumps 12V 2amps DC) being used by the FarmBot earlier were damaged, so during the trials, the pump had to be replaced. There were some issues with seeding and some plants sprouted late compared to other plants. In some cases, certain spots were reseeded with the assumption that they did not sprout, which led to duo plants at the same spot in some instances, making the statistical analysis skewed. There were concerns with insect infestation and pests that the project team had to also deal with, particularly for the outdoor setup. A similar field trial with peanuts and FarmBots will be repeated in the future. The experience gathered by the project team and the observations documented throughout the growth cycle of the plant will allow the project team to lay out logistics and implementation details in a more informed way.

5.0 Student learning outcomes

The graduate student leading the project has indicated that for the engineering and other STEM undergraduates, it took some time to become comfortable with the demands of the field efforts but they eventually worked well together. The out-of-classroom experiences are not limited to problem-solving from textbooks, structured laboratory studies, or even open-ended design projects that are constrained by compartmentalization of knowledge in academic disciplines, and as such integrate aspects of the real work environment that most students will join after completing their graduation requirements. Overall campus experiences of the students are enhanced by involving them in such efforts although at times non-academic aspects of the fieldwork may appear to be of little educational relevance.

Learning can be categorized into developing skills in three broad domains - cognitive, affective, and psychomotor. Higher education typically focuses largely on the cognitive domain following Bloom’s taxonomy – knowledge, comprehension, application, and evaluation [10]. ABET outcomes for engineering education integrate developing student abilities in both the affective and cognitive domains [11]. Integrating out-of-classroom active learning experiences for students such as the one described above provide rich learning outcomes that integrate academic, life skills, and civic responsibility outcomes in land grant settings that are difficult to address from within the classroom. Often the artificial silos limit the overall educational experiences for students in some majors. The broad dimensions of the project allowed land grant mission objectives of campuses such as UMES to be creatively integrated with experiential learning field experiences for all participating students from different majors. Moreover, the food, energy, environment, and water use considerations integrated with the project along with advanced digital technologies provided avenues for discussion related to sustainable development goals of the future [12]. The project team has experimented with growing other vegetables as well as hemp using FarmBots in the past, the unique growth characteristics of peanuts, their importance globally as a food crop, and the remarkable contributions of Dr. Carver who is also known as the “father of the peanuts industry” were some of the considerations in selecting the crop for the trial reported in this paper. In the context of STEM programs in a historically black institution such as UMES, knowing about African American role models and their scientific contributions can go a long way to motivate young and driven African American students, and peanuts are an excellent segway to discuss the legacy of this exemplary African American scientist. Moreover, apart from oil, peanuts are widely used for the production of peanut butter, confections, roasted peanuts, snack products, extenders in meat product formulation, soups, and desserts that students can readily relate to. A number of these popular uses of peanuts have their foundation in the work done by Dr. Carver[13].

6.0 Acknowledgment

The authors would like to thank UMES farm and physical plant personnel for supporting the project efforts. Besides the authors, several UMES undergraduate STEM students and summer exchange students participated in the project efforts. In particular, the contributions of Reese

Snook and Jackson Cuppett from UMES and summer exchange undergraduate interns Arya Das from the University of Maryland Baltimore County (UMBC) and Anthony Reyna from Capital Technology University (CTU) in advancing project goals and field trials are acknowledged with thanks. Maryland Space Grant Consortium and NIFA Evans Allen Grant have funded the experiential learning and research efforts outlined in this paper. The MDSGC and NIFA support is also gratefully acknowledged.

Bibliography

[1] Nagchaudhuri, A., & Pandya, J. R., & Mitra, M., & Ford, T. (2020, June), Education and Research at the Nexus of Food, Energy, and Water with a 3-Axis Farming Robot Paper presented at 2020 ASEE Virtual Annual Conference Content Access, Virtual Online. 10.18260/1-2—34492

[2] Nagchaudhuri, A., Hartman, C., Ford, T., and Pandya, J., "Recent Field Implementation Of Contemporary and Smart Farming Technologies at the University of Maryland Eastern Shore, Proceedings of the ASME IDETC/CIE 2021 *(IEEE/ASME Mechatronics and Embedded Systems Application*) (Virtual) August17-19. 2021

[3] Pandya, J., Ford, T., Davis, K., Nagchaudhuri, A., Nindo, C., and Mitra M.," *FarmBot—A Platform for Backyard Precision Farming: Installation and Initial Experimental Layout* ", Paper # 1900194 Proceedings of ASABE International Meeting, July 7-10, Boston, MA

[4] Kolb, D. A. (1984). *Experiential learning: Experience as the source of learning and development*,V1, Englewood Cliffs, NJ: Prentice-Hall.

[5] Coyle, E. J., Allebach, J. P., and Garton-Krueger, J., 2006. "The Vertically-Integrated Projects (VIP) Program in ECE at Purdue: Fully Integrating Undergraduate Education and Graduate Research," Proceedings of the 2006 ASEE Annual Conference and Exposition, Washington, D.C.

[6] Averill, K.M.; Westbrook, A.S.; Pineda-Bermudez, L.; O'Briant, R.P.; DiTommaso, A.; Ryan, M.R. Effects of Tertill® Weeding Robot on Weed Abundance and Diversity. Agronomy 2022, 12, 1754. https://doi.org/10.3390/agronomy12081754

[7] Boote, K.J. (1982). Growth Stages of Peanut (Arachis hypogaea L.). Peanut Science, 9: 34-40.

[8] Palai, J.B., Malik, G.C., Maitra, S. and Banerjee, M. 2021. Role of Rhizobium on Growth and Development of Groundnut: A Review. IJAEB, 14(1): 63-73.

[9] Carver, G.W., "How to Grow the Peanut: And 105 Ways of Preparing It for Human Consumption", May 1917, Bulletin #31, Tuskegee Inst., Al, https://www.nal.usda.gov/exhibits/ipd/carver/items/show/27

[10] B.S. Bloom. (1984). Taxonomy of Educational Objectives. 1. Cognitive Domain. New York, Longman.

[11] ABET, "Criteria for Accrediting Engineering Programs, 2020 – 2021" Available Online: https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2020-2021/

[12] Biggs, E.M., (et Al.,) "Sustainable development and the water–energy–food nexus: A perspective on livelihoods", Environmental Science & Policy, Volume 54, 2015, Pages 389-397, ISSN 1462-9011

[13] Britannica, The Editors of Encyclopaedia. "George Washington Carver". *Encyclopedia Britannica*, 1 Jan. 2023, https://www.britannica.com/biography/George-Washington-Carver. Accessed 19 February 2023.