



---

*Dedicated to my parents*

---



## DECLARATION

---

I do hereby declare that the thesis entitled, “**Impact of Moisture Deficit Stress on Nitrogen and Phosphorous Mineralization Under Legume Cultivation: Role of Soil Amendments**” being submitted to the Department of Environmental Science, Tezpur University, in partial fulfillment for the award of the degree of **Doctor of Philosophy in Environmental Science**, is a record of original research work carried out by me under the supervision of **Dr. Nirmali Gogoi** and Co-Supervision of **Dr. Dhrubajyoti Nath**. All help received by me from various sources have been duly acknowledged. I also declare that neither this work as a whole nor a part of it has been submitted to any other university, institute or other organizations for any other degree, diploma or award.

*Subham Chandra Mondal*

**(Subham Chandra Mondal)**

Place: Tezpur, Assam

Date: 31|01|2023

Regn No.: TZ155560 of 2015



तेजपुरविश्वविद्यालय/ TEZPUR UNIVERSITY

(संसदके अधिनियम द्वारा स्थापित केंद्रीय विश्वविद्यालय)

(A Central University established by an Act of Parliament)

तेजपुर-784028 :: असम/ TEZPUR-784028 :: ASSAM

**Dr. Nirmali Gogoi**  
Associate Professor  
Department of Environmental Science  
School of Sciences  
Tezpur University

Email: nirmali@tezu.ernet.in  
Phone: +91-94350 83469

### **CERTIFICATE OF SUPERVISOR**

This is to certify that the thesis entitled, “**Impact of Moisture Deficit Stress on Nitrogen and Phosphorous Mineralization Under Legume Cultivation: Role of Soil Amendments**” submitted to the **School of Sciences**, Tezpur University in partial fulfilment for the award of the degree of **Doctor of Philosophy in Environmental Science**, is a record of research work carried out by **Mr. Subham Chandra Mondal** under my supervision and guidance.

All help received by him from various sources have been duly acknowledged.

No part of this thesis has been submitted elsewhere for award of any other degree.

Place: Tezpur, Assam

Date: 31/01/2023

(Dr. Nirmali Gogoi)



**ASSAM AGRICULTURAL UNIVERSITY**  
(A Feeder University of North East India and a Premier Institute of Assam)  
Jorhat, Assam – 785013  
District- Jorhat, Assam, India

**Dr. Dhruvajyoti Nath**

**Phone:** +91-94357 38912

Principal Scientist

**Email:** [ndhrubajyoti@yahoo.in](mailto:ndhrubajyoti@yahoo.in)

Department of Soil Science

Assam Agricultural University

---

### **CERTIFICATE OF Co-SUPERVISOR**

This is to certify that the thesis entitled, “**Impact of Moisture Deficit Stress on Nitrogen and Phosphorous Mineralization Under Legume Cultivation: Role of Soil Amendments**” submitted to the **School of Sciences, Tezpur University** in partial fulfilment for the award of the degree of **Doctor of Philosophy in Environmental Science**, is a record of research work carried out by **Mr. Subham Chandra Mondal** under my Co-supervision and guidance.

All help received by him from various sources have been duly acknowledged.

No part of this thesis has been submitted elsewhere for award of any other degree.

Place: Tezpur, Assam

Date: 27/10/23

(Dr. Dhruvajyoti Nath)



तेजपुरविश्वविद्यालय/ TEZPUR UNIVERSITY

(संसदके अधिनियम द्वारा स्थापित केंद्रीय विश्वविद्यालय)

(A Central University established by an Act of Parliament)

तेजपुर-784028 :: असम/ TEZPUR-784028 :: ASSAM

## CERTIFICATE OF EXTERNAL EXAMINER

This is to certify that the thesis entitled, “Impact of Moisture Deficit Stress on Nitrogen and Phosphorous Mineralization: Role of Soil Amendments” submitted to the School of Sciences, Tezpur University in partial fulfillment for the award of the degree of Doctor of Philosophy in Environmental Science, has been examined by us on 27.10.2023 and found to be satisfactory.

The committee recommends for the award of the Degree of Doctor of philosophy

Supervisor

*Gogoi*

(Dr. Nirmali Gogoi)

Date: 27/10/2023

*Rajeev*  
27/10/2023

External Examiner

Date: 27.10.2023

## Acknowledgement

It is a pleasure to begin my thesis by expressing my gratitude to everyone who helped this study succeed in a variety of ways and who made my doctoral experience something I will always treasure.

I want to start by expressing my gratitude and sincerest thanks to my supervisor, *Dr. Nirmali Gogoi*, for her immensely valuable inspiration, advice, guidance, and unwavering support throughout the course of my research. She offered her unreserved assistance and direction, guiding me step-by-step through the process of writing the thesis and beginning with choosing an appropriate subject. Her kindness, encouragement and motherly love enabled me to get through many difficult circumstances and complete this dissertation. Her zeal, holistic approach to research, and commitment to producing excellent work will forever motivate me to investigate new avenues.

I also want to express my sincere gratitude to my co-supervisor, *Dr. Dhrubajyoti Nath*, for all of his helpful advice and insightful criticism throughout the course of my research. He helped me feel more confident throughout the course of my research, and I am appreciative of that.

I appreciate the constructive criticism, insightful suggestions, and in-depth discussion that my doctoral committee members, *Prof. Ashalata Devi*, and *Dr. Nima D. Namsa*, provided regarding my work.

I also offer my gratitude and sincere thanks to all the present and former faculty members of the Department of Environmental Science, Tezpur University *Prof. K.K. Baruah, Prof. K. P. Sarma, Prof. A.K. Das, Prof. R. R. Hoque, Dr. S.S. Bhattacharya, Dr. A. Prakash, Dr. M. Kumar, Dr. S. Mitra, Dr. Sumi Handique and Dr. Pratibha Deka, Dr. Nayanmoni Gogoi, and Dr. Santa Kalita* for their valuable advice and suggestions during the Ph.D. tenure.

I am thankful to CSIR India and Tezpur University for partially funding the research and providing me the opportunity and all the necessary facilities to carry out my research work.

My special thanks go to the technical staff of the Department of Environmental Science, Tezpur University for their help and support during my study. I extend my

sincere thanks to the entire family of Department of Environmental Science, Tezpur University for the valuable support throughout the course of my research.

I would like to express my gratitude *Dr. Dhruvajyoti Sarma* (Dimoria College, Khetri) for his constant motivation and providing me with and the greenhouse required for the study. I would also like to thank *Dr. Bikrom Borkotoky* (Assam Agricultural University) for providing me with the knowledge of biochar production.

I am extremely thankful to my seniors, *Bhaswatee ba, Sreyashi ba, Nandita ba, Banashree ba, Himolin da, Bidyut da, Rajesh da, Jyotiprakash da, Patel da, and Abhijit da* for staying beside me and for their endless help, support and encouragement. I am extremely thankful to my fellow lab-mates, *Nijara, Juri, Palakshi ba, Amlan, Anuran* and *Deeksha* for their endless help and support throughout the period of my study.

My special thanks to *Dr. Reetashree Bordoloi* for always being beside me, motivating and supporting me throughout this journey. I am deeply indebted to my dear friends, Anupam, Madhav, Sandhyani, Priyanka, Nilamani, Vikash, Bodhaditya, Sahbaz, Yalyo, and Shilpa their endless help, support and encouragement. Due to space restrictions, I am unable to name many of my other friends or fellow hostel residents; I hope they will read their own names in between.

I am extremely indebted to my father, *Mr. Radheshyam Mondal* and my mother, *Mrs. Sefali Mondal* their unconditional love, motivation, support, encouragement, blessings and prayer in every step of my life. I am also thankful to my sister *Sagarika* and Brother-in-law, *Pankaj*, and my uncle *Mr. Subhash Mondal*, for their constant love and motivation. Besides my family, the one person who has eagerly anticipated my Ph.D. completion is *Ms. Karishma Das Purkayastha*. I appreciate all of the years of moral support, care, and encouragement she has provided.

Above all, I give thanks to the Almighty lord Shiva, for everything he has given me, especially for giving me the knowledge, health, and strength to embark on this journey.

# Table of Contents

	<b>Page No.</b>
<i>Abstract</i>	i
<i>Declaration by the candidate</i>	iii
<i>Certificate of Supervisor</i>	iv
<i>Certificate of Co-Supervisor</i>	v
<i>Certificate of External Examiner</i>	vi
<i>Acknowledgements</i>	vii
<i>Table of Contents</i>	ix
<i>List of Tables</i>	xi
<i>List of Figures</i>	xiii
<i>List of Abbreviations</i>	xviii
<b>CHAPTER 1</b>	
<b>INTRODUCTION</b>	
1.1 Objectives	1-2
1.2 Hypothesis	1-3
<b>CHAPTER 2</b>	
<b>REVIEW OF LITERATURE</b>	
2.1 N and P nutrition under water stress in legumes	2-1
2.2 Effect of soil amendment on N and P nutrition	2-6
2.3 Soil biological properties and effect of drought	2-8
2.4 Impact of soil amendments on soil biological properties	2-10
2.5 Effect of drought on grain quality of the crops	2-11
2.6 Effect of soil amendment on grain quality of the crops	2-14
<b>CHAPTER 3</b>	
<b>MATERIALS AND METHODS</b>	
3.1 Experimental Location	3-1
3.2 Experimental design and materials used	3-1
3.3 Sampling	3-6
3.4 Analyses	3-7
3.5 Statistical Analyses	3-17



## **CHAPTER 4**

### **RESULTS**

4.1	Results of objective 1	4-1
4.2	Results of objective 2	4-19
4.3	Results of objective 3	4-44

## **CHAPTER 5**

### **DISCUSSIONS**

5.1	Effect of drought on soil properties and grain quality	5-1
5.2	Effect of drought and soil amendment on soil properties and grain quality	5-4
5.3.	Effect of drought and soil amendments on soil properties at harvest	5-7

## **CHAPTER 6**

### **CONCLUSIONS AND FUTURE PROSPECTS**

### **APPENDIX**

a.	Supporting Data Results	A-1
----	-------------------------	-----

## List of Tables

<b>Table No.</b>	<b>Title</b>	<b>Page No.</b>
3.1	Table showing pH and bulk density of the basic soil and after the application of soil amendments.	3-2
<b>Objective 1</b>		
4.1	Table showing correlation matrix amongst soil nitrogen fractions, phosphorus fractions and SOC affected by drought and application of soil amendments at stress completion.	4-17
4.2	Table showing correlation matrix amongst soil nitrogen fractions, phosphorus fractions and SOC affected by drought and application of soil amendments at harvest.	4-18
<b>Objective 2</b>		
4.3	Bacterial, fungal, and actinobacterial CFU (Mean $\pm$ SD) as affected by drought and application of soil amendments at stress completion	4-38
4.4	Bacterial, fungal, and actinobacterial CFU (Mean $\pm$ SD) as affected by drought and application of soil amendments at harvest	4-39
4.5	Table showing correlation matrix amongst soil biological properties as affected by drought and application of soil amendments at stress completion.	4-40
4.6	Table showing correlation matrix amongst soil biological properties as affected by drought and application of soil amendments at harvest	4-41
<b>Objective 3</b>		
4.7	Root, shoot, pod and total biomass of the crops (Mean $\pm$ SD) as affected by drought and application of soil amendments	4-46

4.8	Mineral content of the grains (Mean $\pm$ SD) as affected by drought and application of soil amendments in year 1	4-61
4.9	Mineral content of the grains (Mean $\pm$ SD) as affected by drought and application of soil amendments in year 2	4-62
4.10	Table showing correlation matrix amongst grain quality of the crops as affected by drought and application of soil amendments in year 1.	4-63
4.11	Table showing correlation matrix amongst grain quality of the crops as affected by drought and application of soil amendments in year 2.	4-63

## **Appendix**

7.1	Table showing correlation matrix amongst leaf water potential, photosynthesis, leaf proline, POD, and SOD of the crops as affected by drought at vegetative stage and application of soil amendments in year 1.	A-15
7.2	Table showing correlation matrix amongst leaf water potential, photosynthesis, leaf proline, POD, and SOD of the crops as affected by drought at vegetative stage and application of soil amendments in year 2.	A-15
7.3	Table showing correlation matrix amongst leaf water potential, photosynthesis, leaf proline, POD, and SOD of the crops as affected by drought at reproductive stage and application of soil amendments in year 1.	A-15
7.4	Table showing correlation matrix amongst leaf water potential, photosynthesis, leaf proline, POD, and SOD of the crops as affected by drought at reproductive stage and application of soil amendments in year 2.	A-16

## List of Figures

<b>Fig. No.</b>	<b>Title</b>	<b>Page No.</b>
3.1	Experimental design	3-4
3.2	Field layout of the study	3-5
3.3	Experimental site at Lower Brahmaputra valley Agro-climatic zone Assam	3-6
<b>Objective 1</b>		
4.1	Soil total N and its fraction at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage	4-4
4.2	Soil total N and its fraction at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage	4-5
4.3	Microbial biomass N at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage	4-6
4.4	Microbial biomass N at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage	4-7
4.5	Soil phosphorus fractions at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage	4-13
4.6	Soil phosphorus fractions at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage	4-14
4.7	Soil oxidizable C at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage	4-15
4.8	Soil oxidizable C at harvest as affected by application of biochar and FYM as soil amendments under drought at	4-16

vegetative and reproductive stage

## **Objective 2**

- |      |   |      |
|------|---|------|
| 4.9  | Arylsulphatase activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage                    | 4-22 |
| 4.10 | Arylsulphatase activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage                              | 4-23 |
| 4.11 | $\beta$ -glucosidase activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage              | 4-24 |
| 4.12 | $\beta$ -glucosidase activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage                        | 4-25 |
| 4.13 | Dehydrogenase activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage                     | 4-26 |
| 4.14 | Dehydrogenase activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage                               | 4-27 |
| 4.15 | Fluorescein di-acetate hydrolysis activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage | 4-28 |
| 4.16 | Fluorescein di-acetate hydrolysis activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage           | 4-29 |
| 4.17 | Acid phosphomonoestrerase activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive               | 4-30 |

	stage	
4.18	Acid phosphomonoestrerase activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage	4-31
4.19	Alkaline phosphomonoestrerase activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage	4-32
4.20	Alkaline phosphomonoestrerase activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage	4-33
4.21	Urease activity at stress completion as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage	4-36
4.22	Urease activity at harvest as affected by application of biochar and FYM as soil amendments under drought at vegetative and reproductive stage	4-37

### **Objective 3**

4.23	Grain total carbohydrates as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 1	4-47
4.24	Grain total carbohydrates as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 2	4-48
4.25	Grain total protein as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 1	4-49
4.26	Grain total protein as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at	4-50

	vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 2	
4.27	Grain phytic acid as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 1	4-51
4.28	Grain phytic acid as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 2	4-52
4.29	Grain <i>in-vitro</i> protein digestibility as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 1	4-53
4.30	Grain <i>in-vitro</i> protein digestibility as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 2	4-54
4.31	Grain protein fractions as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 1	4-59
4.32	Grain protein fractions as affected by application of (a) biochar and FYM as soil amendments and (b) under drought at vegetative and reproductive stage and application of biochar and FYM as soil amendments in year 2	4-60

## **Supporting**

### **Data**

7.1	Leaf water potential as affected by application of biochar and FYM as soil amendments and drought exposure at (a) vegetative and (b) reproductive stage in year 1.	A-2
7.2	Leaf water potential as affected by application of biochar and	A-3

	FYM as soil amendments and under drought at (a) vegetative and (b) reproductive stage in year 2.	
7.3	Photosynthesis as affected by application of biochar and FYM as soil amendments and under drought at (a) vegetative and (b) reproductive stage in year 1	A-4
7.4	Photosynthesis as affected by application of biochar and FYM as soil amendments and under drought at (a) vegetative and (b) reproductive stage in year 2	A-5
7.5	Peroxidase activity as affected by application of biochar and FYM as soil amendments and under drought at (a) vegetative and (b) reproductive stage in year 1	A-7
7.6	Peroxidase activity as affected by application of biochar and FYM as soil amendments and under drought at (a) vegetative and (b) reproductive stage in year 2	A-8
7.7	Superoxide dismutase activity as affected by application of biochar and FYM as soil amendments and under drought at (a) vegetative and (b) reproductive stage in year 1	A-9
7.8	Superoxide dismutase activity as affected by application of biochar and FYM as soil amendments and under drought at (a) vegetative and (b) reproductive stage in year 2	A-10
7.9	Leaf proline as affected by application of biochar and FYM as soil amendments and under drought at (a) vegetative and (b) reproductive stage in year 1	A-11
7.10	Leaf proline as affected by application of biochar and FYM as soil amendments and under drought at (a) vegetative and (b) reproductive stage in year 2	A-12
7.11	Leaf protein as affected by application of biochar and FYM as soil amendments and under drought at (a) vegetative and (b) reproductive stage in year 1	A-13
7.12	Leaf protein as affected by application of biochar and FYM as soil amendments and under drought at (a) vegetative and (b) reproductive stage in year 2	A-14



## List of Abbreviations

N	Nitrogen
P	Phosphorus
FYM	Farmyard Manure
SON	Soil organic nitrogen
MBN	Microbial biomass nitrogen
SOC	Soil oxidizable carbon
RBD	Randomized block design
DAS	Days after sowing
LWP	Leaf water potential
C	Carbon
FDA	Fluorescein di-acetate
PME	Phosphomonoesterase
CFU	Colony forming units
MBC	Microbial biomass carbon
TCA	Trichloro acetic acid
KSCN	Potassium sulfocyanate
IVPD	In-Vitro protein digestibility
ICP-MS	Inductively coupled plasma- Mass spectroscopy
POD	Peroxidase
SOD	Superoxide dismutase
DHA	Dehydrogenase
ANOVA	Analysis of variance
HSD	Honestly significant difference
LEA	Late embryogenesis abundant
CDSP	Chloroplastic drought-induced stress protein