Virginia Corn Board 3rd Year Report and Proposal

Title: **Rapid Determination of Cover Crop Biomass for Nutrient Management and Evaluation of Biological/Biostimulants in Virginia Corn Production.**

Principal Investigator: Dr. William "Hunter" Frame
Field Crops Agronomist/Associate Professor
Virginia Tech
Tidewater AREC
PH: 757-807-6539
Email: whframe@vt.edu

Co-PI(s): Dr. Ryan Stewart
Soil Water Management/Soil Physics
PH:540-231-0253
Email: rds@vt.edu

Project Initiation: April 2025

Project Duration: April 2024 – October 2027 (1-year for the current proposal)

Objectives:

1. Develop a rapid method to determine cover crop biomass at the field level using NDVI/LIDAR for precision nitrogen management in corn.

2. Develop nitrogen response recommendations based on cover crop biomass and nutrient content within different cover crop species/group to better estimate nitrogen application rates across fields.

3. Evaluate six to twelve commercial biological/biostimulant formulations on nutrient uptake and efficiency in corn in Virginia.

Locations: *Experiment 1:* On-farm locations across Virginia (Split between Coastal Plain and Piedmont)

Experiment 2: Tidewater Agricultural Research and Extension Center (Suffolk, Va) and VA Ag Expo Location (Orange, VA in 2025)

Summary for SDI study in Virginia Corn (2022 – 2024)

Executive Summary

The three-year study of subsurface drip irrigation (SDI) in corn production system at Tidewater AREC was a success. Over the course of the study, it was found that SDI increased corn grain yields by an average of 60+ bu per acre and that the optimum dripline spacing was 36 inches. Corn grain yields were improved as much as 100 bu per acre in 2022 when a prolonged drought occurred and substantially reduced non-irrigated corn yields. The system performed as well as you could have hoped and depending on the SDI management strategy producers can expect a return on their initial investment for SDI within 7-12 years. With a given dripline life of 20-25 years this allows for producers to have yield stability and increased profits for over have the expected life of the SDI system. Implementing SDI as opposed to traditional overhead irrigation systems will allow a larger percentage of field area to be irrigated, use less water, and increase the efficiency of irrigation water to maximize corn yields. This will be an important consideration moving forward as climate change influences weather patterns such as rainfall quantities and frequencies.

Weather Conditions and SDI Capabilities

Weather data can be found in Figure 1 for each year of the study from 2022 -2024. In 2022, the lack of substantial rainfall events (> 1.0 inch (25.4 mm)) from May through July aid in the understanding of the significance response to irrigation observed during that year. Whereas in 2023 and 2024 there were significant rainfall events throughout the growing season that reduced the response to irrigation during those years (Figure 1). Though from June 5th through

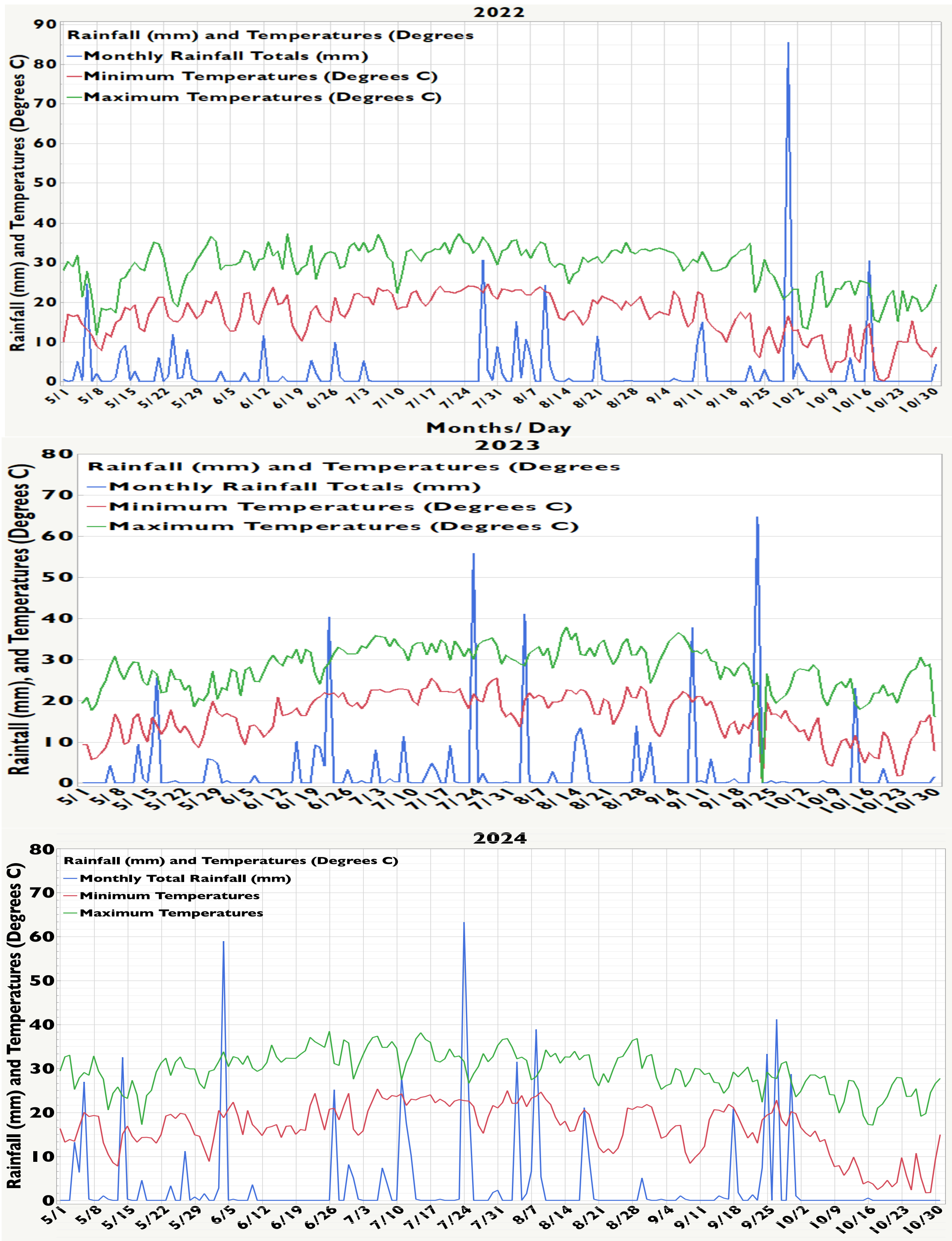


Figure 1: Weather (Daily Rainfall (mm), Daily Minimum and Maximum Temperatures (°C) from 2022 (above), 2023 (middle) 2024 (below) at the Suffolk VA, experimental site (36° 39' 48.48" N, 76° 44' 10.56" W). Data source: <u>Infonet</u>.

June 27 in 2024 no significant rainfall events did increase irrigation response in grain yield over the effect observed in 2023. Figure 2 details the soil volumetric moisture content (VWC) measured by sensors down to 36 inch depth in increments of 4 inches. For the soil type at the site the determined soil moisture at field capacity was 21% and a threshold of 14% was set to trigger irrigation. Even though the surface soil in 2023 was consistently lower than this the subsurface soils stayed near this level. In 2022, the lack of precipitation is also evident from the soil moisture data (Figure 2).

The irrigation amounts are plotted against the cumulative rainfall totals in Figure 3. Data for 2022 and 2024 are shown only, as the 2023 irrigation data was lost due to Netafim shutting down its online server that stores the irrigation data. We were not notified of the shutdown thus all irrigation was lost for that growing season. In 2024, the irrigation data was hand recorded from the irrigation controller as it occurred. However, from the two graphs you can see that irrigation amounts double the total cumulative water applied in 2022 where there was only a modest increase above precipitation in 2024 (Figure 3). The substantially lower rainfall from both the weather data and the irrigation amounts applied support the 100+ bu per acre yield increases observed in 2024.

Corn Grain Yield and SDI Performance

Corn grain yield response to irrigation was highly dependent on precipitation each year of the study, however there was a significant effect of SDI management strategy each year of the study (Table 1). Non-irrigated yields were 98, 147, and 109 bu per acre for 2022, 2023, and 2024, respectively with a three-year average of 117 bu per acre. For the 36-inch dripline spacing the three-year average was 183 bu per acre and was the highest of any SDI system. The 36-inch dripline + VWC sensor was the next highest yielding with a three-year average of 176 bu per

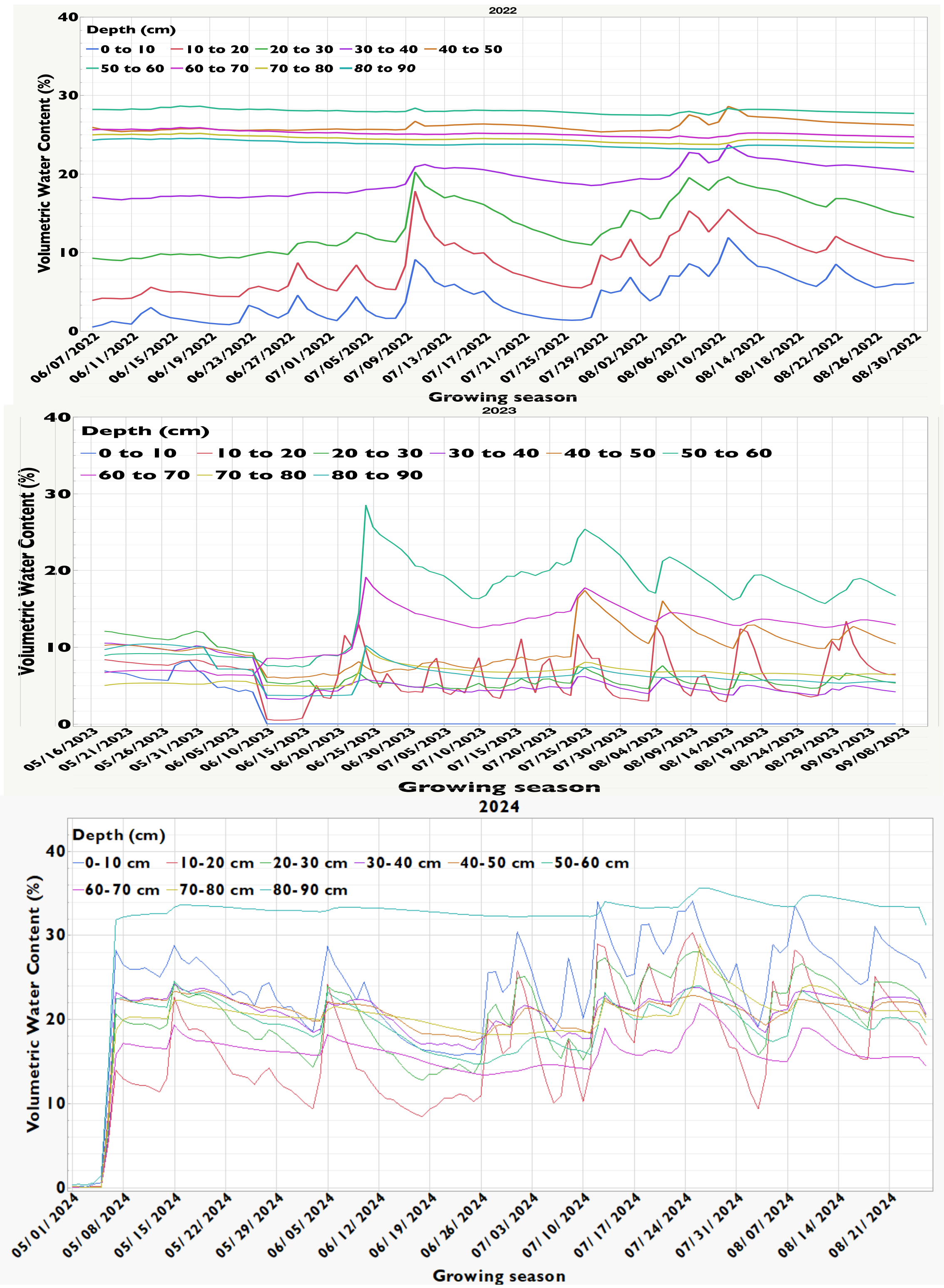
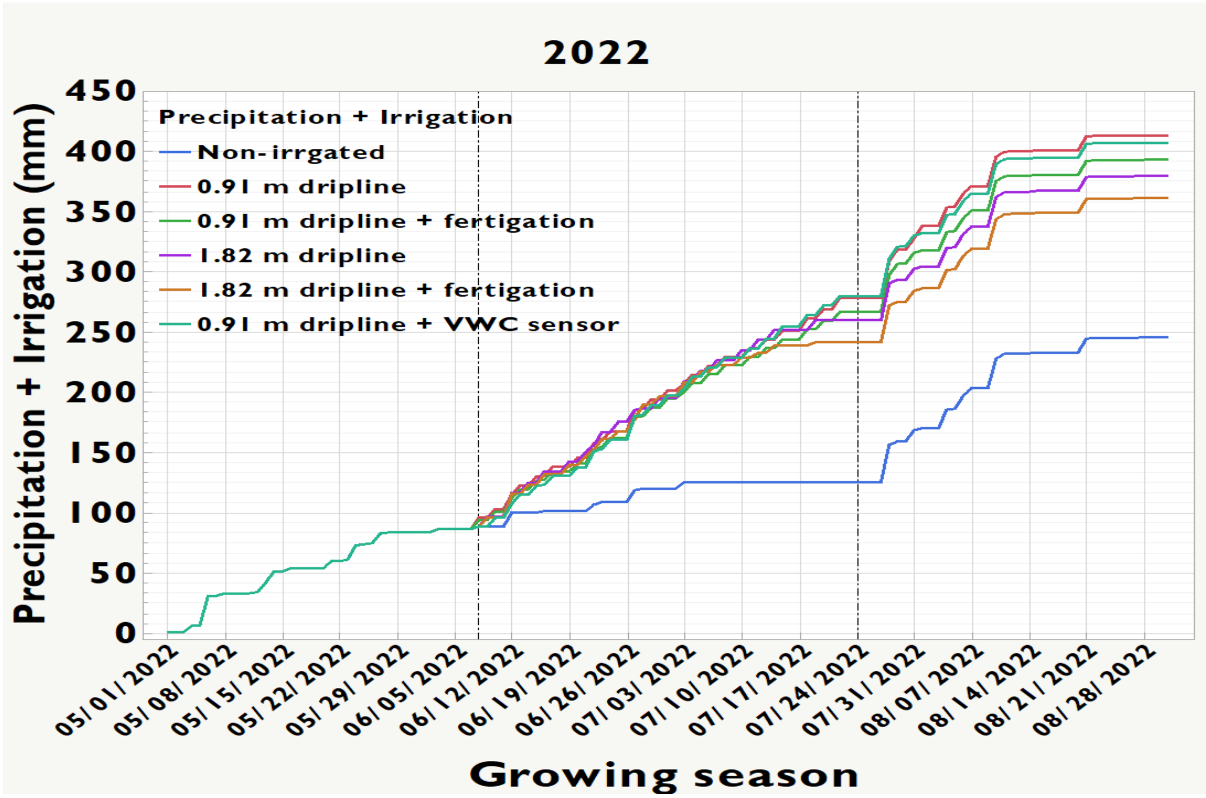


Figure 2: Soil volumetric water content for the SDI system in 2022 (top), 2023 (middle), and 2024 (bottom). Data was collected from field sensors using data loggers, which provide continuous monitoring of soil moisture levels at various depths in the root zone.



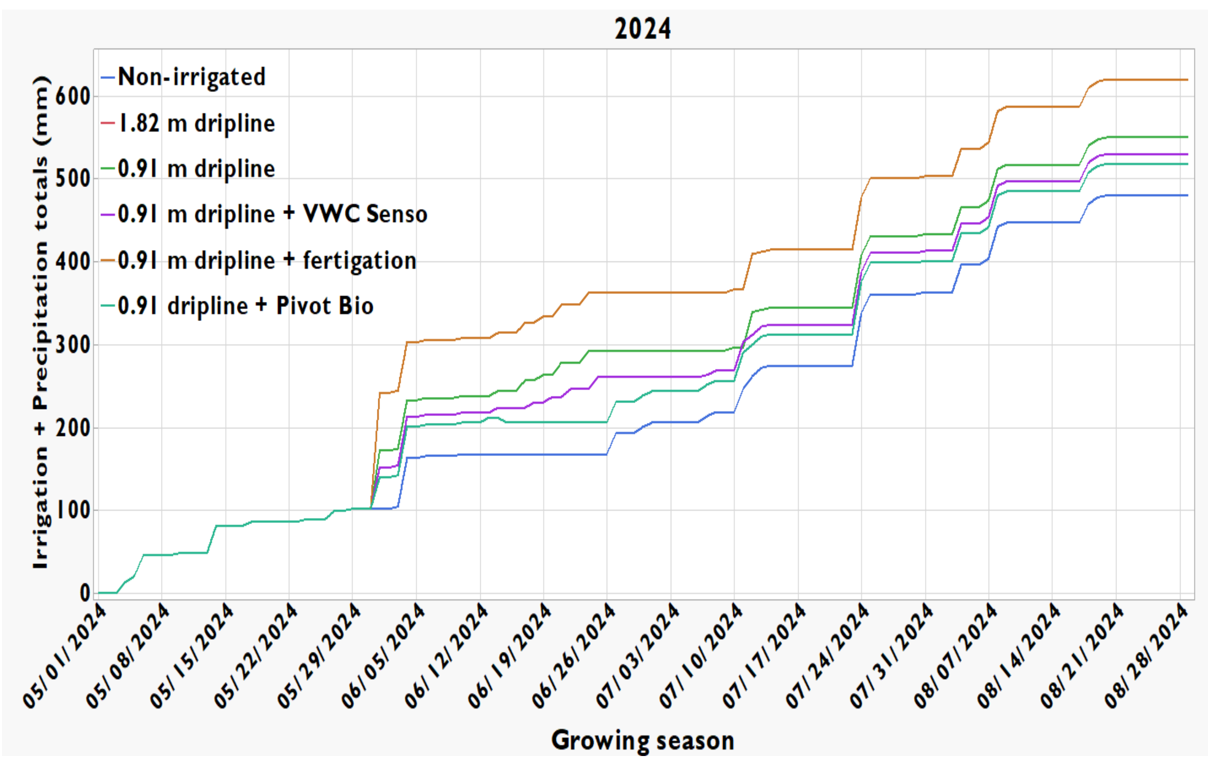


Figure 3: Total seasonal moisture (irrigation + precipitation) in 2022, above) and total precipitation + supplemental irrigation for 2024 (bottom) at the Suffolk VA, experimental site. Rainfall data source: Infonet

acre. In 2022, the 72-inch dripline + fertigation was only tested that year so the data in Table 1 are not complete as its performance was lower in 2022 compared to the 36-inch dripline system. Overall, the 36-inch dripline system has the highest economic return with $327 per acre followed by the 36-inch dripline + VWC sensors at $276 per acre. The return of initial investment for the SDI systems ranged from 7.6 – 11.2 years, but with a life expectancy of 20 – 25 years this pays for the system with the opportunity for increased returns during the second half of the system's life.

When evaluating production practices such as seeding rates and N application rates using SDI, it was found that seeding rates of 30,000 seeds per acre were sufficient to maximize grain yields (Table 2). It should be noted that corn in this study was planted on 36-inch row spacing with could have influenced response to higher seeding rates due to inter-row competition. For N application rates, corn grain yield responded up to 240 lb N per acre during the three-year study (Table 2). This rate is modestly higher than current N application rates for corn though grain yields in this study did not reach 200 bu per acre for that N application rate. There was an N application rate by irrigation system during each year of the study (Figure 4). The non-irrigated treatments did not response to N application in 2 out of 3 years of the study.

Conclusions from three-year study

Overall SDI was found to be a suitable option for irrigating corn in Virginia and the Mid-Atlantic U.S. More work is needed to fine tune recommendations on when to start irrigation and fertigation in corn as the fertigation treatment did not perform as was expected. Narrower dripline spacing seemed to be more suitable for the soil types in the study which does increase the cost of an SDI system. Over an SDI system will provide a ROI to producers within 10-years of installation and allow the maximum coverage of irregular shaped fields.

Table 1: Grain yields, average grain yield increase, gross revenue returns, and system ROI for corn produced under varying SDI irrigation management practices from 2022 - 2024.

Irrigation Management Strategy	Yearly Grain Yield (bu/ac)			Avg. Grain Yield	Δ Avg. Yield	Increased Revenue @ $5.00/bu	System ROI[†] @ $5.00/bu
	2022	2023	2024	bushel/acre		$ / acre	years
Non-irrigated	97 f*	147 f	109 f	117	-	-	-
36 inch Driplines	193 c	178 a	177 a	183	65.5	$327.27	7.6
36 inch Driplines + Fertigation	205 b	152 e	157 d	171	54.2	$270.84	9.2
36 inch Driplines + Pivot Bio	-	171 b	173 b	172	44.6	$223.10	11.2
36 inch Driplines + VWC	211 a	163 d	154 e	176	58.9	$294.28	8.5
72 inch Driplines	181 e	164 c	157 d	167	50.0	$249.80	10.0
72 inch Driplines + Fertigation	183 d	-	-	183	86.2	$430.89	5.8
P-Value	< 0.0001	0.089	< 0.0001	-	-	-	-

[†]ROI = Return on investment (initial installation costs of $2,500 per acre for SDI system)

* Means with the same letter within year are not significantly different at alpha = 0.1.

Table 2: Main effects of seeding rate and nitrogen application rate on corn grain yield from 2022 – 2024 using SDI management strategies.

Main Effects	Year			Relative Yield
	2022	2023	2024	%
	--------- Grain yield (bu ac^{-1}) ---------			
Seeding Rate (seed/ac)				
24,000	167 b*	156 b	150 b	0.82 b
30,000	183 a	158 b	156 ab	0.87 a
36,000	185 a	170 a	153 ab	0.89 a
42,000	179 a	166 a	159 a	0.88 a
P-value	**<0.001**	**0.044**	**<0.001**	**<0.001**
Nitrogen Application Rate (lb N/ac)				
120	154 c	139 c	134 c	0.77 c
180	181 b	162 b	154 b	0.87 b
240	187 ab	172 a	164 a	0.90 a
300	191 a	176 a	166 a	0.92 a
P-value	**<0.001**	**<0.001**	**<0.001**	**<0.001**

* Means with the same letter within year are not significantly different at alpha = 0.1.

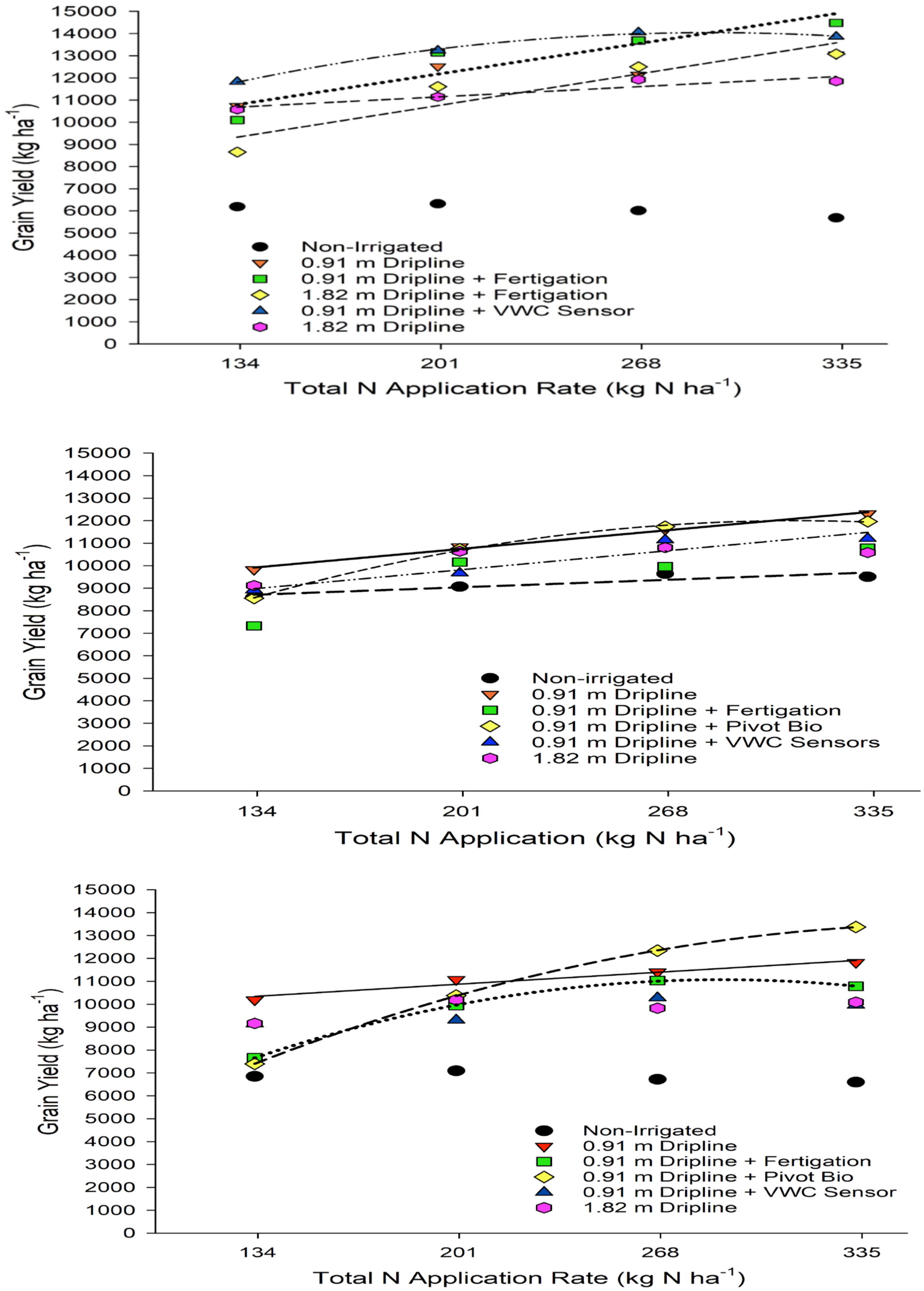


Figure 4: Corn grain yield response to varying SDI management strategies and N application rates for 2022 (top), 2023 (middle), and 2024 (bottom). Lack of regression line indicated grain yields were not responsive to N application for that irrigation strategy.

2025 Research Proposal

Justification

Objectives 1 and 2

As cover crops become an increasing part of Virginia's agroecosystems, especially for non-legumes such as corn and cotton, there is an increasing need to better understand how cover crops impact that cropping system. Nutrient cycling, especially nitrogen (N), can be modified greatly depending on the cover crop species and biomass accumulation present in each field. Species of cover crops affect N cycling differently as their carbon to nitrogen ratio (C:N) can varying greatly (Figure 4). At C:N ratios greater than 25:1, N can be immobilized/taken up by microorganisms who are competing with the crop for available N. Below 25:1, N is mineralized or released from the cover crop biomass at a level where competition with microorganisms is not a concern. Also, N uptake across cover crop species can vary greatly with small grains averaging 20 – 30 lb N per acre and leguminous species averaging from 99 – 210 lb N per acre (Figure 4).

Cover Crop Species	Biomass and Nutrient Uptake (lb/ac)							
	Biomass	N	P_2O_5	K_2O	Mg	Ca	S	C:N
Brassicas	2,198	26	17	59	6	33	10	31.9
Cereal Rye	2,301	25	17	52	3	6	3	38.4
Triticale	3,363	30	25	72	4	9	4	46.8
Black Oats	4,269	29	22	97	4	8	5	66.9
Winter Oats	4,099	31	24	80	6	10	4	54.9
Winter Wheat	3,063	24	18	54	4	8	3	50.9
Barley	4,024	26	23	84	7	12	6	56.8
Annual Ryegrass	3,017	26	17	60	5	16	4	46.5
Crimson Clover	6,022	138	36	229	14	81	9	16.9
Austrian Winter Peas	5,892	189	56	203	16	64	15	12.6
Hairy Vetch	5,872	210	55	219	15	70	15	11.6
Winter Lentil	3,304	99	26	74	6	25	6	13.8
Balansa Clover	6,769	199	51	309	21	117	19	13.2
Red Clover	3,650	111	23	138	11	49	7	12.4
White Vetch	3,436	116	25	93	8	45	8	11.6

Figure 5: Dry biomass, nutrient accumulation and C:N ratio for various cover crop species in a cover crop variety trial conducted at the Tidewater AREC in 2022.

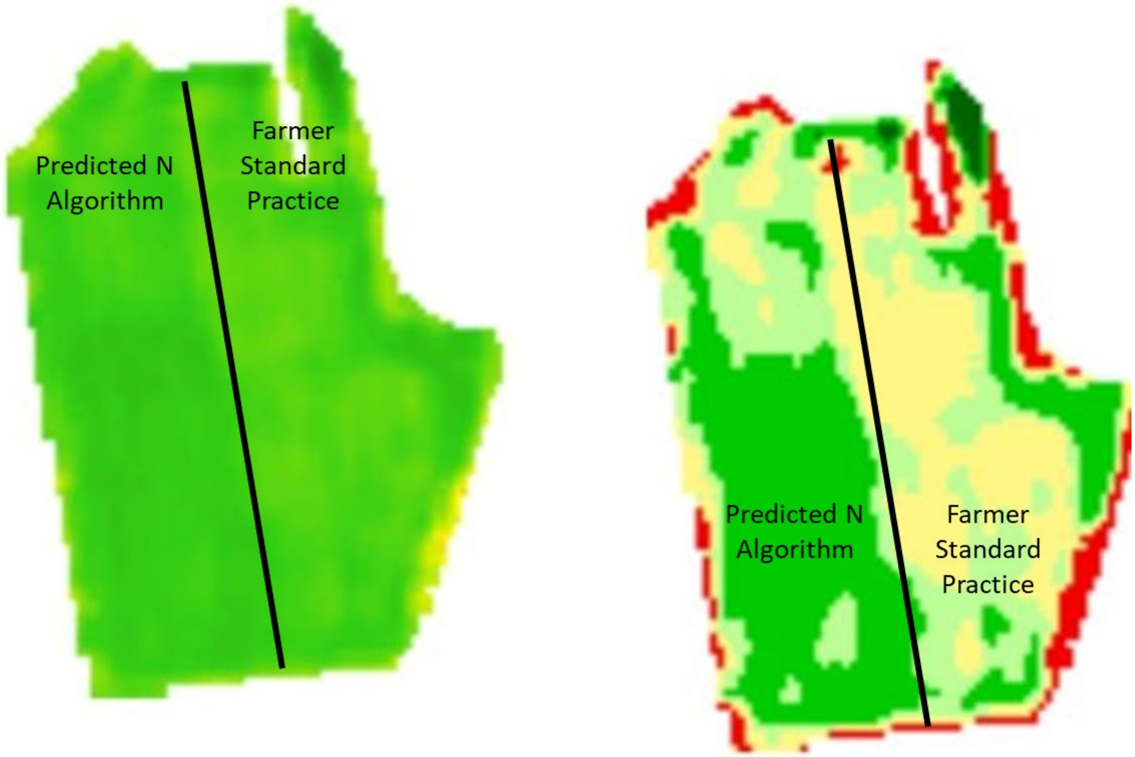


Figure 6: Normalized difference vegetative index (left) of cotton field in 2023 for a N prediction study with varying zones of poor (red – beige) and good growth (green) flown with a UAV and multispectral camera.

Agricultural fields are not uniform is production and crop growth (including cover crops) can be variable. Remotely measuring crop growth allows for a rapid determination of crop health or status during the growing season (Figure 6). Similarly to other aspects of measuring crop health this can be used to develop precision-based management strategies in real-time to optimized input efficiency and crop yield. Swoish et al. (2022) measured 86 sites in 26 agricultural fields in Virginia and found that the biomass prediction accuracy of satellite measured normalized difference vegetative index (NDVI) had an R^2 of 0.79. This gives confidence that cover crop biomass can be accurately predicted with current technologies, however little data exists that further evaluates the actual release of N in the biomass to the subsequent corn crop in manner to optimize grain yields. Other methodologies are also available that allow cover crop biomass to be measured more accurately such as normalized difference red edge (NDRE) index and light detection and ranging (LiDAR) (Miller et al, 2024 and Colaço et al., 2021). Prediction of cover crop biomass and resulting nutrient release to corn needs to be studied further and a model that accurately utilizes remote sensing data to predict nutrient release and uptake to optimize fertilizer N applications in corn is needed. A savings of just 10 lb N per acre across the 460,000 acres of corn would equate to 4.6 million lb of N with a value of $2.3 million savings to Virginia corn producers. Some data suggest that cover crops could provide greater than 100 lb N per acre which would be a value of $23 million in fertilizer N saving at $0.50 / lb N.

Objective 3

With ever increasing input costs in agricultural systems and commodity prices remaining flat for the past 10-15 years, there has been an increased emphasis on products that increase nutrient use efficiency or decrease reliance on fertilizers. This relatively new industry can be referred to as the Biologicals/Biostimulant industry and is estimated to have a total value of $13 billion by 2028. However, there are hundreds if not thousands of products on the market that are labeled as biofertilizer, biostimulants, and/or inoculants and this can be confusing for producers to wade through on which products work and will give them a return on investment. Figure 7 gives a representation of the biological companies (not products) that are currently advertising. There have been some regional studies across the United States Corn Belt that have had varying results. A study published by a joint research team found that across 61 sites, only two sites had

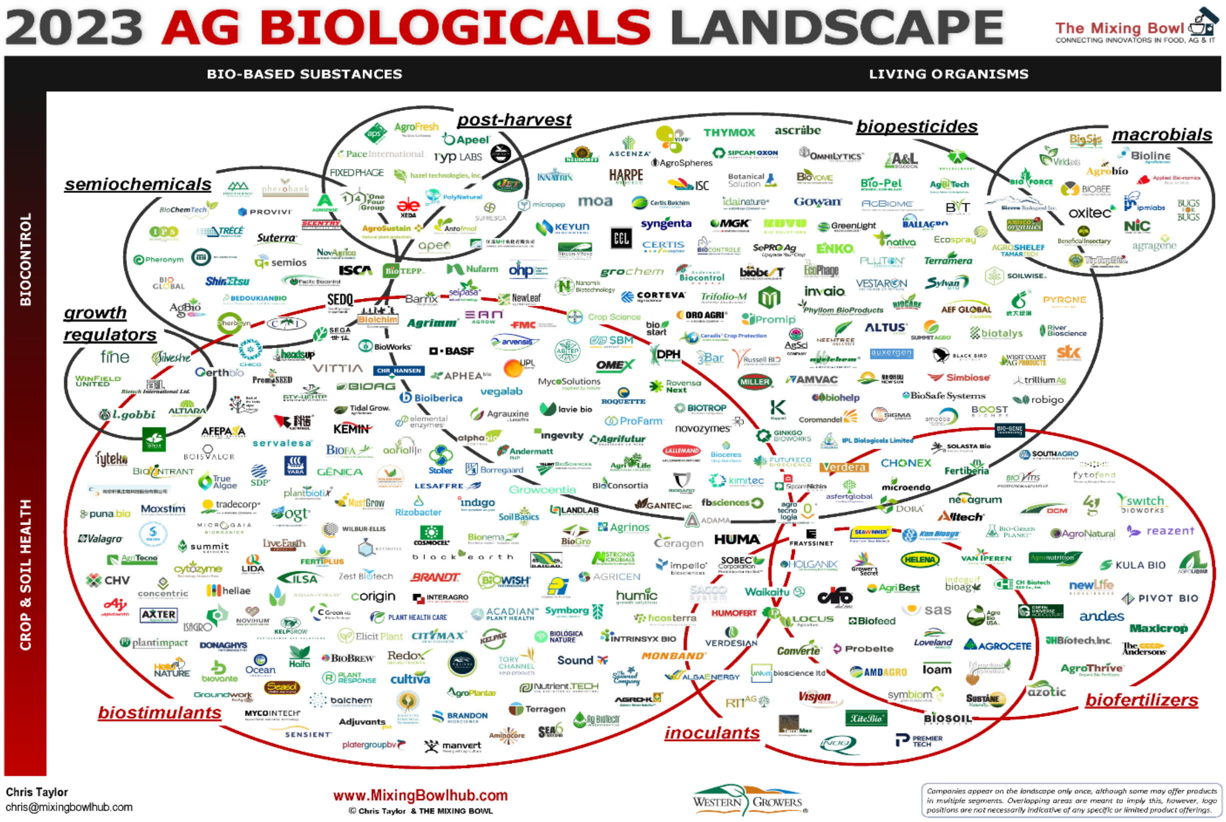


Figure 7: Companies that sell a agricultural biological product and the different classification of products in 2023. Taken from https://www.mixingbowlhub.com/landscape/2023-ag-biologicals-landscape

significant responses to biological products (Franzen et al., 2023). Gessinger et al (2024) also detailed multiple research projects for three prominent biological products in corn and report similar mixed responses to materials across all universities and studies. There is a need to better understand how some of the industry leading products aid in nutrient cycling and how they can be beneficial to corn producers in Virginia.

Background

Experiment 1

Cover crop research has been ongoing for thousands of years with the primary source of nutrients coming from animal manures and green manure crops (cover crops) up until 1930's and the Green Revolution. Research has shown in Virginia that other crops such as cotton can be produced without any supplemental fertilizer N following green manure legume cover crops. This system drastically reduces the fertilizer input costs and increases the producer's profitability. However, cotton does not require as great of quantities of N as corn, so the reality of supplying 100% of the corn N demand may be a stretch. With the development of cost-share programs in Virginia that have incentivized cover crop adoption there is a need for a more in-depth look at how cover crop impact current production practices in regard to nutrient management. Couple this with the technological ability to accurately and rapidly measure cover crop biomass using remote sensing technologies and you have the ability to predict how much N fertilizer a producer will need to apply to his corn crop (Swoish et al., 2022; Futerman et al., 2023; Hütt et al., 2023; and Prabhakara et al., 2015). Swoish et al. (2022) have proven this concept for cover crops in Virginia, but that study did not go into how that cover crop biomass influences corn N uptake and grain yield across Virginia.

Experiment 2

Agricultural biological products are a relatively new product class in the United States, though inoculants have been used for legume crops for centuries. The sheer volume of products and companies selling these products is overwhelming and little information is available on their performance. In Virginia, some data have been collected on a select few biologicals though these

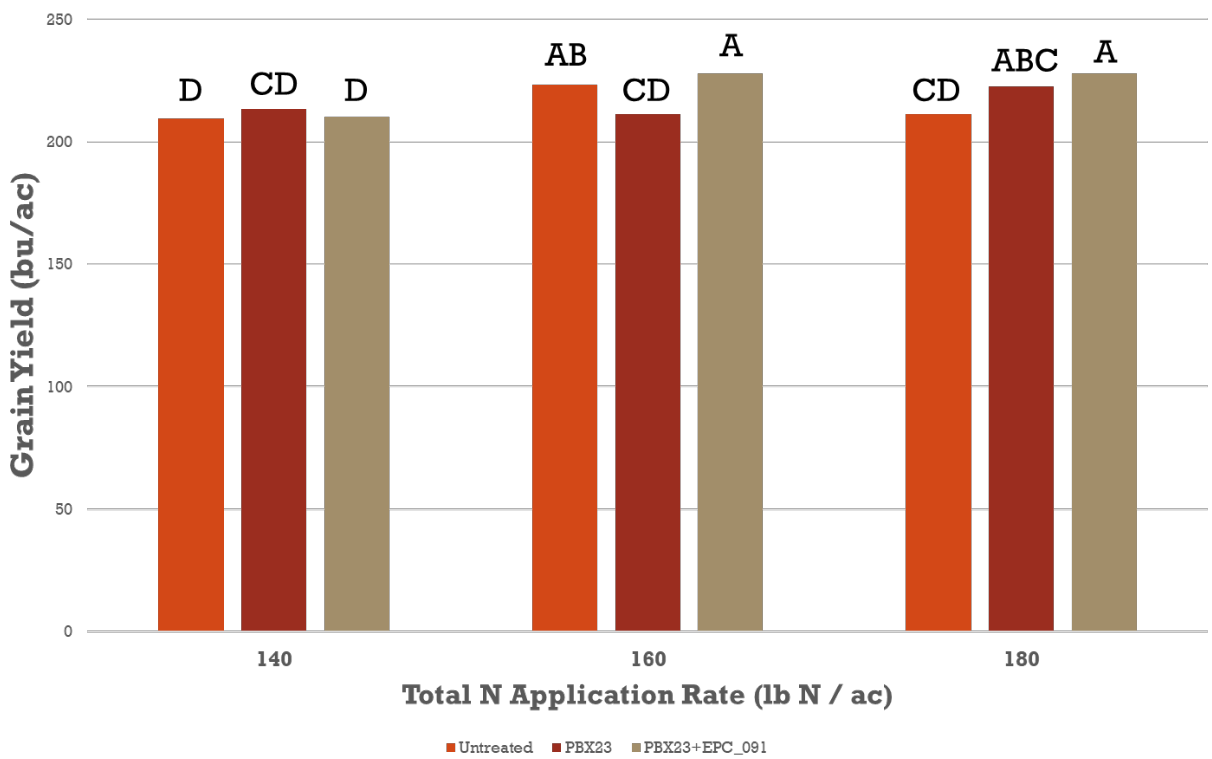


Figure 8: Corn grain yield impacted by Pivot Bio's ProveN40 (PBX23) and an experimental additive in 2023 at Tidewater AREC.

products have not been tested over a large geographic area. Figure 8 is a study conducted in Virginia evaluating Pivot Bio's ProveN40 product in corn and there were inconsistent yield responses during the trial. A study also on ProveN40 found about an 8 bu per acre yield increase applied in conjunction with subsurface drip irrigation in Virginia. Other than a handful of studies very little data is available outside of company data presented data. No significant responses to products such as Utrisha N and Envita have been observed when applied to cotton in Virginia as well. More data is needed to ascertain the real impact of the most prevalent biological/biostimulant products for Virginia's corn producers.

Procedure

The proposal will include two experiments with the first experiment (Objectives 1 and 2) being conducted at three locations across Virginia (on-farm locations to be determined) and the second experiment (Objective 3) being conducted at two locations (Tidewater AREC and VA Ag Expo Site). Each experiment will be conducted for three years (2025 – 2027) with a total of nine locations for experiment 1 and six locations for experiment 2.

Experiment 1

Sites for experiment 1 will be selected based on cover crop species present as it is critical that at least one small grain location, one legume location, and one location where a combination of species is present. Locations for experiment 1 will be located in the Coastal Plain and Piedmont regions of Virginia as this is the major corn production area in the state. Cover crop variability will be mapped using a UAV with a multispectral camera and NDVI will be mapped using Pix4D software in late February. This initial mapping will be to determine areas of good growth and areas of poor growth within the selected field to sample for biomass and nutrient accumulation. During the last week of March or before cover crop termination the field will again be measured with a UAV and multispectral camera as well as a ground-based Lidar sensor at select points of varying cover crop growth. The other crop indices that will be used is NDVI and NDRE to compared estimates for cover crop biomass.

To generate biomass estimates we will use a LiDAR scanner that will be calibrated for simultaneous localization and mapping (SLAM). The SLAM procedure will automatically capture point cloud data and build a three-dimensional map of the field. To process the point cloud data, we will first adjust all elevation data to start from the ground and then remove the ground points. We will next measure pulse heights, in which we assess how many laser pulses bounce from different height levels. We will then convert the point cloud data into a grid of three-dimensional cubes (called voxels), where each cube represents a small area of space and holds information about the points inside it. We will quantify biomass volume based on the number of voxels associated with above-ground plant material and will convert the volume to mass using dry density values determined from plant samples. Biomass estimates will be calibrated and evaluated using physical samples of all aboveground biomass from within randomly placed and geolocated 0.25 sq. m samples. Cover crop biomass samples will be dried to a constant weight at 60ºC and ground to pass a 0.5 mm sieve. Samples will be sent to Water's Agricultural Laboratory for complete nutrient analysis.

Two to three areas will be selected within the field to quantify corn N application response in varying cover crop biomass zones. Within these zones five N application rates will be applied to corn with each N application rate replicated four times. The N application rates will be 0, 50, 100, 150, and 200 lb N per acre. Plot size will be 4-rows by 25 feet in length. Nitrogen will be applied in a split application with 40 lb N applied at planting and the remaining balance of N applied at V5-V7. At blacklayer, a 1-m section of row will be sampled from the 1st row of each plot, weighed, and a 2-plant subsample will be ground using a woodchipper to measure N uptake and N use efficiency (NUE). Samples will be dried to a constant weight at 60ºC and ground to pass a 0.5 mm sieve. Samples will be sent to Water's Agricultural Laboratory for complete nutrient analysis.

Grain yield will be measured by harvesting the center two rows of the plots with a Zurn 150 plot combine. A grain subsample will be collected for NIR analysis to determine protein, starch, and ash content. Using grain yield agronomic efficiency will be calculated to determine the quantity of grain produced per lb N applied at each site. Data from grain yield, cover crop biomass, nutrient accumulation and NUE will be correlated with remote sensing data to develop a N prediction model for Virginia that can accurately optimize yields following cover crops.

Experiment 2

For experiment 2, there will be two locations over the 3-year study for a total of six site years. The first location will be at the Tidewater AREC and the second location will be at the Virginia Ag Exp site to demonstrate the effectiveness of biological products. There will be a total of 10 – 12 treatments each year with a N response curve at each location to detail the response of the site to N fertilization. The N response curve will have rates of 0, 50, 100, 150, and 200 lb N per acre. The biological treatments will be evaluated at 100 lb N per acre, as this should be in the responsive portion of N response curve and is where you will most likely observe a response to products enhancing N uptake. The three standard products that will serve as "controls" will be Pivot Bio's ProveN40 (in-furrow), Utrisha N (Corteva Agriscience), and Envita (Syngenta). The remaining 3-4 products will be those sold by retailers in Virginia. Plots will be 4-rows in width and 25 ft in length.

To test the early season impact on corn growth and development, products that will be applied at planting will have plant population and nutrient uptake/biomass samples collected at V5-V7. Samples will be collected from 1-m of row from the 1st row of the plot. Samples will be dried to a constant weight at 60^{o}C and ground to pass a 0.5 mm sieve. Samples will be sent to Water's Agricultural Laboratory for complete nutrient analysis

At blacklayer, a 1-m section of row will be sampled from the 1st row of each plot, weighed, and a 2-plant subsample will be ground using a woodchipper to measure N uptake and

N use efficiency (NUE). Samples will be dried to a constant weight at 60ºC and ground to pass a 0.5 mm sieve. Samples will be sent to Water's Agricultural Laboratory for complete nutrient analysis.

Grain yield will be measured by harvesting the center two rows of the plots with a Zurn 150 plot combine. A grain subsample will be collected for NIR analysis to determine protein, starch, and ash content. Using grain yield agronomic efficiency will be calculated to determine the quantity of grain produced per lb N applied at each site.

Personnel and Facilities

This project will be based at the Tidewater AREC in Suffolk Virginia. This project will require the labor of a research technician (Research Technician (TBD), Extension faculty/staff (Dr. Hunter Frame and Mr. Billy Taylor), various farm workers, and summer technicians to establish plots, collect and analyze soil and tissue samples, harvest, data analysis, and reporting. The Tidewater AREC has laboratory facilities for nutrient sample preparation, sample analysis for carbon, nitrogen, potassium, and sulfur, and necessary tractors, combines, spraying equipment, and other necessary resources to complete this project.

Dr. Ryan Stewart's Lab will serve as the lead of sampling with the LiDAR instrument and analyzing the data for cover crop biomass prediction. Dr. Stewart's lab currently is the owner of a LiDAR sensor that will be used on this project.

Other Entities

We will contract with Water's Agricultural Laboratory to analyze cover crop, corn, and corn grain biomass for macro- and micro-elements they can conduct the work cheaper than Virginia Tech labs.

Source of Other Funds

For the cover crop project, a similar project has been submitted to the National Fish and Wildlife Foundation to conduct this research on additional sites. In that proposal, Earth Optics is a partner and will be provide the remote sensing for the sites. If funded, Earth Optics would also help with the locations in this proposal.

Budget

Salary, Research Specialist (Frame Lab) ……………………………	$ 7,763.00
Fringe Benefits…………………………………………….…..	$ 3.721.00
Wage, Stewart Lab……………………………………………….	$ 6,900.00
Fringe Benefits…………………………………………….…..	$ 578.00
Materials/Supplies……………………………………...................	$ 3,500.00
Cover Crop Nutrient Analysis……………………………………..	$ 2,500.00
Whole Plant Corn @ Black Layer…………………………………	$ 2,500.00
2025 Funds Requested	**$ 27,462.00**

Budget Justification

The salary and fringe benefits included in the budget are for my research technician will be implementing the trial, collecting data during the trial, and conducting the data analyses post-harvest. The materials and supplies for the trial will be to acquire nitrogen fertilizer and other materials (i.e. flags, stakes, etc.) needed to properly carry out the protocol.

Submitted by:

Signature:

Printed Name: William Hunter Frame
Title: Field Crop Agronomist/Associate Professor

References:

Colaço, A., M. Schaefer, and R. Bramley. 2021. Broadacre Mapping of Wheat Biomass Using Ground-Based LiDAR Technology. Remote Sensing. 13:3218. https://doi.org/10.3390/rs13163218

Franzen, D., J. Camberato, E. Nafiziger, D. Kaiser, K. Nelson, G. Singh, D. Ruiz-Diaz, E. Lentz, K. Steinke, J. Grove, E. Ritchey, L. Bortoion, C. Rosen, B. Maharjan, and L. Thompson. 2023. Performance of Selected Commercially Available Asymbiotic N-fixing Products in the North Central Region. NDSU Extension: SF2080.

Futerman, S., Y. Laor, G. Eshel, and Y. Cohen. 2023. The potential of remote sensing of cover crops to benefit sustainable and precision fertilization. Science of the Total Environment. 891:164630. http://dx.doi.org/10.1016/j.scitotenv.2023.164630

Geissinger, M. D. Marzu, and M. Broeske. 2024. A review of common nitrogen biological products for corn. University of Wisconsin Extension. www.ipcm.wisc.edu

Hütt, C., A. Bolten, H. Hüging, and G. Bareth. 2023. UAV LiDAR Metrics for Monitoring Crop Height, Biomass and Nitrogen Uptake: A Case Study on a Winter Wheat Field Trial. 2023. PFG. 91:64-76. https://doi.org/10.1007/s41064-022-00228-6

Miller, J., A. Shober, and J. Taraila. 2024. Assessing relationships of cover crop biomass and nitrogen content to multispectral imagery. Agronomy Journal. DOI: 10.1002/agj2.21554

Prabhakara, K., W.D. Hively, G. McCarty. 2015. Evaluating the relationship between biomass, percent groundcover and remote sensing indices across six winter cover crop fields in Maryland, United States. International Journal of Applied Earth Observation and Geoinformation. 39:88-102. http://dx.doi.org/10.1016/j.jag.2015.03.002

Swoish, M., J. Da Cunha Leme Filho, M. Reiter, J. Campbell, and W. Thomason. 2022. Comparing satelittes and vegetation indices for cover crop biomass estimation. Computers and Electronics in Agriculture. 196: 106900. https://doi.org/10.1016/j.compag.2022.106900