Interdisciplinary Research (IDR) Origination Awards

Cover Page

Project Title

Smart Seeds: A Platform for Widely Dispersed Soil Sensing

Principal Investigator(s) (full-time faculty)

Name (PI listed first)	Department	College
Brian Mazzeo, Professor, PI	Electrical and Computer Engineering	Engineering
Wood Chiang, Associate Professor, Co-PI	Electrical and Computer Engineering	Engineering
Douglas Cook, Assistant Professor, Co-PI	Mechanical Engineering	Engineering
Nathan Crane, Professor, Co-PI	Mechanical Engineering	Engineering
Neil Hansen, Professor, Co-PI	Plant and Wildlife Sciences	Life Sciences
Matthew Madsen, Assistant Professor, Co-PI	Plant and Wildlife Sciences	Life Sciences

Track

Track Two

Abstract

Precision agriculture has tremendous environmental and economic potential, including more efficient use of water, fertilizer, pesticides, and herbicides. Dr. Hansen's research team recently evaluated Variable Rate Irrigation (VRI) on a full-sized irrigated wheat field in Grace, ID (22 ha) and showed a savings in irrigation of 38 mm (equivalent to over 2 million gallons of water saved) [1]. Even with a small adoption rate of VRI, the potential water savings is huge. To enable precision VRI, high-resolution spatial and vertical surveillance of soils is required. This is not yet possible because soil sensing is currently performed with extremely low spatial resolution. We propose to extensively leverage existing VRI infrastructure and novel technologies to create the Smart Seed Platform for Soil Sensing. Smart Seeds are normal seeds that have been augmented with miniaturized sensors. We hypothesize that Smart Seeds, with natural and augmented growth, sensing, and communication abilities, could transform data collection and modeling of soils. The objective of this project is to establish the viability, basic design parameters, and physiological and technological constraints inherent to deploying Smart Seeds for extensive soil sensing. This preliminary data will significantly strengthen external funding applications to carry out the long-term development goals of this interdisciplinary work.

Summary of Plans for External Funding

In 2020 our BYU team submitted a $1.2M proposal to the NSF Signals in the Soils program on this topic. The ideas were recognized as innovative and transformative. However, the biggest proposal criticism was that we did not provide sufficient preliminary data on the concepts in the complex soil environment. We want to address this deficiency specifically with IDR Track Two funding, which will be sufficient to generate necessary preliminary data. This data will allow us to resubmit another proposal at the end of 2021 to the NSF Cyber-Physical Systems program (partnered with USDA National institute of Food and Agriculture (NIFA)). We plan to resubmit to the re-booted NSF Signals in the Soils program. Depending on the success of those applications, we will apply again to NSF Cyber-Physical Systems/Signals in the Soils or NIFA programs in 2023.

Project narrative

Precision agriculture has potential to dramatically improve efficiency of water, fertilizer, pesticides, and herbicides by locally tuning application to the optimal levels. High-resolution spatial and temporal surveillance of soils can be a key to full realization of these goals. However, direct soil sensing is currently performed with low spatial resolution relative to the scale of precision management (less than one sensor per square kilometer is common). High-resolution soil sensing is primarily limited by three factors: sensor cost, data collection, and sensor distribution.

As shown in Figure 1, we propose to extensively leverage Variable Rate Irrigation (VRI) infrastructure as well as novel technologies to create the Smart Seed Platform for Soil Monitoring. Despite over 20 years of research and more than 10 years of public availability, commercial adoption of VRI has been slow. However, increased availability of VRI systems, drought, and scarcity of freshwater have continued to drive interest in and development of VRI [2]. This proposal addresses a major factor that has limited adoption, specifically information about within-field variation of soil water and how to delineate a field into irrigation zones. Our proposed Smart Seed consists of a normal dicotyledonous seed augmented by miniaturized sensors and an antenna. Smart Seeds could be planted along with normal seeds using conventional sowing equipment, thus addressing the distribution concern. After planting, a water-soluble adhesive will allow the primary soil sensor to detach from the Smart Seed and remain in the soil. The Smart Seed will deploy its own antenna by leveraging the mechanisms used by the seed to push the cotyledon out of the soil. After the antenna is deployed, the associated plants may continue to grow or may be selectively controlled by an herbicide, leaving behind an array of functional soil sensors.

We will pilot the technology using an application of sensing soil moisture and temperature for precision VRI under center pivot sprinklers. Center pivot irrigation currently provides water to over 28 million acres of farmland in the US [3]. In this setting, we propose to mount solar-powered, low-cost data collection units on irrigation lines. Data collection units will interrogate the sensors attached to each Smart Seed and relay this information to data collection centers via wireless communication. When combined with ultra-low-power electronics, these complementary technologies will provide an effective and efficient platform for exceptionally broad distribution of Smart Seeds reporting a wide variety of physical and biological quantities of the soil.

We hypothesize that Smart Seeds, with natural and augmented sensing and communication, could transform sensing and modeling of soils. **The objective of this IDR project is to establish the viability, basic design parameters, and key constraints (both physiological and technological) in deploying Smart Seeds for extensive soil sensing. This preliminary data will enable us to successfully pursue external funding for large-scale development and deployment of this technology.**

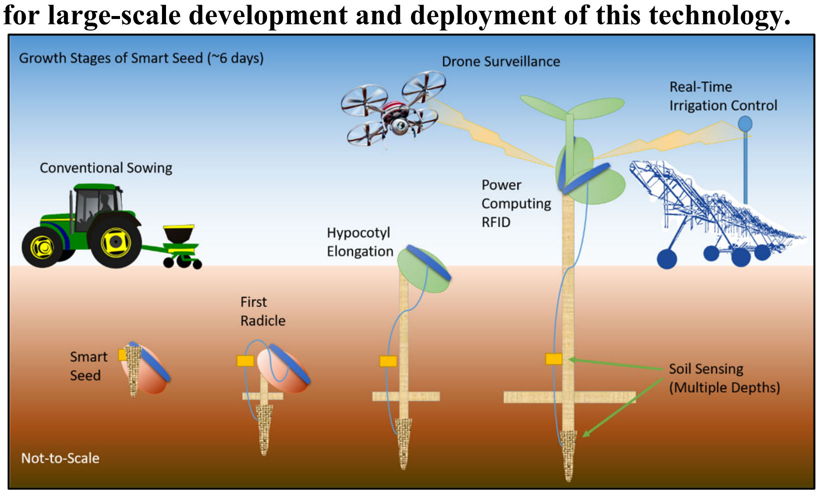

Figure 1. Overview of research focusing on deployment of an advanced sensor platform through conventional planting. The communications platform rises above ground during germination to simplify and increase reliability, localization, and powering of RF communications capabilities.

Research Plan

Our research plan for this short-term, targeted project to create preliminary data for a larger project consists of three, limited Specific Aims as shown in Figure 2. The first two aims are focused on demonstration of basic principles needed to create the Smart Seed Platform and the development of tools to make this platform a reality. The final Specific Aim addresses the first attempt at demonstrating the real-world application of this technology. The three Specific Aims are:

1. Determine the payload delivery capacities of soybeans in both the upward and downward directions,

2. Determine capabilities and limitations of miniaturized soil monitoring electronics in a Smart Stake form factor as a preliminary step towards Smart Seeds, and

3. Collect high-density, real-world data using the Smart Stake Test Platform.

The biological system selected as the research platform will be the soybean (Glycine max). Soybeans are grown worldwide (more than 300 million tons) and come in many varieties specific to conditions and environments. The soybean has a short germination period, which allows it to be studied effectively in the laboratory. Its hypocotyl extends naturally and lifts the seed out of the soil. Additionally, its growth is characterized by a single radicle descending deep into the soil in the first few days. These characteristics make the soybean platform ideal for widespread deployment, even if it is planted along with a different crop as a means to deploy the sensor and then is selectively controlled.

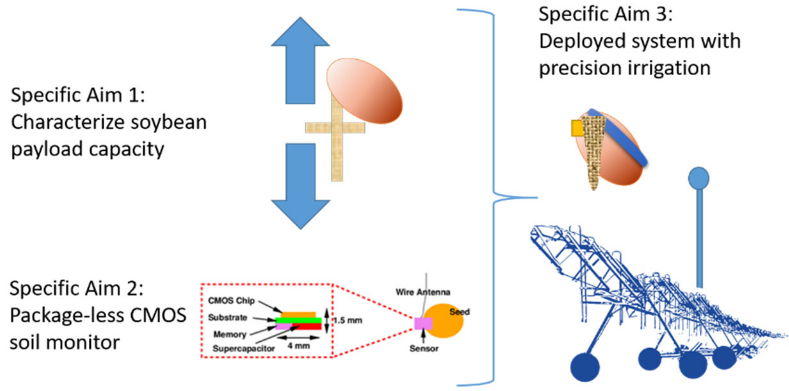

Figure 2. Specific Aims outlined in the Research Plan.

Specific Aim 1 addresses the fundamental biomechanical germination and emergence forces of soybean seeds. The soybean hypocotyl (embryonic stem) breaks the soil crust and pushes virtually the entire seed (cotyledon and seed coat) through the soil surface. It is not yet known how much extra weight the soybean can push upwards while still (a) successfully emerging from the soil and (b) retaining sufficient stored energy to become a viable plant. Similarly, the first radicle (embryonic root) pushes downward in a snake-like motion through the least-resistive paths in the soil. Harnessing and quantifying this motion will yield new insights in biomechanical forces and the balances between friction and penetration. A key result of this aim will be quantification of relevant biomechanics of both mechanisms – which is required preliminary data to support further development of the Smart Seed concept.

Specific Aim 2 requires investigation of a miniature electronic sensor platform to explore the advantages and limitations of this integrated sensing and communications approach. Instead of a full package-less CMOS soil monitor platform desired for the externally-funded proposal, we propose to use a Silicon Labs BGM220P Bluetooth platform (12.9mm x 15.0mm x 2.2mm) to demonstrate RF communication in the field environment, low-power operation, energy harvesting, sensing and logging capability in a small form factor [4]. This "Smart Stake" will generate preliminary data to support creation of a tiny, package-less electronics design for future deployment with the seeds themselves. Smart Seeds can be planted with conventional agricultural sowing equipment and enable efficient distribution.

Specific Aim 3 relates to mapping of soil properties and deployment of the Smart Seed Platform in an agricultural application. Soil conditions will be produced synthetically in order to create management zones and to understand placement and utility of sensors. Modeling of sensor relationships with other variables, such as weather, will enhance the prediction capability of the sensors. In this limited work, the key result will be to demonstrate that the Smart Stake can be used in an agricultural environment over a period of days and months and provide useful sensor data that, in future work, will enable actionable decisions about irrigation and chemical usage. The proposed technological basis will be to use solar-powered batteries and cellular phones with Bluetooth 5.2 capability (direction finding and long-range, low-power modes) mounted to an agricultural boom to read the Smart Stake sensor data during typical irrigation cycles. This lays the groundwork for the eventual dispersal of and communication with Smart Seeds in a conventional agricultural environment.

Current Status of Project

The PIs have been meeting over the last year to allow the PIs and students to collaborate and share results, consistent with the goal of generating the preliminary data necessary for a successful proposal resubmission. Currently, two undergraduate students in electrical engineering are working on: (1) ultra-low-power operation of the Silicon Labs chipset as the computational basis, and (2) energy harvesting and storage. These students have some preliminary operational models but have not yet realized these models in hardware. A mechanical engineering undergraduate student has begun experiments on soybean growth and successfully demonstrated deployment of an anchored wire from the soil (a future, possible antenna). A team in the Plant and Wildlife Sciences department have been studying the role of in-situ soil sensors in crop fields equipped with variable rate irrigation technology. The work is done with traditional, low density sensors but has highlighted the value and need for low cost, high-density sensors in a production setting. These efforts are ongoing and have been supported by small, internal seed funds and faculty discretionary accounts while this IDR funding and external funding sources are being pursued.

Interdisciplinary Team

The established project team reflects the project need to have a variety of experts working synergistically to develop and deploy the Smart Seed Platform. No single faculty member possesses all the skills necessary to develop this system. Each faculty member brings unique, complementary skills. We qualify as a team for IDR Track One, but the budget size of Track Two should be adequate to generate the preliminary data required to resubmit our proposal to NSF.

Brian Mazzeo, Professor and Co-Director, BYU Capstone, has been researching systems to nondestructively evaluate civil infrastructure for more than a decade. Designing and deploying advanced acoustic and electronic devices in aggressive environments has been a hallmark of his research. He has also advanced characterization of Li-ion battery materials using electronics and optics. Recently, through a grant from Corteva Agriscience, Douglas Cook and Mazzeo developed an electromagnetic device to detect European Corn Borer damage in maize. He has received more than $2.7M in external funding and is a co-inventor on 13 U.S. patents with others pending. Technology developed in his group is licensed to Advanced Bridge Inspections and has been demonstrated in more than 22 states.

Wood Chiang, Associate Professor, is an expert in ultra-low-power analog circuit design. His research group has demonstrated some of the most efficient analog-to-digital conversion technology in the world. He brings a wealth of experience in low-power circuitry and sensing, along with the capability of producing custom silicon chips through his industry collaborations, which will be critical in stages beyond the initial phases of this project. In particular, the energy harvesting, sensing, electronic packaging, and power management aspects of this project align well with his expertise.

Douglas Cook, Assistant Professor, is an expert in crop biomechanics with an emphasis on maize. He has developed and deployed a number of devices that allow researchers to quantitatively assess crop phenotypes. Additionally, he performs numerical simulations of plant biomechanics with an emphasis on understanding how these biomechanical properties yield positive agricultural traits. He is uniquely qualified to perform the mechanical analysis of the seed germination process and to quantitatively assess seed ability to generate the forces necessary to deploy our sensing platform. As mentioned, Mazzeo and Cook have also been working together on advanced maize sensing devices, independent of this project.

Nathan Crane, Professor, has researched manufacturing techniques with an emphasis on additive manufacturing and digital microfluidics. He brings experience in methods to attach and deploy mechanical and electrical sensors. In particular, he is investigating the attachment, miniaturization, and capabilities of soil moisture devices as the primary sensor in the Smart Seeds platform. His expertise complements those of Doug Cook and brings advanced manufacturing design and expertise in capillary phenomena to the team.

Neil Hansen, Professor and Department Chair, is a recognized expert in water use and conservation in agricultural and natural systems. In particular, he has studied precision irrigation in commercial agriculture. He brings a wealth of practical field experience in soil sensor deployment and data collection. He will be primarily responsible for deployment of the Smart Stakes in field trials, interpretation of field data, and development of the closed-loop feedback necessary to link dynamic field conditions to precision irrigation and chemical application in center-pivot-based agricultural systems.

Matthew Madsen, Assistant Professor, has developed a number of seed enhancement technologies (e.g., seed coating, pelleting, deterrents, biological and physiological treatments, and other non-traditional methods) and has been instrumental in studying ecosystem restoration after wildfires. His expertise in seed coating technology, dispersal in challenging conditions, and data collection strategies over large areas, rounds out the research team to understand, develop, and deploy the Smart Seeds system.

Project Plan

Task and lead PI/PIs	21Q3	21Q4	External Proposal Submission(s) (21Q4)	22Q1	22Q2	22Q3	22Q4	23Q1	23Q2	External Proposal Submission(s) (23Q2)
A. Germination Biomechanics (SA1): DC										
B. Communication Backbone (SA2): BM										
C. Energy Management (SA2): WC										
D. Sensor Development (SA2,3): NC										
E. System Integration (SA1,2,3): BM										
F. System Deployment (SA1,2,3): NH, MM										
G. System Refinement (SA1,2,3): NH, BM										
H. Effectiveness Analysis (SA3): NH, BM										

Figure 3. Project plan outline during the two-year funding IDR funding period.

The project plan matches the Specific Aims of this project to generate necessary preliminary data for a future funding application. The project outline is found in Figure 3. The project plan includes a notable set of goals in Q3 and Q4 of the first year – to determine many of the necessary platform parameters for construction of a complete system. These are broken down as follows:

A. It is anticipated that both the energy and the maximum upward forces that soybean seeds exert upon the soil are influenced by planting depth, soil characteristics, seed size and diameter [5]. Upward forces exerted by soybean seeds will be measured using a modified version of the experimental apparatus described by Goyal et al. [6]. This experiment will be performed with three different soybean varieties, and with variation in the ambient temperature, soil compaction, and humidity. This information will be used to determine the sensitivity of the maximum vertical force to these factors.

B. Because the selected Gecko platform can reportedly retain some RAM and a real-time clock at less than 3 µW in its low-power sleep mode, we aim to demonstrate average power consumption of ~10µW (given 10ms 1:6000 duty cycle transmission burst at ~29mW). It is envisioned that sensor data (also collected at minute intervals) will be stored in nonvolatile FLASH memory to reduce power consumption. C. These power parameters will determine the size of onboard batteries and solar energy collection. Initial energy management includes specialized power converters to charge a button-cell battery onboard.

D. For moisture sensing, we propose interdigitated fringe capacitors using deposited metal on printed circuit boards in this preliminary work. A nanoporous layer such as sol gel [7] will be deposited over the capacitor to amplify the moisture absorption. As the electric fields interact with the soil, different soil moisture levels alter the dielectric constant of the capacitor. In [8], it was shown that a 6% to 16% soil moisture change leads to about 6× capacitance change for an interdigitated capacitor. Temperature sensing is accomplished with integrated diodes and voltage/current references. Similarly, soil conductivity can be measured by integrated 4-point measurement and readout circuits. E. The results of tasks A, B, C, and D will result in a complete system architecture that will be built. F. This system will be deployed in synthetic environments at first. These sensors will then be tested under field conditions through arrangements that Hansen already has established on other VRI projects. This initial deployment after a year of development will allow the technology to be holistically assessed. G. Based on the assessment, significant design changes will enhance the capabilities of the platform and another deployment will occur in the final quarter of the project. Soybean lifting capability will determine the level of system integration that can be achieved in early iterations of this system.

H. Evaluation and assessment will determine how closed-loop feedback can be incorporated with VRI to improve water and nutrient utilization in a commercial operation. Comparison will be made between conventional monitoring strategies utilizing fixed sensors using extensive wires, power, and communication requirements and the new Smart Seeds Platform.

Expected Outcomes

The outcomes of this projects are to generate preliminary data on (1) soybean sensor deployment capability, (2) basic electronic systems necessary for communication and sensing, and (3) field deployment data showing potential value to agricultural stakeholders. These stakeholders can provide letters of support for future funding applications. Measures of success include:

1. Ultra-low-power consumption (average of ~10 µW).
2. Energy harvesting/storage capability for long-term operation (at least one growing season)
3. Long-range Bluetooth communication with base stations (≥100m)
4. Soil temperature monitoring (at least half-hour intervals)
5. Soil moisture monitoring (accuracy ±5% of commercial sensor)
6. Deployment of ≥5 sensors in professional agricultural setting (by end of 23Q2)

Data will be used in NSF and USDA NIFA proposals that will secure funding for further development. We will also explore commercial implementation with a full VRI system through our existing partner, Christiansen Farms in Grace, ID. Even if applied water is not reduced using VRI, the technology can translate to more efficient crop water use. One extensive study of VRI study demonstrated that with the same amount of applied irrigation water there was a four percent improvement in potato yield and improved tuber quality that led to \$159 ha-1 greater income [9]. Smart Seed Technology, as a seamless way to assess soil conditions, has the potential to revolutionize agriculture.

Budget and Budget Narrative

The budget is allocated to support the development of the preliminary data for external proposals. It is expected that students will also participate in the ECEn IMMERSE undergraduate research program during spring/summer and that students will log less hours during the regular academic year compared to the spring/summer period.

Table 1. Year 1 Budget

Item	Time Hrs/wk	Rate	Duration (quantity)	$ Total
EE Ugrad (MCU/communication)	10 hrs/wk	$12/hr	50 wks	$6,000
ME Ugrad 1 (biomechanics of soybean emergence)	10 hrs/wk	$12/hr	50 wks	$6,000
ME Ugrad 2 (sensor/system packaging)	10 hrs/wk	$12/hr	50 wks	$6,000
Fabrication Supplies (Bluetooth hardware, PCB fabrication, sensor packages)				$1000
Base station smartphone, L1+L5 GPS, BLE 5.2, ~Moto G 4G+		$300	2	$600
Soybean varieties, force measurement apparatus				$200
Site Travel to ID farm (1x visit)				$200
			Total	**$20,000**

Table 2. Year 2 Budget

Item	Time Hrs/wk	Rate	Duration (quantity)	$ Total
EE Ugrad 1 (MCU/BLE system)	10 hrs/wk	$12/hr	25 wks	$3,000
EE Ugrad 2 (power system)	10 hrs/wk	$12/hr	25 wks	$3,000
ME Ugrad 1 (sensor/system packaging)	10 hrs/wk	$12/hr	50 wks	$6,000
ME Ugrad 2 (biomechanics analysis)	10 hrs/wk	$12/hr	30 wks	$3,600
PWS Ugrad (high-density sensor placement analysis)	10 hrs/wk	$12/hr	30 wks	$3,600
Fabrication Supplies				$400
Site Travel to ID farm (2x visits)				$400
			Total	**$20,000**

The first year of power generation/storage research will be funded through other seed money. Smartphones will be used as base stations. Low-cost hardware (BGM220 Bluetooth Module Explore Kits are only $9.99) and low-cost sensors (e.g. TI TMP235A temperature sensor is $0.76) should keep chip costs relatively low. PCB creation and packaging will require more significant funds – especially in initial trial stages. Total bill of materials cost for each Smart Stake should not exceed $20. Majority of costs is directed towards students working under the supervision of the PIs to support technology development, deployment, and characterization of the system to generate data.

References

[1] E. Woolley, "Soil Water Dynamics within Variable Rate Irrigation Zones of Winter Wheat," MS, Plant and Wildlife Sciences, Brigham Young University, Provo, UT, 2020.

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[4] "BGM220P Wireless Gecko Bluetooth Module Data Sheet," Silicon Labs, 2020. [Online]. Available: https://www.silabs.com/documents/public/data-sheets/bgm220p-datasheet.pdf

[5] C. Morton and W. Buchele, "Basic factors affecting the emergence energy of seedlings," *Journal of Agricultural Engineering, St. Joseph, Michigan, USA,* vol. 41, no. 7, pp. 428-431, 1960.

[6] M. R. Goyal, L. O. Drew, G. L. Nelson, and T. J. Logan, "Critical time for soybean seedling emergence force," *Transactions of the ASAE,* vol. 23, no. 4, pp. 831-0835, 1980.

[7] R. Cardoso, G. Sarapajevaite, O. Korsun, S. Cardoso, and L. Ilharco, "Microfabricated sol-gel relative humidity sensors for soil suction measurement during laboratory tests," (in English), *Can Geotech J,* vol. 54, no. 8, pp. 1176-1183, Aug 2017, doi: 10.1139/cgj-2016-0419.

[8] S. F. Pichorim, N. J. Gomes, and J. C. Batchelor, "Two solutions of soil moisture sensing with RFID for landslide monitoring," *Sensors,* vol. 18, no. 2, p. 452, 2018.

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Plans for External Funding

In 2020 our BYU team submitted a $1.2M proposal to the NSF Signals in the Soils program on this topic. The complete intellectual merit strengths statement from the review was: “The proposal brings a truly innovative approach to develop a continuous and precise soil sensor platform. The proposal is originated from very interesting and innovative ideas. Task 1 in the proposal is well written. The miniaturization with device integration concept for the payload detection is very good. Research plan mentioned in the proposal is meaningful. The PIs have a good collaboration plan.” In addition to this overall feedback on the proposal it was evident from comments that the reviewers also made that the ideas contained in the proposal had strong intellectual merit.

However, there were some items that needed to be addressed if the proposal would be selected in future programs. The weakness list started off with perhaps the most important item: “Preliminary data on actual device development of various types (e.g., RFID, solar cells) in the complex soil environment is weak. No descriptions on device interference, device and circuit noise are mentioned with potential solution. The correlation of real-world spatialtemporal variations to actual sensor development is weak…” It was clear that we needed to demonstrate working aspects of the system to enable us to be positioned for this NSF program and other related programs.

In this IDR proposal, we address these weaknesses in multiple ways: (1) Illustrating through example and quantitative experiments that seeds can lift payloads out of the soil will greatly reduce the risk perceived by reviewers, (2) Demonstration of long-range Bluetooth working from a low-power platform near the soil floor will address concerns about communication in the field environment, and (3) Field data from sensors embedded in a professional agricultural operation will address concerns about viability of the system, data comparisons to traditional systems, and applicability to real problems related to irrigation and nutrient application. These aims should also address concerns by other national funding agencies.

This project fits nicely into the NSF Cyber-Physical Systems as they have partnered with USDA NIFA for this joint program specifically to advance agricultural technologies. We want to see how far we can get in the first year of funding to see if we can address many of these concerns so we can submit to this system. Upon consultation with the NSF SitS program manager, that program should become available as a funding target in another year or so. NIFA also runs the Agriculture and Food Research Initiative – Sustainable Agricultural Systems (AFRI SAS) program, in which low-cost sensor systems would be perfectly suited. This IDR targets these because “approaches must demonstrate current needs and anticipate future social, cultural, behavioral, economic, health, and environmental impacts.”

Besides federal sources, agricultural monitoring corporations, such as Meter Group-Environment, with whom we have relationships, would be interested in partnering with us in technology development. Initially, however, we will work with Christiansen Farms in Grace, ID as a commercial partner.

Table 1. List of federal funding options for this project.

Agency	Program	Solicitation/Target
NSF/USDA NIFA	Cyber-Physical Systems	Anytime/End of 2021
USDA NIFA	AFRI SAS	July 1, 2021/Target 2022 cycle
NSF	Signals in the Soils	(Anticipated 2022)/June 2022
USDA NIFA	AFRI SAS	July 1, 2021/Target 2023 cycle
NSF/NIFA	Cyber-Physical Systems	Anytime/Q2 of 2023

NSF BIOGRAPHICAL SKETCH

NAME: Mazzeo, Brian

ORCID: 0000-0002-3558-1461

POSITION TITLE & INSTITUTION: Professor, Brigham Young University

(a) PROFESSIONAL PREPARATION

INSTITUTION	LOCATION	MAJOR / AREA OF STUDY	DEGREE (if applicable)	YEAR YYYY
Massachusetts Institute of Technology	Cambridge, MA	Electrical Engineering	BS	2005
University of Cambridge	Cambridge	Electrical Engineering	PHD	2008

(b) APPOINTMENTS

2019 - present Professor, Brigham Young University, Electrical and Computer Engineering, Provo, UT

2014 - 2019 Associate Professor, Brigham Young University, Electrical and Computer Engineering, Provo, UT

2008 - 2014 Assistant Professor, Brigham Young University, Electrical and Computer Engineering, Provo, UT

2006 - 2008 Supervisor, Tripos IB Paper 7, Mathematical Methods, University of Cambridge Sidney Sussex College, Cambridge, Cambridgeshire

2004 - 2005 Graduate Research Assistant, MIT Microsystems Technology Laboratory, Cambridge, MA

2003 - 2004 Research Associate, Electrotextiles, Milliken Research Corporation, Spartanburg

(c) PRODUCTS

Products Most Closely Related to the Proposed Project

1. Larsen J, McElderry J, Baxter J, Guthrie W, Mazzeo B. Automated sounding for concrete bridge deck inspection through a multi-channel, continuously moving platform. NDT & E International. 2020 January; 109:102177-. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0963869518304031 DOI: 10.1016/j.ndteint.2019.102177
2. Yao J, Cassler J, Wheeler D, Mazzeo B. Characterization of mechanical properties of thin-film Li-ion battery electrodes from laser excitation and measurements of zero group velocity resonances. Journal of Applied Physics. 2019 August 28; 126(8):085112-. Available from: http://aip.scitation.org/doi/10.1063/1.5108950 DOI: 10.1063/1.5108950
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Other Significant Products, Whether or Not Related to the Proposed Project

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5. Mellor B, Cruz Cortés E, Busath D, Mazzeo B. Method for Estimating the Internal Permittivity of Proteins Using Dielectric Spectroscopy. The Journal of Physical Chemistry B. 2011 March 17; 115(10):2205-2213. Available from: https://pubs.acs.org/doi/10.1021/jp1111873 DOI: 10.1021/jp1111873

(d) SYNERGISTIC ACTIVITIES

1. Currently performing funded research activity in nondestructive measurements of maize stalks supported by Corteva Agrisciences.
2. Licensed technology developed by Mazzeo research group successfully deployed by Utah startup company, Advanced Bridge Inspections, LLC across the United States.
3. Co-Director, BYU Capstone Program, College of Engineering, Brigham Young University, Provo, UT, USA.
4. Faculty Mentor, BYU IMMERSE undergraduate research program
5. Faculty Advisor, BYU Chapter, Society of Hispanic Professional Engineers

Biographical Sketch

Shiuh-hua Wood Chiang

Professional Preparation
University of Waterloo, Waterloo, Canada, Computer Engineering, B.S., 2007
University of California, Irvine, Irvine, CA, Electrical Engineering, M.S., 2009
University of California, Los Angeles, Los Angeles, CA, Electrical Engineering, Ph.D., 2013
Postdoctoral Scholar, University of California, Los Angeles, Los Angeles, CA, 2013

Appointments
Associate Professor, Brigham Young University, Provo, UT, 2020-present
Assistant Professor, Brigham Young University, Provo, UT, 2014-2020
Visiting Associate Professor, National Chiao Tung University, Taiwan, 2016-present
Visiting Assistant Professor, National Chiao Tung University, Taiwan, 2016-2020
Editorial Review Board Member, IEEE Solid-State Circuits Letters, 2017-present
Chapter Chair, IEEE Solid-State Circuits Society Utah Chapter, 2019-present
Chapter Vice-Chair, IEEE Solid-State Circuits Society Utah Chapter, 2017-2019
Senior Engineer, Qualcomm, Irvine, CA, 2013-2014

Publications Related to the Proposed Project

Eric Swindlehurst, Hunter Jensen, Alexander Petrie, Yixin Song, Yen-Cheng Kuan, Yong Qu, Mau-Chung Frank Chang, Jieh-Tsorng Wu, and Shiuh-hua Wood Chiang, "An 8-bit 10-GHz 21-mW time-interleaved SAR ADC with grouped DAC capacitors and dual-path bootstrapped switch," *IEEE Journal of Solid-State Circuits (JSSC)*, 2021. (Accepted)

Alexander Petrie, Whitney Kinnison, Yixin Song, Kent Layton, and Shiuh-hua Wood Chiang, "A 0.2-V 10-bit 5-kHz SAR ADC with dynamic bulk biasing and ultra-low-supply-voltage comparator," *IEEE Custom Integrated Circuits Conference (CICC)*, Mar. 2020.

Khalil Gammoh, Cameron Peterson, David Penry, and Shiuh-hua Wood Chiang, "Linearity theory of stochastic phase-interpolation time-to-digital converter," *IEEE Transactions on Circuits and Systems I (TCAS-I)*, vol. 67, no. 12, pp. 4348-4359, Dec. 2020.

Devon Janke, Andrew Monk, Eric Swindlehurst, Kent Layton, and Shiuh-hua Wood Chiang, "A 9-Bit 10-MHz 28-µW SAR ADC using tapered bit periods and a partially interdigitated DAC," *IEEE Transactions on Circuits and Systems II (TCAS-II)*, vol. 66, no. 2, pp. 187-191, Feb. 2019.

Other Publications

Yixin Song, Jace Rozsa, Joan Magalhaes, Shea Smith, Benjamin Karlinsey, Whitney Kinnison, Elaura Gustafson, Daniel Austin, Aaron Hawkins, and Shiuh-Hua Wood Chiang, "A solid-state charge detector with gain calibration using photocurrent," *IEEE Transactions on Instrumentation and Measurement*, vol. 69, no. 12, pp. 9398-9407, Dec. 2020.

Yixin Song, Whitney Kinnison, Jace Rozsa, Daniel Austin, Aaron Hawkins, and Shiuh-hua Wood Chiang, "A compact measurement technique for detector capacitance of charge amplifiers," *IEEE International Symposium on Circuits and Systems (ISCAS)*, Oct. 2020.

Jia-Sheng Huang, Yu-Cheng Huang, Chia-Wei Kao, Che-Wei Hsu, Shiuh-hua Wood Chiang, and Chia-Hung Chen, "A two-step multi-stage noise-shaping incremental analog-to-digital converter," *International Midwest Symposium on Circuits and Systems (MWSCAS)*, Aug. 2020. (Invited paper)

Devon Webb, Yixin Song, Jace Rozsa, Elaura Gustafson, Daniel Austin, Aaron Hawkins, and Shiuh-hua Wood Chiang, "Low-noise, low-power pulse shaper for particle detection," *International Midwest Symposium on Circuits and Systems (MWSCAS)*, Aug. 2020. (Invited paper)

Jace Rozsa, Yixin Song, Devon Webb, Naomi Debaene, Austin Kerr, Elaura Gustafson, Tabitha Caldwell, Halle Murray, Daniel Austin, Shiuh-hua Wood Chiang, and Aaron Hawkins, "Simulation and measurement of image charge detection with printed-circuit-board detector and differential amplifier", *AIP Review of Scientific Instruments*, vol. 91, no. 5, May 2020.

Andres Galan, Gregory Nordin, and Shiuh-hua Wood Chiang, "Design and characterization of a package-less hybrid PDMS-CMOS-FR4 contact-imaging system for microfluidic integration," *SPIE Journal of Micro/Nanolithography, MEMS, and MOEMS*, vol. 17, no. 3, pp. 034501-1-034501-8, Jul. 2018.

Nathan Whitehead, Yixin Song, and Shiuh-hua Wood Chiang, "Direct measurement of high-gain and complementary charge-steering amplifiers," *IEEE Transactions on Circuits and Systems II (TCAS-II)*, vol. 65, no. 6, pp. 714-718, Jun. 2018.

D. Bustamante, D. Janke, E. Swindlehurst, and S. Chiang, "High-precision, mixed-signal mismatch measurement of metal-oxide-metal capacitors," *IEEE Trans. Circuits and Systems II (TCAS-II)*, vol. 64, no. 11, pp. 1272-1276, Nov. 2017.

Synergistic Activities

1. Designed an ultra high-speed ADC in collaboration with UCLA, National Chiao Tung University, and an industry consortium for high-speed mmWave mobile wireless communications. The ADC achieved the highest power efficiency among state-of-the-arts at the time of publication.
2. Designed an ultra low-power ADC in collaboration with ON Semiconductor for remote sensors that can operate at a supply voltage as low as 0.1 V while tolerating process, voltage, and temperature variations. The ADC demonstrated operation at the lowest supply voltage and the highest speed among state-of-the-arts at the time of publication.
3. Designed a low-noise charge amplifier for a Mars dust analyzer for NASA as part of the collaboration between BYU's ECE and Chemistry departments involving both graduate and undergraduate students. The project has received wide press attention including news articles in dozens of sites such as US News & World Report and Associated Press.
4. Organized educational activities to promote scholarship and service for graduate, undergraduate, junior high, and underrepresented high school students at Brigham Young University.

BIOGRAPHICAL SKETCH

Dr. Douglas Cook

Professional Preparation

Utah State University	Logan, UT	Mechanical Engineering *Minors: Mathematics, Mandarin Chinese*	B.S. 2003
Purdue University	West Lafayette, IN	Mechanical Engineering	M.S. 2005
Purdue University	West Lafayette, IN	Mechanical Engineering	Ph.D. 2009

Appointments

2018 – present	Assistant Professor, Mechanical Engineering, Brigham Young University
2012 - 2018	Assistant Professor, Engineering Division, New York University Abu Dhabi
2009 - 2012	Faculty Fellow, Engineering Division, New York University Abu Dhabi

Products:

Publications:

1. Sekhon, R. S., Joyner, C. N., Ackerman, A. J., McMahan, C. S., Cook, D. D., & Robertson, D. J. (2020). Stalk bending strength is strongly associated with maize stalk lodging incidence across multiple environments. Field Crops Research, 249, 107737. link
2. Cook, D. D., de la Chapelle, W., Lin, T. C., Lee, S. Y., Sun, W., & Robertson, D. J. (2019). DARLING: a device for assessing resistance to lodging in grain crops. Plant methods, 15(1), 102. link
3. Stubbs, C. J., Sun, W., & Cook, D. D. (2019). Measuring the transverse Young's modulus of maize rind and pith tissues. Journal of biomechanics, 84, 113-120. link
4. Stubbs, C. J., Baban, N. S., Robertson, D. J., Al Zube, L., & Cook, D. D. (2018). Bending stress in plant stems: models and assumptions. In *Plant Biomechanics* (pp. 49-77). Springer, Cham. link
5. Al-Zube, L. A., Robertson, D. J., Edwards, J. N., Sun, W., & Cook, D. D. (2017). Measuring the compressive modulus of elasticity of pith-filled plant stems. Plant methods, 13(1), 99. link
6. Robertson, D.J., Julias, M., Lee, S.Y., and Cook, D.D., (2017) "Maize Stalk Lodging: Morphological Determinants of Stalk Strength." Crop Science. 57(2): 926-934 link
7. Robertson, D.J., Julias, M.J., Gardunia, B.W., Barten, T., and Cook, D. D. (2015) "Corn Stalk Lodging: a Forensic Engineering Approach Provides Insights into Failure Patterns and Mechanisms", Crop Science. 55(6): 2833-2841. link
8. von Forell, G., Robertson, D., Lee, S.Y., and Cook, D.D., (2015) "Preventing lodging in bioenergy crops: a biomechanical analysis of structural stresses in maize stalks suggests a new approach" Journal of Experimental Botany, 66 (14): 4367-4371. link
9. Robertson, D., Smith, S., Cook, D., (2015) "On measuring the bending strength of septate grass stems" American Journal of Botany, 102(1), pp. 5 – 11. link

Patent:

10. Cook, D., Robertson, D., Julias, M., & Lee, S. Y. (2019). "Apparatus and method for assessing plant stem strength." U.S. Patent 10,337,951, Issued July 2, 2019. link

Synergistic Activities

Collaborations with Academic Plant Scientists

Genome-wide association mapping of maize stalk strength. Ongoing with Dr. Rajandeep Sekhon, Genetics and Biochemistry, Clemson University and Dr. Seth DeBolt, Department of Horticulture, University of Kentucky. This project has thus far involved thousands of tests using the DARLING device, with one publication in print (reference 1 above), and one other publication in review: “Genetic Architecture of Maize Rind Strength”.

Assessment of the structural influence of brace roots. A collaboration with Dr. Erin Sparks, Department of Plant and Soil Sciences has resulted in the first study aimed at assessing the structural influence of maize brace roots. This study involved the use of the DARLING device and has resulted in a paper currently in review: “Maize brace roots anchor stalks independent of flowering time.”

The influence of maize stalk chemistry on stalk strength. This collaboration involved plant-level measurement of maize stalk strength and chemical composition. Dr. Stephen Kresovitch (Clemson University Dept. of Genetics and Biochemistry), lead the chemistry aspect of this study. We have found that the relationship between stalk chemistry and strength is much weaker than previously thought. We believe that this is because important intermediate effects at the cellular and subcellular scale have previously been overlooked. A manuscript on this topic is in the late stages of preparation with candidate journals including the Proceedings of the National Academy of Sciences.

Collaboration with Industry

NSF GOALI Grant. An ongoing research collaboration with plant breeders and scientists at Bayer Crop Science (formerly Monsanto Company) resulted in an NSF GOALI grant (Grant Opportunities for Academic Liaison with Industry). A detailed description of the outcomes of this grant were described in the Results of Prior NSF Funding section of the proposal. Briefly stated, this project supported numerous advances and resulted in over 10 scientific publications.

Research Funding from Bayer. A project titled “Biomechanical analysis of stalk strength for improved phenotyping of late-season lodging” received $120k in research funding from Bayer. This funding supported the maize stalk chemistry research mentioned above.

Research Funding from Corteva Agriscience. I am currently partnering with Corteva Agriscience (DowDuPont subsidiary) on a funded project to develop a novel device to rapidly and non-destructively assess the degree of disease and/or pest damage within maize stalks.

Industry Scientists as Collaborators. Dr. Alexander Renaud (Bayer) and Dr. Andrew Baumgarten (Corteva) have agreed to provide expertise and input in support of the successful completion of this project (see letters of collaboration). Dr. Zach Benton, founder of Carolina Seed Systems is also a current collaborator on the stalk chemistry study mentioned above.

NAME: Nathan B Crane

POSITION TITLE & INSTITUTION: Professor, Mechanical Engineering

A. PROFESSIONAL PREPARATION
(see PAPPG Chapter II.C.2.f.(i)(a))

INSTITUTION	LOCATION	MAJOR/AREA OF STUDY	DEGREE (if applicable)	YEAR (YYYY)
Brigham Young University	Provo, UT	Mechanical Engineering	BS	1998
Brigham Young University	Provo, UT	Mechanical Engineering	MS	1999
Massachusetts Institute of Technology	Cambridge, MA	Mechanical Engineering	PhD	2005
Sandia National Laboratories	Albuquerque, NM	Organic Materials	PostDoctoral Appointee	2005

B. APPOINTMENTS
(see PAPPG Chapter II.C.2.f.(i)(b))

From - To	Position Title, Organization and Location
2018-Present	Professor, Brigham Young University, Provo, UT
2018-Present	Visiting Professor, University of South Florida, Tampa, FL
2012-2018	Associate Professor, University of South Florida, Tampa, FL
Aug-Dec 2014	Visiting Lecturer, University of Sheffield, UK
2006-2012	Visiting Professor, University of South Florida, Tampa, FL
May-July 2006	Visiting Faculty, Sandia National Laboratories
1999-2001	Engineer, Pratt & Whitney Aircraft

C. PRODUCTS

(see PAPPG Chapter II.C.2.f.(i)(c))

Products Most Closely Related to the Proposed Project

1) N. B. Crane, "Impact of part thickness and drying conditions on saturation limits in binder jet additive manufacturing," Additive Manufacturing, Vol 33, May 2020, Article 101127.
2) M. Ziaee and N. B. Crane, "Binder Jetting: A Review of Process, Materials, and Methods," Additive Manufacturing, Vol 28, Aug 2019, pg 781-801.
3) J. Pierce and N. B. Crane, "Impact of pulse length on the accuracy of defect depth measurements in pulse thermography," Journal of Heat Transfer, v 141, n 4, April 1, 2019
4) M. Ziaee, E. M. Tridas, and N. B. Crane, "Binder-Jet Printing of Fine Stainless Steel Powder with Varied Final Density," Journal of Materials, v 69, n 3, p 592-596, March 1, 2017, special edition of select papers from the 2016 Solid Freeform Fabrication Symposium.
5) N. B. Crane, Wilkes, J., Sachs, E., Allen S. M., "Improving Accuracy of Powder-based SFF Processes by Metal Deposition from a Nanoparticle Dispersion," Rapid Prototyping Journal, Vol 12, No 5, 2006, p 266-274.

Other Significant Products, Whether or Not Related to the Proposed Project

1) N. B. Crane, J. Tuckerman, and G. N. Nielson, "Self Assembly in Additive Manufacturing: Opportunities and Obstacles," Rapid Prototyping Journal, Vol 17, No 3, 2011, p 211-217.
2) K. H. Church, N. B. Crane, P. L. Deffenbaugh, T. P. Ketterl, C. Neff, P. Nesbitt, J. Nussbaum, J. Wang, and T. M. Weller, "Multi-Material and Multi-Layer Direct Digital Manufacturing of 3D Structural Microwave Electronics," Proceedings of the IEEE, February 13, 2017, DOI 10.1109/JPROC.2017.2653178.
3) G. Craft, J. Nussbaum, N. Crane, J.P. Harmon, "Impact of extended sintering times on mechanical properties in PA-12 parts produced by powder bed fusion processes," Additive Manufacturing, V 22, p 800-806, Aug 2018.
(Form will not allow entry of additional references.)

D. SYNERGISTIC ACTIVITIES

(see PAPPG Chapter II.C.2.f.(i)(d))

• Associate Editor for Elsevier's Additive Manufacturing journal (Impact factor: 7.1)
• Fulbright Scholar at the University of Sheffield, UK in the Fall 2014. Researched project on design of additive manufacturing structures for customized mechanical properties.
• Establishing a series of relationships with K-12 education with regular presentations on engineering and manufacturing to multiple schools from K-12.
• Served as PI and technical lead for I-Corp program on method for large area sintering of polymer powders. The technology was licensed and has received over $500k of external support.
• Leadership in Micro/Nano Devices at ASME IMECE including Chair of the MEMS Division Executive Committee

NSF BIOGRAPHICAL SKETCH

NAME: Hansen, Neil C.

POSITION TITLE & INSTITUTION: Professor and Chair, Department of Plant and Wildlife Sciences

(a) PROFESSIONAL PREPARATION

INSTITUTION	LOCATION	MAJOR / AREA OF STUDY	DEGREE (if applicable)	YEAR YYYY
Brigham Young University	Provo, Utah	Agronomy and Horticulture	BS	1992
Brigham Young University	Provo, Utah	Agronomy	MS	1994
University of Minnesota	St. Paul, MN	Soil Science	PHD	1998

(b) APPOINTMENTS

2018 - present Professor and Chair, Department of Plant and Wildlife Sciences, Brigham Young University, Provo, UT

2017 - 2018 Professor, Brigham Young University, Provo, UT

2013 - 2017 Associate Professor, Brigham Young University, Provo, UT

2004 - 2013 Associate Professor, Colorado State University, Fort Collins, CO

2004 - 2004 Associate Professor, Univeristy of Minnesota, St. Paul, MN

1998 - 2004 Assistant Professor, University of Minnesota, St. Paul, MN

(c) PRODUCTS

Products Most Closely Related to the Proposed Project

1. Cid P, Taghvaeian S, Hansen N. Evaluation of the Fao-56 Methodology For Estimating Maize Water Requirements Under Deficit And Full Irrigation Regimes In Semiarid Northeastern Colorado. Irrigation and Drainage. Oct; 67(4):605-614. DOI: 10.1002/ird.2245
2. Pugh S, Heaton M, Svedin J, Hansen N. Spatiotemporal Lagged Models for Variable Rate Irrigation in Agriculture. Journal of Agricultural, Biological and Environmental Statistics. 2019 December 01; 24(4):634-650. Available from: https://doi.org/10.1007/s13253-019-00365-3 DOI: 10.1007/s13253-019-00365-3
3. Hopkins B, Hansen N. Phosphorus Management in High-Yield Systems. Journal of Environmental Quality. Sep-; 48(5):1265-1280. DOI: 10.2134/jeq2019.03.0130
4. Ortiz-Cano H, Hernandez-Herrera J, Hansen N, Petersen S, Searcy M, Mata-Gonzalez R, Cervantes-Mendívil T, Villanueva-Morales A, Park P, Stewart J. Pre-Columbian Rock Mulching as a Strategy for Modern Agave Cultivation in Arid Marginal Lands. Frontiers in Agronomy. 2020; 2(10). Available from: https://www.frontiersin.org/article/10.3389/fagro.2020.00010 DOI: 10.3389/fagro.2020.00010
5. Zhou S, Hu X, Ran H, Wang W, Hansen N, Cui N. Optimization of irrigation and nitrogen fertilizer management for spring maize in northwestern China using RZWQM2. Agricultural Water Management. 2020 October 01; 240:106276. Available from: http://www.sciencedirect.com/science/article/pii/S0378377419322413 issn: 0378-3774

Other Significant Products, Whether or Not Related to the Proposed Project

1. Hansen N. Blue Water Demand for Sustainable Intensification. Agronomy Journal. Jul-; 107(4):1539-1543. DOI: 10.2134/agronj14.0138

2. Foster E, Hansen N, Wallenstein M, Cotrufo M. Biochar and manure amendments impact soil nutrients and microbial enzymatic activities in a semi-arid irrigated maize cropping system. Agriculture Ecosystems & Environment. Oct; 233:404-414. DOI: 10.1016/j.agee.2016.09.029
3. Nielsen D, Vigil M, Hansen N. Evaluating Potential Dryland Cropping Systems Adapted to Climate Change in the Central Great Plains. Agronomy Journal. Nov-; 108(6):2391-2405. DOI: 10.2134/agronj2016.07.0406
4. Carroll D, Hansen N, Hopkins B, DeJonge K. Leaf temperature of maize and Crop Water Stress Index with variable irrigation and nitrogen supply. Irrigation Science. Nov; 35(6):549-560. DOI: 10.1007/s00271-017-0558-4
5. Messick R, Heaton M, Hansen N. MULTIVARIATE SPATIAL MAPPING OF SOIL WATER HOLDING CAPACITY WITH SPATIALLY VARYING CROSS-CORRELATIONS. Annals of Applied Statistics. Mar; 11(1):69-92. DOI: 10.1214/16-aoas991

(d) SYNERGISTIC ACTIVITIES

1. Currently P.I. or co-P.I. on Precision Variable Rate Irrigation projects funded by USDA and BARD with agency and international collaboration.
2. Faculty Advisor: BYU Environmental Science Club
3. Teaching: I teach 2 sections of Soil Science Lecture and 4 Lab sections per year approximately 150 students per year. I teach Environmental Biology as a general science course to over 100 students per year. I also teach a course in International Agricultural Development.
4. International Collaborations: China - China Agricultural University (Beijing), Northwest Agricultural and Forestry University (Yangling); Israel - Institute of Soil, Water and Environmental Sciences, Agricultural Research Organization
5. Professional Memberships: Soil Science Society of America, American Society of Agronomy, Crop Science Society of America, Irrigation Association, Soil and Water Conservation Society

MATTHEW D. MADSEN, PH.D.

Assistant Professor
Department of Plant and Wildlife Sciences
Brigham Young Univasterity
5048 LSB, Provo, UT 84602
Phone: (801) 422-2458
Email: matthew.madsen@byu.edu
Website: http://lifesciences.byu.edu/~mdmadsen

RESEARCH OBJECTIVE

The primary objective of my research program is to determine the limiting factors controlling seeding success and utilize this knowledge in the development of methodologies and technologies that result in the establishment of functional plant communities or productive agricultural crops. Linked objectives include: 1) quantifying the role and impact of edaphic, climatic and biotic factors on plant survival and plant productivity; 2) determining how barriers to seeding success vary across the landscape; and 3) developing and or identifying seed enhancement technologies (e.g., seed coating, pelleting, deterrents, biological and physiological treatments, and other non-traditional methods) that are capable of mitigating ecological processes and conditions limiting plant establishment and growth.

EDUCATION

2010	Ph.D.	Wildlife and Wildlands Cons.	Brigham Young University, Provo UT.
2007	M.S.	Soil Science	Utah State University, Logan UT.
2004	B.S.	Watershed Science	Utah State University, Logan UT.

PROFESSIONAL EXPERIENCE

Assistant Professor. Brigham Young University, Provo, UT 2015-present.
Research Ecologist. USDA-Agricultural Research Service, Burns, OR. 2010-2015.

PRODUCTS RELATED TO THE PROPOSED PROJECT

Patents

- **Madsen, M.D.**, B.W. Hoose, R.M. Anderson. 2019. Seed conglomeration: A disruptive innovation to reduce cleaning requirements of small seed species. U.S. Patent Application No. 16262864.
- **Madsen, M.D.**, and T.J. Svejcar. 2016. Development and application of "Seed Pillow" technology for overcoming the limiting factors controlling rangeland reseeding success. U.S. Patent Application No. 14/039,873, Patent Publication No. US9326451 B1.
- **Madsen, M.D.**, S.J. Kostka, and M.F. McMillan. 2015. Seed composition for enhancing germination and plant growth having a low-dose application of non-ionic alkyl terminated block copolymer surfactant. US Patent Application No. 62/055,386.
- **Madsen, M.D.**, S.L. Petersen, and A.G. Taylor. 2010. Seed coating compositions and methods for applying soil surfactants to water-repellent soil. US Patent Application No. WO/2010/111309. International Application No. PCT/US2010/28371. European patent number 02410833/EP-B1, Chinese Patent No. CN 102438439 B, Israel patent No. 215329, Australian Patent No. 2010230024.

Publications

1. Taylor, J.B., K.L. Cass, D.N. Armond, **M.D. Madsen**, D.E. Pearson, S.B. St. Clair. 2020. Deterring rodent seed-predation using seed-coating technologies. Restoration Ecology In Press https://doi.org/10.1111/rec.13158.

2. Hoose, B.W., R.S. Call, T.H. Bates, R.M. Anderson, B.A. Roundy, and **M.D. Madsen**. 2019. Seed conglomeration: a disruptive innovation to address restoration challenges associated with small-seeded species. Restoration Ecology 5(27): 959 - 956. doi:10.1111/rec.12947
3. Richardson W.C., T. Badrakh, B.A. Roundy, Z.T. Aanderud, S.L. Petersen, P.S. Allen, D.R. Whitaker, and **M.D. Madsen**. 2019. Influence of an abscisic acid (ABA) seed coating on seed germination rate and timing of bluebunch wheatgrass. Ecology and Evolution. 9(13):7438-7447. doi: 10.1002/ece3.5212
4. Pearson, D.E., M. Valliant, C. Carlson, G.C. Thelen, Y.K. Ortega, J.L. Orrock, and **M.D. Madsen**. 2019. Spicing up restoration: can chili peppers improve restoration seeding by reducing seed predation? Restoration Ecology. 27(2):254-260. doi:10.1111/rec.12862
5. Chandler D.G., N. Day, **M.D. Madsen**, and J. Belnap J. 2019. Amendments fail to hasten biocrust recovery or soil stability at a disturbed dryland sandy site. Restoration Ecology. 27(2):289-297. doi.org/10.1111/rec.12870
6. Richardson, W.C., D.R. Whitaker, K.P. Sant, N.S. Barney, and R.S. Call, B.A. Roundy, Z.T. Aanderud, **M.D. Madsen**. 2018. Use of auto-germ to model germination timing in the sagebrush-steppe. Ecology and Evolution. 8(23):11533-11542. doi.org/10.1002/ece3.4591
7. Chandler, D.G., Y. Cheng, M.S. Seyfried, **M.D. Madsen**, C.E. Johnson, and C.J. Williams 2018. Seasonal Wetness, Soil Organic Carbon, and Fire Influence Soil Hydrological Properties and Water Repellency in a Sagebrush-Steppe Ecosystem. Water Resources Research. 54(10):8514-8527. doi:10.1029/2017WR021567
8. **Madsen, M.D.**, L. Svejcar, J. Radke, and A. Hulet. 2018. Inducing rapid seed germination of native cool season grasses with solid matrix priming and seed extrusion technology. PLOS ONE. 13(10):e0204380. doi.org/10.1371/journal.pone.0204380
9. **Madsen**, **M.D.**, K.W. Davies, C.S. Boyd, J.D. Kerby, and T.J. Svejcar. 2016. Emerging seed enhancement technologies for overcoming barriers to restoration. Restoration Ecology: 24: S77-S84. http://dx.doi.org/10.3368/npj.17.3.230
10. **Madsen, M.D.**, A. Hulet, K. Phillips, J.L. Staley, K.W. Davies, and T.J. Svejcar. 2016. Extruded seed pellets: A novel approach to enhancing sagebrush seedling emergence. Native Plants Journal 17: 230-243. http://dx.doi.org/10.3368/npj.17.3.230
11. **Madsen, M.D.**, S.J. Kostka, M.A. Fidanza, N.S. Barney, T. Badrakh and M.F. McMillan. 2016. Low-dose Application of non-ionic alkyl terminated block copolymer surfactant enhances turfgrass seed germination and plant growth. HortTechnology 26: 379-385. doi.org/10.21273/HORTTECH.26.4.379
12. **Madsen, M.D**., K.W. Davies, D.L. Mummey, and T.J. Svejcar. 2014. Improving Restoration of Exotic Annual Grass-Invaded Rangelands Through Activated Carbon Seed Enhancement Technologies. Rangeland Ecology & Management 67:61-67. https://doi.org/10.2111/REM-D-13-00050.1
13. **Madsen, M.D.**, K.W. Davies, C.J. Williams, and T.J. Svejcar. 2012. Agglomerating seeds to enhance native seedling emergence and growth. Journal of Applied Ecology 49:431–438. http://dx.doi.org/10.1111/j.1365-2664.2012.02118.x

NSF CURRENT AND PENDING SUPPORT

PI/co-PI/Senior Personnel: Mazzeo, Brian

PROJECT/PROPOSAL CURRENT SUPPORT

1. Project/Proposal Title: Smart Seeds: A Platform for Widely Dispersed Soil Sensing

   Proposal/Award Number (if available):

   Source of Support: BYU

   Primary Place of Performance: BYU

   Project/Proposal Support Start Date (if available): 2020/11

   Project/Proposal Support End Date (if available): 2021/11

   Total Award Amount (including Indirect Costs): $12,500

   Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2021	0.1

2. Project/Proposal Title: Long-Term Performance of Low Permeable Concrete for Structures

   Proposal/Award Number (if available):

   Source of Support: Utah Valley University (UDOT)

   Primary Place of Performance: BYU

   Project/Proposal Support Start Date (if available): 2020/09

   Project/Proposal Support End Date (if available): 2021/09

   Total Award Amount (including Indirect Costs): $15,000

   Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2021	0.15

3. Project/Proposal Title: Enabling Electrified Flight through Utah-Sourced Material for Improving Lithium-Ion Batteries

   Proposal/Award Number (if available):

Source of Support: Utah NASA Space Grant Consortium

Primary Place of Performance: Brigham Young University, Provo, UT

Project/Proposal Support Start Date (if available): 2020/05

Project/Proposal Support End Date (if available): 2021/05

Total Award Amount (including Indirect Costs): $24,000

Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2020	0.1

4. Project/Proposal Title: Spectral Correlation Based Defect Recognition System to Enable In-Process, Real-Time Non-Destructive Examination for Friction Stir Welding

   Proposal/Award Number (if available):

   Source of Support: Utah NASA Space Grant Consortium

   Primary Place of Performance: Brigham Young University, Provo, UT

   Project/Proposal Support Start Date (if available): 2020/05

   Project/Proposal Support End Date (if available): 2021/05

   Total Award Amount (including Indirect Costs): $25,000

   Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2020	0.1

5. Project/Proposal Title: Validation of Service Life Prediction for a 28-Year-Old Parking Garage Constructed of Low Permeability Concrete

   Proposal/Award Number (if available):

   Source of Support: Utah Valley University (ACI Foundation)

   Primary Place of Performance: BYU

   Project/Proposal Support Start Date (if available): 2020/05

   Project/Proposal Support End Date (if available): 2021/08

   Total Award Amount (including Indirect Costs): $23,000

   Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2021	0.3

6. Project/Proposal Title: Nondestructive Evaluation of Corn Stalk Integrity

   Proposal/Award Number (if available):

   Source of Support: Corteva Agriscience

   Primary Place of Performance: Brigham Young University, Provo, UT

   Project/Proposal Support Start Date (if available): 2020/03

   Project/Proposal Support End Date (if available): 2021/03

   Total Award Amount (including Indirect Costs): $50,000

   Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2020	0.25

7. Project/Proposal Title: Evaluation of Halloysite-Derived Nano-Silicon as Anode Material for Lithium-Ion Batteries

   Proposal/Award Number (if available):

   Source of Support: BYU

   Primary Place of Performance: BYU

   Project/Proposal Support Start Date (if available): 2020/02

   Project/Proposal Support End Date (if available): 2021/02

   Total Award Amount (including Indirect Costs): $9,300

   Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2020	0.1

PROJECT/PROPOSAL PENDING SUPPORT

1. Project/Proposal Title: Domestic Halloysite-Derived Silicon as a Low-Cost High-Performance Anode Material for Li-Ion Batteries

Proposal/Award Number (if available):

Source of Support: Applied Minerals Inc. (Department of Energy)

Primary Place of Performance: BYU

Project/Proposal Support Start Date (if available): 2021/06

Project/Proposal Support End Date (if available): 2022/06

Total Award Amount (including Indirect Costs): $80,000

Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2021	0.4

2. Project/Proposal Title: IDR: Smart Seeds: A Platform for Widely Dispersed Soil Sensing

   Proposal/Award Number (if available):

   Source of Support: BYU

   Primary Place of Performance: BYU

   Project/Proposal Support Start Date (if available): 2021/04

   Project/Proposal Support End Date (if available): 2023/04

   Total Award Amount (including Indirect Costs): $40,000

   Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2021	0.1
2022	0.1

3. Project/Proposal Title: Mentored Research Grant: Measuring pavement smoothness from the perspective of e-scooters

   Proposal/Award Number (if available):

   Source of Support: BYU

   Primary Place of Performance: BYU

   Project/Proposal Support Start Date (if available): 2021/04

   Project/Proposal Support End Date (if available): 2022/04

Total Award Amount (including Indirect Costs): $25,000

Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2021	0.1

Shiuh-hua Wood Chiang Ongoing Research Support

Title: Miniaturized Components for Compact GC/MS Instruments
Sponsor: Perkin Elmer Corp.
Performance Period: Mar. 2016 – Dec. 2021
Time Committed: 0.5 calendar year
Award Amount: $850,000

Title: A Printed Circuitboard Analyzer for Characterizing the Charge and Mass of Martian Dust
Sponsor: NASA
Performance Period: Aug. 2017 – May 2021
Time Committed: 0.5 calendar year
Award Amount: $640,000

Title: Continuous Variable Integrated Quantum Photonics
Sponsor: Department of Energy
Performance Period: Dec. 2020 – Aug. 2023
Time Committed: 0.5 calendar year
Award Amount: $400,000

Title: Low-Power ADCs for Digital Phased-Array Remote Sensing
Sponsor: NASA
Performance Period: Sep. 2019 – May 2023
Time Committed: 0.1 calendar year
Award Amount: $32,000

Title: Circuit Techniques for Robust Near-Zero-Power Sensors
Sponsor: BYU
Performance Period: May 2020 – Dec. 2021
Time Committed: 0.1 calendar year
Award Amount: $25,000

Title: A CMOS Digital Amplifier for Space Dust Analyzer
Sponsor: NASA
Performance Period: May 2020 – May 2021
Time Committed: 0.1 calendar year
Award Amount: $15,000

Shiuh-hua Wood Chiang Pending Research Support

Title: Smart Seeds: A Platform for Widely Dispersed Soil Sensing
Sponsor: BYU
Performance Period: Apr. 2021 – Apr. 2023
Time Committed: 0.1 calendar year
Award Amount: $40,000

Title: A Space Dust Analyzer Based on Charge-Detection Mass Spectrometry
Sponsor: BYU
Performance Period: Apr. 2021 – Apr. 2023
Time Committed: 0.2 calendar year
Award Amount: $120,000

*PI/co-PI/Senior Personnel Name: Douglas Cook

***Required fields**

Note: NSF has provided 15 project/proposal and 10 in-kind contribution entries for users to populate. Please leave any unused entries blank.

Project/Proposal Section:

Current and Pending Support includes all resources made available to an individual in support of and/or related to all of his/her research efforts, regardless of whether or not they have monetary value.[1] Information must be provided about all current and pending support, including this project, for ongoing projects, and for any proposals currently under consideration from whatever source[2], irrespective of whether such support is provided through the proposing organization or is provided directly to the individual. Concurrent submission of a proposal to other organizations will not prejudice its review by NSF, if disclosed.[3]

Please enter your support entries so they are grouped together based on the "Status of Support" and are in the order of Current, Pending, Submission Planned, and Transfer of Support from top to bottom

[1] If the time commitment or dollar value is not readily ascertainable, reasonable estimates should be provided.
[2] For example, Federal, State, local, foreign, public or private foundations, non-profits, industrial or other commercial organizations or internal funds allocated toward specific projects.
[3] The Biological Sciences Directorate exception to this policy is delineated in PAPPG Chapter II.D.2.

Projects/Proposals

1. *Project/Proposal Title : Nondestructive Evaluation of Corn Stalk Integrity

*Status of Support : (•) Current ( ) Pending ( ) Submission Planned ( ) Transfer of Support

Proposal/Award Number (if available): n/a

*Source of Support: Corteva Agriscience

*Primary Place of Performance : Brigham Young University

Project/Proposal Start Date (MM/YYYY) (if available) : 03/2020

Project/Proposal End Date (MM/YYYY) (if available) : 02/2021

*Total Award Amount (including Indirect Costs): $ 50,000

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)	Year (YYYY)	Person Months (##.##)
1. 2020	0.00	4.	
2. 2021	0.00	5.	
3.			

2. *Project/Proposal Title : Designing Superior Crop Architecture using Biomechanical Modeling and Field Phenotyping

*Status of Support : ( ) Current (•) Pending ( ) Submission Planned ( ) Transfer of Support

Proposal/Award Number (if available): 2020-08741

*Source of Support: US Dept. of Agriculture - Nat'l Inst. Food and Agriculture

*Primary Place of Performance : Brigham Young University

Project/Proposal Start Date (MM/YYYY) (if available) : 01/2021

Project/Proposal End Date (MM/YYYY) (if available) : 12/2024

*Total Award Amount (including Indirect Costs): $ 500,000

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)	Year (YYYY)	Person Months (##.##)
1. 2021	1.50	4. 2024	1.50
2. 2022	1.50	5.	
3. 2023	1.50		

Projects/Proposals

3. *Project/Proposal Title : The Influence of Leaf Sheath on Greensnap Grain Failure

*Status of Support : ○ Current ◉ Pending ○ Submission Planned ○ Transfer of Support

Proposal/Award Number (if available): 2020-08779

*Source of Support: US Dept. of Agriculture - Nat'l Inst. Food and Agriculture

*Primary Place of Performance : Brigham Young University

Project/Proposal Start Date (MM/YYYY) (if available) : 01/2021

Project/Proposal End Date (MM/YYYY) (if available) : 12/2024

*Total Award Amount (including Indirect Costs): $ 500,000

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)
1. 2021	1.00
2. 2022	1.00
3. 2023	1.00

Year (YYYY)	Person Months (##.##)
4. 2124	1.00
5.	

4. *Project/Proposal Title : Smart Seeds: A Platform for Widely Dispersed Soil Sensing

*Status of Support : ○ Current ◉ Pending ○ Submission Planned ○ Transfer of Support

Proposal/Award Number (if available):

*Source of Support: National Science Foundation (Signals in the Soils Program)

*Primary Place of Performance : Brigham Young University

Project/Proposal Start Date (MM/YYYY) (if available) : 08/2020

Project/Proposal End Date (MM/YYYY) (if available) : 07/2024

*Total Award Amount (including Indirect Costs): $ 1,200,000

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)
1. 2021	1.00
2. 2022	1.00
3. 2023	1.00

Year (YYYY)	Person Months (##.##)
4. 2024	1.00
5.	

Projects/Proposals

5. *Project/Proposal Title : The Influence of Leaf Sheath on Greensnap Grain Failure

*Status of Support : ○ Current ○ Pending ◉ Submission Planned ○ Transfer of Support

Proposal/Award Number (if available):

*Source of Support: National Science Foundation (CMMI - BMMB)

*Primary Place of Performance : Brigham Young University

Project/Proposal Start Date (MM/YYYY) (if available) : 01/2021

Project/Proposal End Date (MM/YYYY) (if available) : 12/2023

*Total Award Amount (including Indirect Costs): $ 400,000

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)
1. 2021	1.00
2. 2022	1.00
3. 2023	1.00

Year (YYYY)	Person Months (##.##)
4.	
5.	

6. *Project/Proposal Title :

*Status of Support : ○ Current ○ Pending ○ Submission Planned ○ Transfer of Support

Proposal/Award Number (if available):

*Source of Support:

*Primary Place of Performance :

Project/Proposal Start Date (MM/YYYY) (if available) :

Project/Proposal End Date (MM/YYYY) (if available) :

*Total Award Amount (including Indirect Costs): $

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)
1.	
2.	
3.	

Year (YYYY)	Person Months (##.##)
4.	
5.	

*PI/co-PI/Senior Personnel Name: Nathan B Crane

***Required fields**

Note: NSF has provided 15 project/proposal and 10 in-kind contribution entries for users to populate. Please leave any unused entries blank.

Project/Proposal Section:

Current and Pending Support includes all resources made available to an individual in support of and/or related to all of his/her research efforts, regardless of whether or not they have monetary value.[1] Information must be provided about all current and pending support, including this project, for ongoing projects, and for any proposals currently under consideration from whatever source[2], irrespective of whether such support is provided through the proposing organization or is provided directly to the individual. Concurrent submission of a proposal to other organizations will not prejudice its review by NSF, if disclosed.[3]

Please enter your support entries so they are grouped together based on the "Status of Support" and are in the order of Current, Pending, Submission Planned, and Transfer of Support from top to bottom

[1] If the time commitment or dollar value is not readily ascertainable, reasonable estimates should be provided.
[2] For example, Federal, State, local, foreign, public or private foundations, non-profits, industrial or other commercial organizations or internal funds allocated toward specific projects.
[3] The Biological Sciences Directorate exception to this policy is delineated in PAPPG Chapter II.D.2.

Projects/Proposals

1. *Project/Proposal Title : Could Slower be Better? Assessing Sintering Time, Temperature, and Area Tradeoffs in 3D printing by Polymer Sintering

*Status of Support : (•) Current ( ) Pending ( ) Submission Planned ( ) Transfer of Support

Proposal/Award Number (if available): 1851728

*Source of Support: National Science Foundation

*Primary Place of Performance : Brigham Young University, Provo, UT

Project/Proposal Start Date (MM/YYYY) (if available) : 08/2018

Project/Proposal End Date (MM/YYYY) (if available) : 07/2021

*Total Award Amount (including Indirect Costs): $ 286,180

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)
1. 2020	0.50
2. 2021	0.25
3.	

Year (YYYY)	Person Months (##.##)
4.	
5.	

2. *Project/Proposal Title : MRI: Acquisition of a Multi-Material Additive Manufacturing Platform for Multi-Disciplinary Research and Education

*Status of Support : (•) Current ( ) Pending ( ) Submission Planned ( ) Transfer of Support

Proposal/Award Number (if available): 1726875

*Source of Support: National Science Foundation

*Primary Place of Performance : University of South Florida, Tampa, FL

Project/Proposal Start Date (MM/YYYY) (if available) : 10/2017

Project/Proposal End Date (MM/YYYY) (if available) : 10/2020

*Total Award Amount (including Indirect Costs): $ 436,980

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)
1. 2020	0.00
2.	
3.	

Year (YYYY)	Person Months (##.##)
4.	
5.	

Projects/Proposals

3. *Project/Proposal Title : Collaborative Research: Microfluidic MM-Wave RF Devices with Integrated Actuation

*Status of Support : (●) Current ( ) Pending ( ) Submission Planned ( ) Transfer of Support

Proposal/Award Number (if available): 1920953

*Source of Support: National Science Foundation

*Primary Place of Performance : Brigham Young University, Provo, UT

Project/Proposal Start Date (MM/YYYY) (if available) : 09/2019

Project/Proposal End Date (MM/YYYY) (if available) : 08/2022

*Total Award Amount (including Indirect Costs): $ 224,952

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)
1. 2020	0.50
2. 2021	0.50
3. 2022	0.50

Year (YYYY)	Person Months (##.##)
4.	
5.	

4. *Project/Proposal Title : GOALI: Tuning Degradation Properties of Metallic Implants through Polymeric Coatings and Surface Texture

*Status of Support : (●) Current ( ) Pending ( ) Submission Planned ( ) Transfer of Support

Proposal/Award Number (if available): 1538727

*Source of Support: National Science Foundation

*Primary Place of Performance : University of South Florida, Tampa, FL

Project/Proposal Start Date (MM/YYYY) (if available) : 09/2015

Project/Proposal End Date (MM/YYYY) (if available) : 08/2020

*Total Award Amount (including Indirect Costs): $ 425,851

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)
1. 2020	0.00
2.	
3.	

Year (YYYY)	Person Months (##.##)
4.	
5.	

Projects/Proposals

5. *Project/Proposal Title : Real-time additive manufacturing defect identification and alleviation using pulsed thermography

*Status of Support : ○ Current ◉ Pending ○ Submission Planned ○ Transfer of Support

Proposal/Award Number (if available):

*Source of Support: Air Force

*Primary Place of Performance : Brigham Young University, Provo, UT

Project/Proposal Start Date (MM/YYYY) (if available) : 04/2020

Project/Proposal End Date (MM/YYYY) (if available) : 10/2020

*Total Award Amount (including Indirect Costs): $ 70,000

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)
1. 2021	0.60
2.	
3.	

Year (YYYY)	Person Months (##.##)
4.	
5.	

6. *Project/Proposal Title : Collaborative Research: Spatial Modulation of Material Properties in Powder Bed AM Processes by InkJet Doping and Thermal Modulation

*Status of Support : ○ Current ◉ Pending ○ Submission Planned ○ Transfer of Support

Proposal/Award Number (if available):

*Source of Support: National Science Foundation

*Primary Place of Performance : Brigham Young University, Provo, UT

Project/Proposal Start Date (MM/YYYY) (if available) : 08/2021

Project/Proposal End Date (MM/YYYY) (if available) : 07/2024

*Total Award Amount (including Indirect Costs): $ 303,015

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)
1. 2021	0.33
2. 2022	0.33
3. 2023	0.33

Year (YYYY)	Person Months (##.##)
4.	
5.	

Projects/Proposals

7. *Project/Proposal Title : Eco Manufacturing through Additive Manufacturing of Origami

*Status of Support : (•) Current ( ) Pending ( ) Submission Planned ( ) Transfer of Support

Proposal/Award Number (if available):

*Source of Support: Brigham Young University College of Engineering

*Primary Place of Performance : Brigham Young University, Provo, UT

Project/Proposal Start Date (MM/YYYY) (if available) : 01/2021

Project/Proposal End Date (MM/YYYY) (if available) : 12/2021

*Total Award Amount (including Indirect Costs): $ 12,500

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)	Year (YYYY)	Person Months (##.##)
1. 2021	0.20	4.	
2.		5.	
3.			

8. *Project/Proposal Title :

*Status of Support : ( ) Current ( ) Pending ( ) Submission Planned ( ) Transfer of Support

Proposal/Award Number (if available):

*Source of Support:

*Primary Place of Performance :

Project/Proposal Start Date (MM/YYYY) (if available) :

Project/Proposal End Date (MM/YYYY) (if available) :

*Total Award Amount (including Indirect Costs): $

*Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project

*Year (YYYY)	*Person Months (##.##)	Year (YYYY)	Person Months (##.##)
1.		4.	
2.		5.	
3.			

NSF CURRENT AND PENDING SUPPORT

PI/co-PI/Senior Personnel: Hansen, Neil

PROJECT/PROPOSAL CURRENT SUPPORT

1. Project/Proposal Title: Spatiotemporal decision support systems for recognizing variability and managing precision irrigation

   Proposal/Award Number (if available): IS-5218-19

   Source of Support: US-ISRAEL BINATIONAL AGRIC RES AND DEV FUND

   Primary Place of Performance: Provo, UT

   Project/Proposal Support Start Date (if available): 2020/01

   Project/Proposal Support End Date (if available): 2022/12

   Total Award Amount (including Indirect Costs): $310,000

   Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2020	0.5
2021	0.25
2022	0.25

2. Project/Proposal Title: Stacking and Intersecting Nutrient and Irrigation 4R's

   Proposal/Award Number (if available):

   Source of Support: The Fertilizer Institute

   Primary Place of Performance: Logan, UT

   Project/Proposal Support Start Date (if available): 2020/01

   Project/Proposal Support End Date (if available): 2022/12

   Total Award Amount (including Indirect Costs): $701,000

   Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2020	0.5

Year	Person-months per year committed
2021	0.5
2022	0.5

3. Project/Proposal Title: Identifying Stacked Conservation Practices that Optimize Water Use in Agriculture

   Proposal/Award Number (if available):

   Source of Support: USDA - Sustainable Agriculture Research and Eduation

   Primary Place of Performance: Provo, UT

   Project/Proposal Support Start Date (if available): 2019/03

   Project/Proposal Support End Date (if available): 2022/02

   Total Award Amount (including Indirect Costs): $118,000

   Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2020	0.25
2021	0.5
2022	0.25

PROJECT/PROPOSAL SUBMISSION PLANNED

1. Project/Proposal Title: Smart Seeds: A Platform for Widely Dispersed Soil Sensing

   Proposal/Award Number (if available):

   Source of Support: BYU

   Primary Place of Performance: Brigham Young University, Provo, UT

   Project/Proposal Support Start Date (if available): 2021/04

   Project/Proposal Support End Date (if available): 2023/04

   Total Award Amount (including Indirect Costs): $40,000

   Person-Month(s) (or Partial Person-Months) Per Year Committed to the Project:

Year	Person-months per year committed
2021	0.1
2022	0.1

CURRENT AND PENDING SUPPORT

Name: Matthew Madsen

NAME (List/PD #1 first)	SUPPORTING AGENCY AND AGENCY ACTIVE AWARD/PENDING PROPOSAL NUMBER	TOTAL $ AMOUNT	EFFECTIVE AND EXPIRATION DATES	% OF TIME COMMITTED	TITLE OF PROJECT
Madsen	Active: USDA-ARS	$26,543	2021	2%	Development and use of a broad portfolio of seed enhancement technologies to reduce the risk of sagebrush seeding failure
Madsen	Utah – DWR	$212,410	2024	5%	Development of novel seed coating technologies to improve wildlife habitat in the sagebrush steppe
Madsen	BLM	$49,000	2021	5%	Use of Flash Flaming, Fungicide, and Abscisic Acid Treatments to Improve Seed Delivery and Establishment of Winterfat (Krascheninnikovia lanata)
Madsen	Rio Tinto	$650,000	2023	10%	Improving Vegetation Establishment on Kennecott Mine Waste Rock Dumps and Tailings
Shackelford	USDA – NIFA	$500,000	2024	5%	From seed to service: Managing the microsite to maximize returns in rangeland restoration and rehabilitation.
Madsen	USDA - NRCS	$550,955	2024	10%	Helping producers improve wildlife habitat with innovative seed coating technologies.
	Pending: No pending proposals				