FINAL REPORT

Industrial hemp yield response curve estimation for various nitrogen and phosphorus rates in Florida

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KEY MESSAGES

- Best Management Practices (BMP) in Florida is a program for agricultural nutrient and irrigation management and the protection of water resources.
- New hemp farmers in Florida expected to enroll in the FDACS BMP Program lack research-based management recommendations to adopt for hemp cultivation.
- Research in three Florida agroecosystems was completed 2021-2022 to quantify the response of hemp development and production to nitrogen (N) and phosphorous (P) rate applications.
- Project observations and analytical results point to a range of 100-200 lbs N/ac application rates depending on location and measure of hemp response analyzed.
- Background P rate without additional fertilizer was sufficient for production.

INTRODUCTION

The Florida Department of Agriculture and Consumer Services Office of Agricultural Water Policy (OAWP) develops, adopts, and assists with the implementation of agricultural best management practices (BMP) to protect and conserve water resources. With the 2018 Farm Bill, hemp (*Cannabis sativa* L., <0.3% delta-9 tetrahydrocannabinol) was reclassified as an agricultural commodity and provided Florida's farmers commercial opportunity to cultivate hemp. Florida law requires agricultural landowners located within Basin Management Action Plan areas, including new hemp farms to either enroll in and implement BMP or conduct water quality monitoring. While there are BMP adopted for other agronomic crops, there is no previous research available on hemp nutrient management to develop BMP for hemp in Florida. This information is also limited nationally and only marginally useful given Florida's unique and diverse environments.

This project represents the first research aimed to develop nutrient and irrigation management recommendations aligned with BMP for hemp in Florida. The primary goal of this project was to identify an operational range of nitrogen (N) and phosphorus (P) for hemp growth and production determined by biomass and yield responses to variable nutrient rates. The project also investigated water use and water quality associated with hemp nutrient management. The project was established at three UF/IFAS research centers representing different soils and agroecosystems in Florida. Each hemp crop type (fiber, seed, flower) was included in experiments distributed across the sites. The research approach involved nutrient rate experiments that compared soil characteristics, nutrient application, leaf tissue, and yield to understand impacts of nutrient availability on hemp development and production. Drain-gauge lysimeters system was installed at one site to document water quality below the root zone. The long-term objective was to generate research-based information used to establish BMP recommendations for economically viable crop yield and minimal loss of nutrients to the environment.

OBJECTIVES

Gather detailed information on hemp growth and production related to nutrient use for hemp.

Hemp fiber, seed, and flower crops were grown in three locations across FL 2021-2022. These sites established management records and datasets including nutrient rate application and plant establishment, height, biomass, and yield. Leaf tissue and soil were also sampled regularly to track nutrient management impacts on plant and environmental health. Experiments, data collection, and sampling were completed for the 2021-2022 planting seasons with an emphasis on soil and plant tissue sampling for N and P

Evaluate hemp growth and yield response curves for a range of six N and five P application rates.

Experiments, data collection, and sampling were completed for the 2021-2022 planting seasons with an emphasis on plant production and soil and plant tissue sampling for N and P. Project observations and analytical results, including yield response curves, point to a range of 100-200 lbs N/ac application rates depending on location and measure of hemp response analyzed. The analysis and following report has emphasized site level responses, though efforts continue to combine sites in the analysis and subject finding to peer review.

Compare soil nutrient availability, nutrient application, leaf tissue, and yield to understand impacts of nutrient availability on crop growth.

In addition to yield, response to nutrient application was investigated for soil nutrient availability and leaf tissue. Adequate leaf tissue nutrition seemed to require less fertilizer than the yield-based analysis. Evidence of excess nutrient application was determined by post-harvest soil and water sampling.

Monitor rain, irrigation applications, and soil moisture status to identify the impact of water availability on crop growth and yield.

Precipitation was monitored by mechanical devices (e.g., Onset, Meter) to adapt irrigation timing to soil water status. A primary challenge of hemp establishment included flooding rain events. These flooding events also likely coincided with loss of fertilizer.

Document water quality in the vadose zone in at least one study location.

Lysimeters were installed prior to the 2021 planting season at PSREU and sampled following flooding rain events or when filled. Movement of sediment and high water table challenged early results. Higher concentrations of nitrate in leachate was observed for higher N fertility rates in 2022.

METHODS

Study Locations

Project experiments were conducted at three UF/IFAS research locations: Tropical Research and Education Center (TREC) in Homestead, Plant Science Research and Education Unit (PSREU) in Citra, and West Florida Research and Education Center (WFREC) in Jay.

Location	Coordinates	Soil Series	Soil pH	Soil N[z]	Soil P[y]
WFREC (Jay, FL)	30.7725° N, 87.1382° W	Dothan fine sandy loam	6.25	553	29
PSREU (Citra, FL)	29.4023° N, 82.1709° W	Arredondo sand	6.25	290	1255
TREC (Homestead, FL)	25.4687° N, 80.5007° W	Krome gravelly loam	8.4	1758	107

[z] Baseline soil nitrogen (N) reported as Total Kjeldahl Nitrogen [ppm].

[y] Baseline soil phosphorus (P) reported as Total Phosphorus.

Hemp Material

Access to suitable hemp genetics remains a critical challenge for cultivation in Florida. As access to and performance of varieties remained variable throughout the study, varieties and cultivation approach for the experiments was determined independently for each site with the first goal of successful trials and then coordination among trials. The following table describes the varieties used for each trial.

Varieties	Use	Origin (Latitude)	Trial
NWG 2730	seed	New West Genetics	All sites N
IH Williams (SS-Beta)	seed	IND Hemp	WFREC N; TREC N
X-59	seed	IND Hemp	PSREU N
Bialobrezeskie	seed	Quantum Group	PSREU N
Wife	flower	ANO CBD	TREC N
Maverick	flower	Kayagene	PSREU N; TREC N

Experimental Design and Data Collection

The project team conducted in-field experiments across sites each year to assess yield response to N and P fertilizer application rates using a randomized block design with treatment factors of site, variety, and nutrient application rate (Fig 1). For the N rate trial, six equally spaced N application rates (0, 50, 100, 150, 200, 250 lbs N/acre) were applied at each site in 2021 and 2022. These total application rates were split based on site soil type and management preference. WFREC had two split applications (50lbs N/acre : Remainder) , PSREU had three split applications (20% : 30% : 50%) and TREC split the total application rate three ways (60% : 20% : 20%). The P fertilizer trial was conducted only at PSREU in 2021 and the other sites in 2022. P fertilizer application rates were five equally spaced intervals (0, 50, 100, 150, 200 lbs P_2O/acre).

Plants for each experimental plot were measured throughout the growing season to assess crop performance, including emergence and height. At harvest, plants were measured for height, aboveground biomass, root biomass, and harvestable biomass. Soil samples were analyzed for N content as total Kjeldahl nitrogen (TKN) at 0-6" depth pretreatment and at the conclusion of the experiment. Plant leaf tissue N, P, and potassium (K) content were collected throughout the growing season and at harvest as sufficient material is available.

D-3 Decagon drain gauge lysimeters were installed at PSREU for collection of water below the root zone. These samples were collected and analyzed according to EPA approved methods.

Data Analysis

N and P soil availability, application, leaf tissue, and yield were compared statistically using ANOVA, LSD post-hoc test, and visualization of data averages with 95% confidence intervals to understand the influence of nutrient availability on crop growth and production across sites. These data were aimed at establishing growth curves used to calibrate nutrient application rates and future fertilizer recommendations.

Figure 1. Field preparation across sites. Upper left: Lysimeter installation PSREU. Upper right: Irrigation installation and seedling emergence WFREC. Bottom: Irrigation (left) and soil moisture sensor (right) installation at TREC.

RESULTS AND DISCUSSION

The project team completed both years of trials and published hemp fertility guidelines and literature review (Mylavarapu et al., 2020; Kaur et al., 2023). These investigations identified a provisional moderate to high N rate application guideline not to exceed 150 lbs N/ac across multiple hemp crop types and Florida environments. These rates were referenced by guidelines for dryland corn in Florida and hemp crops outside of Florida but in the southeastern United States. The field experiments supported an upper bound of fertilizer at 150 lbs N/ac. In some rare cases of highly vigorous plant growth, rates exceeding 150 lbs N/ac resulted in greater biomass. However, there were also features of hemp growth and production improved by 50 lb N/ac that were not statistically distinguished from higher rates.

Moderate rate guidelines (50-150 lbs N/ac) were marginally supported by in-field experiments, though challenges in field establishment remained a barrier to overall study operations and objectives. For example, establishment at WFREC in 2021 was poor due to early season floods, but a late season replant allowed for performance analysis at or below commercial stand establishment and yield goals. Experiments at WFREC in 2022 and PSREU both years performed well with respect to commercial stand establishment goals (Fig 2). Three varieties were observed to perform well for commercial stand establishment and seed yield at WFREC and PSREU. In both years at TREC, seed producing plants suffered from poor emergence and establishment and were further stunted due to early season heat and drought and failed to reach commercial production. In addition, hemp genetics that experience early flowering remained a challenge. Despite the challenges, flower and grain N experiments at TREC remained adequate for analysis (Fig 3).

Preliminary results from the in-field experiments indicate a range of 100-200 lbs N/ac optimal application rates for guidelines depending on location and measure of hemp response (Fig 4). For example, an optimum rate of 200 lbs N/ac for total biomass was indicated at PSREU in 2021, though that rate was not statistically distinguishable from the 150 and 250 kg/ha N rate applications. Total biomass was significantly greater at PSREU than the other sites in 2021.

Grain yield reached commercially viable loads (~900 kg/ha) only at PSREU with 200 and 250 lbs N/ac rates statistically distinguished from 0 kg/ha N, but not the other rates. Operationally, plant development was slow across sites with as much as a month for early season establishment and canopy cover. This also affected early leaf tissue sampling (<45 days after planting). Leaf tissue sampling was emphasized later in the season and at harvest. Future plantings will require better stand establishment for destructive early season tissue sampling. Total Kjeldahl Nitrogen in leaf tissue mid-season was statistically distinguishable from the 0 lb N/c rate at PSREU at 50 and 150 lb N/ac and WFREC at 100 lbs N/ac and above (Fig 5).

Figure 2. Photographic panel of performance across N fertilizer treatments for grain hemp variety at PSREU. N application rate increases from top left to lower right.

Figure 3. Photographic panel of performance across N fertilizer treatments for floral hemp variety (seeded dwarf) at TREC. N application rate increases from top left to lower right.

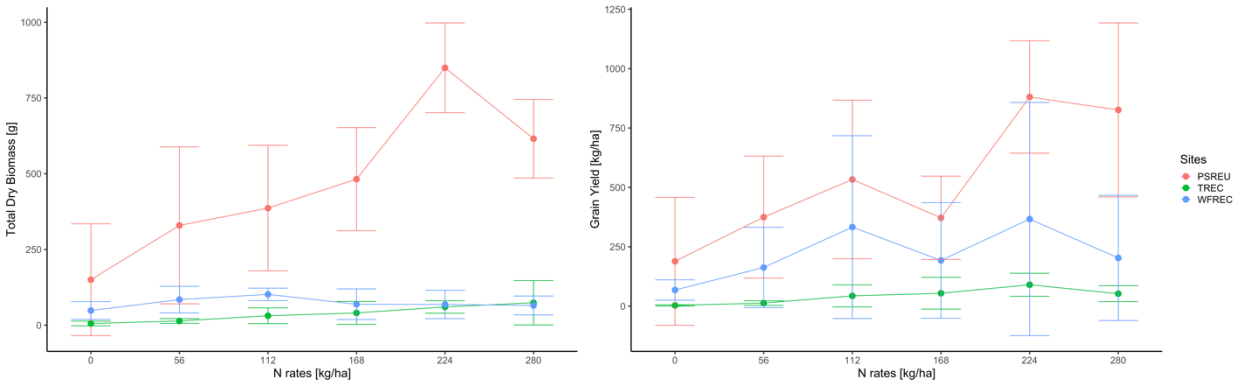


Figure 4. Total dry biomass and grain yield at harvest for hemp grain variety (NWG 2730) across N rate application and three sites. Error bars represent 95% confidence intervals indicative of statistical differences if not overlapping.

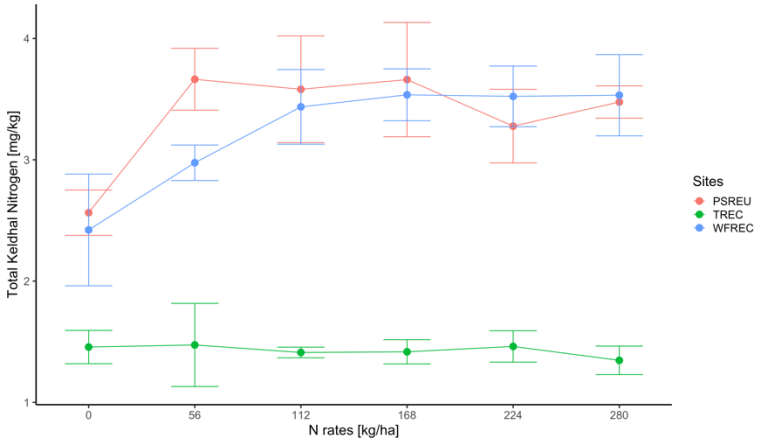


Figure 5. Leaf total keldahl nitrogen in-season for hemp grain variety (NWG 2730) across N rate application and three sites. Error bars represent 95% confidence intervals indicative of statistical differences if not overlapping.

The N rate trial at TREC with flower-type hemp showed plant biomass and yield increased moderately at 100 lbs N/ac of nitrogen and significantly at 150 lbs N/ac for a photo-period sensitive hemp variety (Fig 6). Canopy area and Normalized Difference Vegetation Index (NDVI) was determined from aerial drone imaging to target site-specific fertility management. Aerial imaging showed promising correlation (r^2 = 0.864) with nitrogen fertilizer treatments.

A 2021 trial at PSREU pointed to the limited importance of P application in a sandy soil (Fig 7). P rate trials at WFREC and TREC observed similar non-significant results, indicating background P at each of these sites may be adequate for crop production without additional fertilizer application.

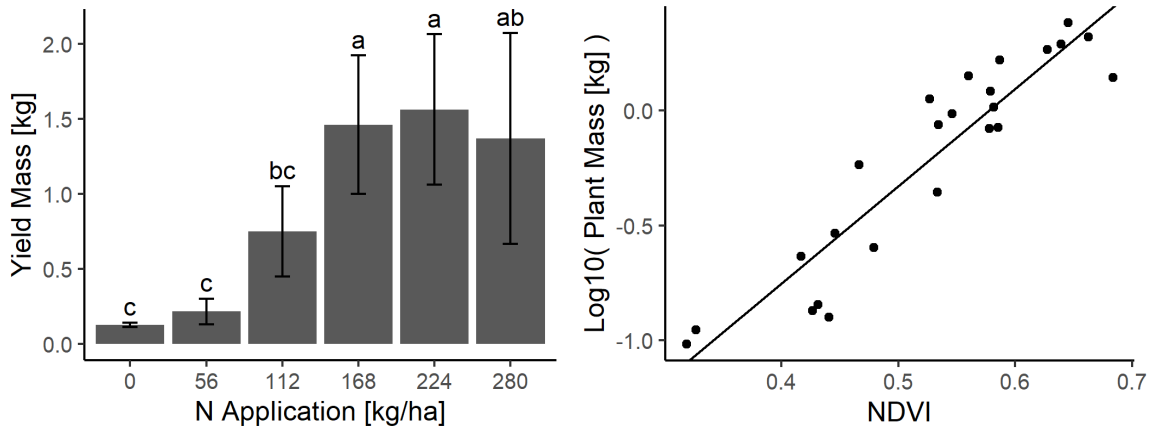


Figure 6. Plant biomass at harvest for flower-type hemp (Wife) response to N rate application (left) and log-transformed plant biomass at harvest to Normalized Difference Vegetative Index acquired through drone-based imaging.

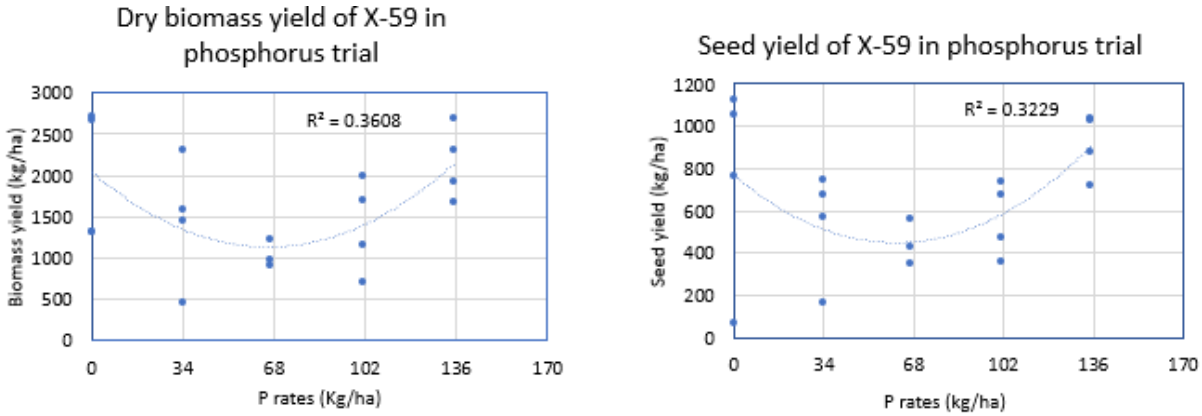


Figure 7. Grain variety biomass and seed yield for PSREU hemp grain variety (X-59).

Lysimeters were installed prior to the 2021 planting season and sampled five times each year following flooding rain events or when lysimeter tank was filled. Lysimeter system data from 2021 was determined to be poor quality due to movement of sediment from installation and possible high water table infiltration. Expected higher concentrations of nitrate in leachate associated with higher N fertility rates was observed in 2022 (Fig 8).

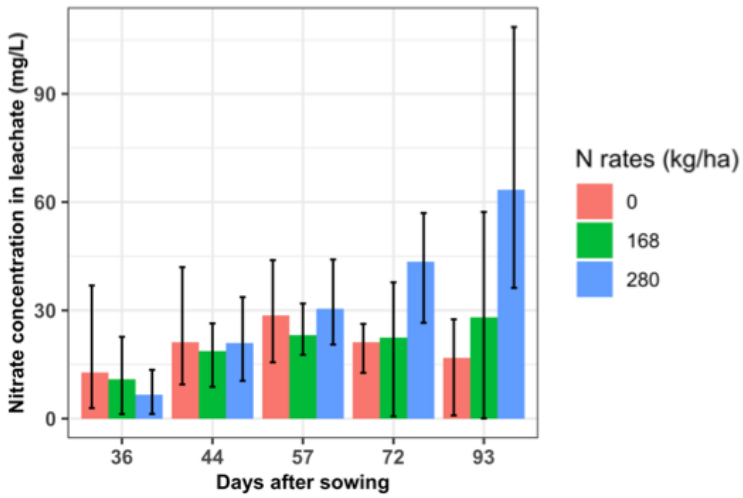


Figure 8. Drain gauge lysimeter nitrate content for water samplings five times throughout the hemp planting season at PSREU. Bars correspond to N rate application (red, 0 lbs N/ac; orange, 150 lbs N/ac; grey, 250 lbs N/ac).

Findings from this project tend to agree with the published preliminary guidelines document and literature review. Research in three Florida agroecosystems quantified the response to N and P rate applications of hemp development and production. Hemp performed like a crop that demands moderate to high rates of fertility. A range of 100-200 lbs N/ac application rates was supported by in-field experiments, but recommendation development may depend on location and hemp crop-type. The aspect of plant growth and production measured may further impact best practices for hemp fertility management. The project also considered plant nutrient status monitoring strategies of leaf tissue sampling or aerial imaging to establish site-specific and adaptive fertility management. Overall, provisional recommendation for hemp N fertilizer need not exceed 150 lbs N/ac in split application for productive crops. In some cases, 50 lbs N/ac was adequate related to comparable benefits from greater nutrient application. Application of P rates did not appear to affect plant productivity at any site. This project provided the motivation and resources to establish a body of evidence for nutrient demands for hemp resulting in an actionable range of N rates for seed and flower production and limited need for P fertilizer applications. These results are being prepared for a provisional nutrient recommendation document and for peer-review publication. These efforts require a minimum of two consistent years of observations established by this project and represent the next formal steps to develop BMP for hemp grown in Florida.

REFERENCES

Kaur, Brym, Monserrate, Sharma. 2023. Nitrogen fertilization impact on hemp (Cannabis sativa L.) crop production: A review. Agronomy Journal, 00, 1– 14. https://doi.org/10.1002/agj2.21345

Mylavarapu, Brym, Monserrate, Mulvaney. 2020. Hemp Fertilization: Current Knowledge, Gaps and Efforts in Florida: A 2020 Report. Electronic Data Information System. https://edis.ifas.ufl.edu/publication/SS689

DELIVERABLES AND MINIMUM PERFORMANCE STANDARDS

DELIVERABLE 1: Establish Study Site.

Study plots and environmental sensors were established at the three study sites April 2021. Irrigation system and fencing were installed at the WFREC April 2020. Lysimeters were installed at PSREU April 2021. The sites remained active in 2022 for the second year of trials.

DELIVERABLE 2: Update UF/IFAS Industrial Hemp Pilot Project website.

Project sponsorship and overview was added to https://programs.ifas.ufl.edu/hemp/. It is stated on the home page that "UF/IFAS is also partnering with the Florida Department of Agriculture and Consumer Services to research crop nutrient applications to help improve crop production and protect Florida's water resources."

DELIVERABLE 3: Conduct ongoing sampling and data collection.

Experiments, data collection, and sampling were completed for the 2021-2022 planting seasons with an emphasis on soil and plant tissue sampling for N and P. Challenges in field establishment and delays in plant development limited sampling for year 1 trials with appropriate adjustments for year 2.

Preliminary data collection is stored publicly at GitHub for the TREC location (https://github.com/TREC-Agroecology/hemp-nutrition). Funded project data (2021-2022) is hosted on Microsoft Teams accessible by the collaborative group.

DELIVERABLE 4: Provide Annual reports and a Final Report.

This document represents the final report.

DELIVERABLE 5: Conduct Education and Outreach Events.

Education and outreach was included throughout the first year of the project with several notable publications and events, including:

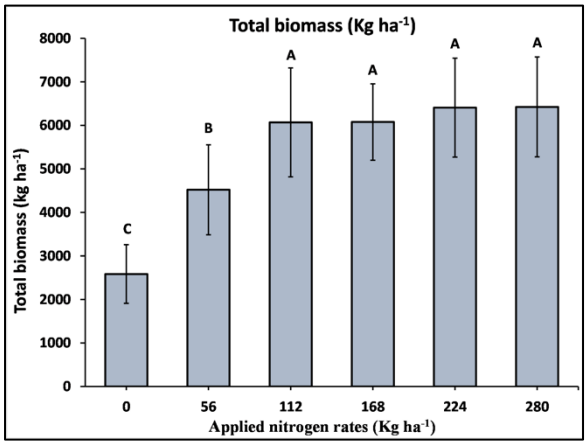
- 2020 Hemp fertility guidelines EDIS doc - https://edis.ifas.ufl.edu/ss689
- 2020 Virtual BMP Summit summary and recording - http://blogs.ifas.ufl.edu/clue/2020/06/23/researching-bmps-for-hemp-production-in-florida/
- 2021 Virtual Hemp Workshop - tinyurl.com/industrial-hemp-program-2020
- 2021 Virtual BMP Summit - https://youtu.be/xzVsJVfIIpE?t=2669
- 2021 Virtual BMP Newsletter Hemp Trial Update
- 2022 Hemp IST Fertility Management Presentation

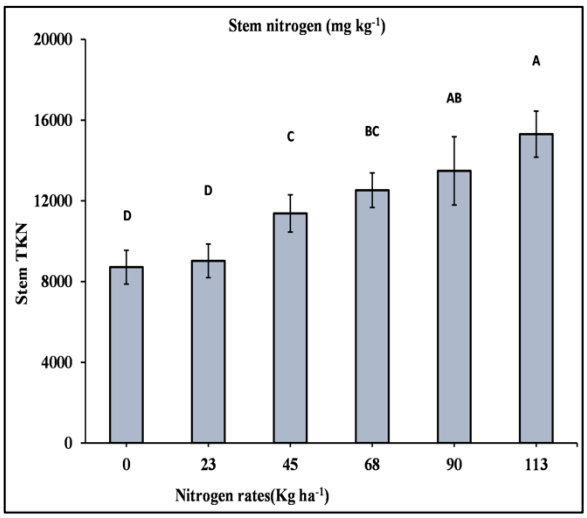
DELIVERABLE 6: Submit the Contract Financial and Reconciliation Reports.

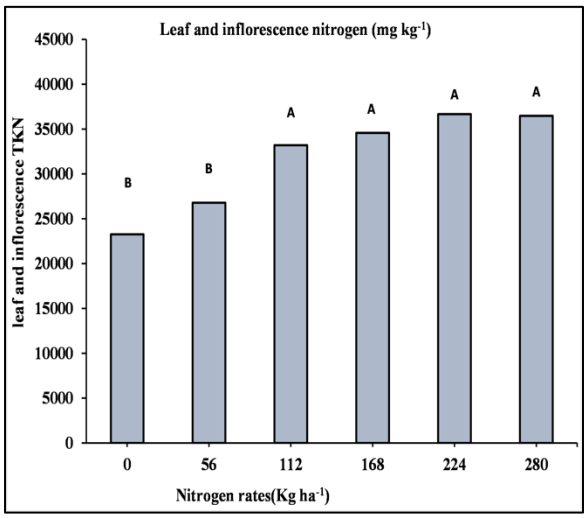
Quarterly reports and associated financial documents have been submitted on a timely basis throughout the project duration.

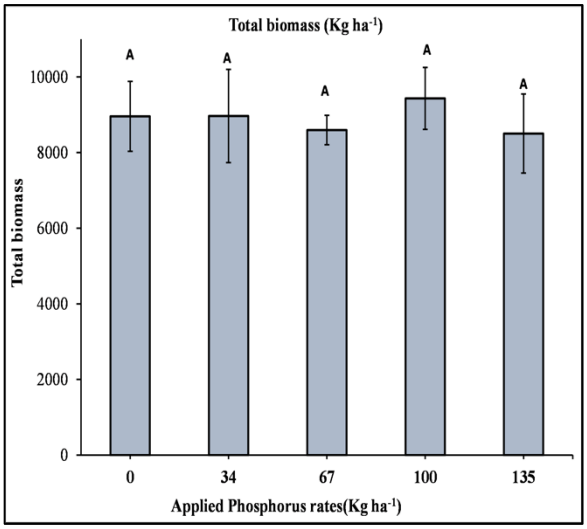
Additional Figures Related to Overall Findings

WFREC 2022

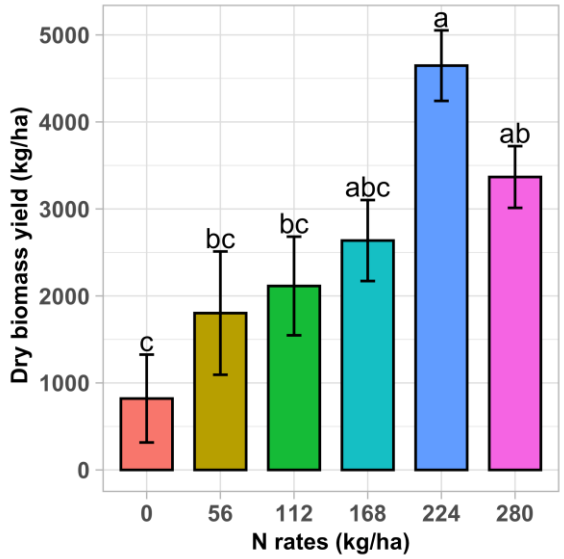


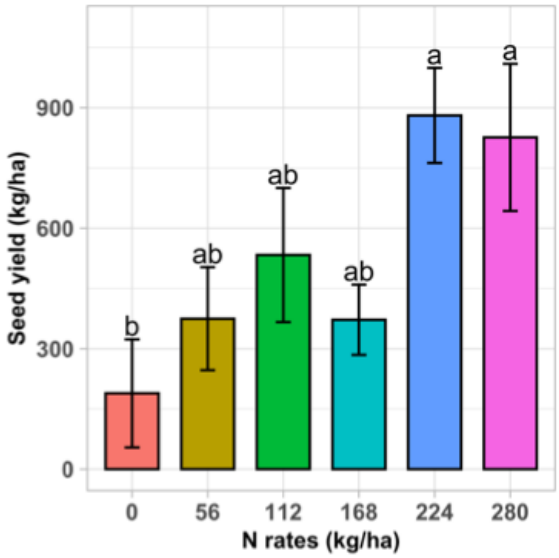






PSREU 2022


Dry biomass yield (kg/ha)
5000
4000
3000
2000
1000
0
c
bc
bc
abc
a
ab
0
56
112
168
224
280
N rates (kg/ha)


Seed yield (kg/ha)
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600
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0
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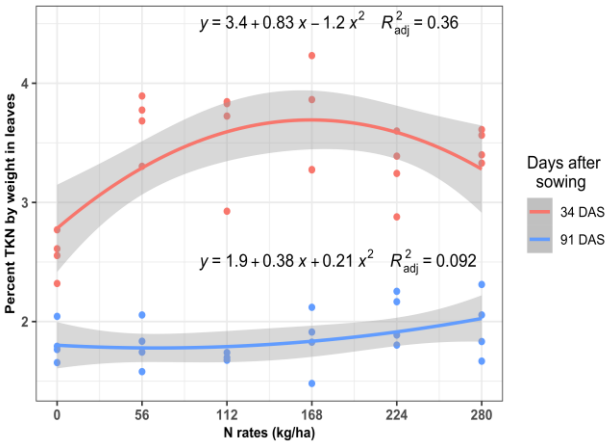
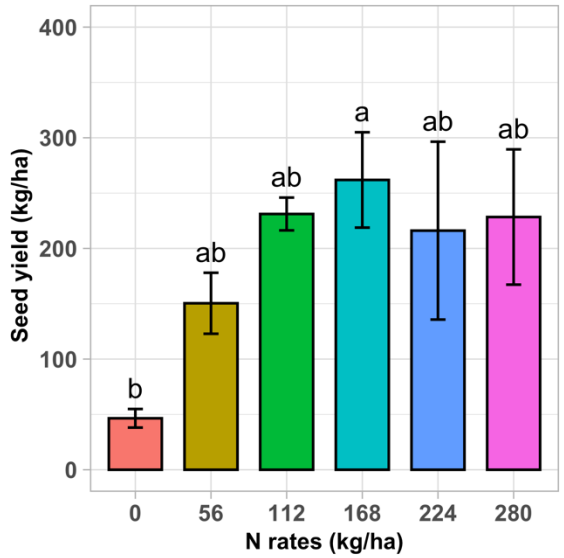
ab
ab
ab
a
a
0
56
112
168
224
280
N rates (kg/ha)


$y = 3.4 + 0.83\,x - 1.2\,x^2$ $R^2_{adj} = 0.36$
$y = 1.9 + 0.38\,x + 0.21\,x^2$ $R^2_{adj} = 0.092$
Percent TKN by weight in leaves
4
3
2
0
56
112
168
224
280
N rates (kg/ha)
Days after sowing
34 DAS
91 DAS


Seed yield (kg/ha)
400
300
200
100
0
b
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ab
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ab
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0
56
112
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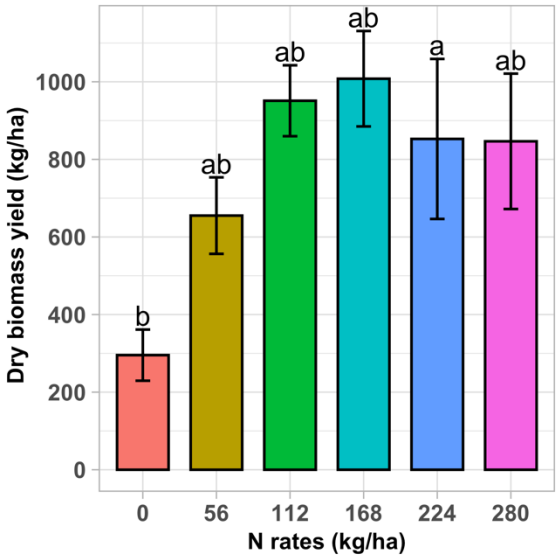
224
280
N rates (kg/ha)


Dry biomass yield (kg/ha)
1000
800
600
400
200
0
b
ab
ab
ab
a
ab
0
56
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168
224
280
N rates (kg/ha)